



Reef infrastructure guidelines: tourist pontoons

IR Kapitzke, MJ Matheson, TA Hardy

James Cook University



*Established and supported under the
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CRC REEF RESEARCH CENTRE TECHNICAL REPORT NO 39

CRC Reef Research Centre Ltd is a joint venture between: Association of Marine Park Tourism Operators, Australian Institute of Marine Science, Great Barrier Reef Marine Park Authority, Great Barrier Reef Research Foundation, James Cook University, Queensland Department of Primary Industries, Queensland Seafood Industry Association and Sunfish Queensland Inc.

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A report funded by the CRC Reef Research Centre Ltd.

CRC Reef Research Centre was established and is supported under the Australian Government's Cooperative Research Centres Program. It is a knowledge-based partnership of coral reef managers, researchers and industry. Its mission is to plan, fund and manage world-leading science for the sustainable use of the Great Barrier Reef World Heritage Area. Members are:

- Association of Marine Park Tourism Operators
- Australian Institute of Marine Science
- Great Barrier Reef Marine Park Authority
- Great Barrier Reef Research Foundation
- James Cook University
- Queensland Department of Primary Industries
- Queensland Seafood Industry Association
- Sunfish Queensland Inc.

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© CRC Reef Research Centre Ltd 2002.

National Library of Australia Cataloguing-in-Publication entry

Kapitzke, I. R.

Reef infrastructure guidelines : tourist pontoons.

Bibliography.

Includes index.

ISBN 1 876054 29 8.

1. Pontoons - Environmental aspects - Queensland - Great Barrier Reef. 2. Great Barrier Reef Marine Park (Qld.) - Management. I. Hardy, T. A. II. Matheson, M. J. (Michael John). III. Title. (Series : CRC Reef Research Centre technical report ; no. 39).

577.789476

This publication should be cited as:

Kapitzke IR, Matheson MJ, Hardy TA. 2002. *Reef infrastructure guidelines: tourist pontoons*. CRC Reef Research Centre Technical Report No 39, CRC Reef Research Centre, Townsville.

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Published by the CRC Reef Research Centre Ltd.

Further copies may be obtained from CRC Reef Research Centre Ltd, PO Box 772, Townsville, QLD 4810 Australia.

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FOREWORD

The Great Barrier Reef Marine Park Authority (GBRMPA) is very pleased with the co-operative approach between CRC Reef researchers, the tourism industry and managers that led to the successful completion of *Reef Infrastructure Guidelines: Tourist Pontoons*.

There is a diversity of infrastructure, including pontoons, marinas, groynes, underwater observatories, boat ramps, cables, artificial reefs, stinger nets, navigation aids, aquaculture facilities and a floating hotel that have been proposed or have been permitted in the Great Barrier Reef Marine Park (GBRMP). Tourist pontoons, anchored on outer reefs, are large, popular facilities and are the focus of these guidelines. The first tourist pontoon was a simple, barge-like structure that was permitted in 1983 at John Brewer Reef offshore from Townsville. There are now approximately 20 large pontoon-type facilities that have been permitted to operate in the GBRMP; they are spread between Agincourt Reef offshore from Port Douglas to Lady Musgrave Island. Pontoon design has evolved. Modern pontoons are purpose-built, multi-level structures in excess of 50 metres long. The largest floating structure that has been permitted in the GBRMP was the Four Seasons Floating Hotel.

There have been some environmental problems with installation and operation of pontoons. In some cases, there were negative impacts on the coral and fish near the pontoons. A major concern has been the risks associated with direct and indirect damage to the environment from a pontoon sinking or breaking free from its moorings in bad weather or cyclonic conditions.

Previously, GBRMPA advocated a precautionary approach to minimise the risk of damage from structures to the GBRMP. The Authority developed a policy that required all structures to be certified by an engineer to withstand category 4 cyclones. However, this policy was criticised by the tourism industry and designers as being too conservative and difficult to implement. GBRMPA responded by initiating discussions with experts on engineering who were developing an alternative approach based on the location of the structure, acceptable risk of failure and structure design life. These discussions were initiated in 1994 with the CRC for Ecologically Sustainable Development of the Great Barrier Reef (which later became CRC for the Great Barrier Reef World Heritage Area or CRC Reef) and in the intervening year there have been numerous staff changes, conference papers, meetings, field trips, reviews and several awards for excellence.

A challenge for all projects is to successfully integrate science and management. I believe that we have been very successful in this objective because of good communication between industry, science and management. The *Reef Infrastructure Guidelines* will form the basis of the GBRMPA's policy for structures in the GBRMP. The guidelines have been designed to provide new and existing operators, designers and managing agencies a 'World's Best Practice' framework and protocol to develop tourist pontoon projects from the concept phase, through feasibility, design and installation, to monitoring and operation.

The guidelines are a lengthy, detailed document and GBRMPA will be directly involved in communicating their importance to the tourism industry and the broader community.

Dr Adam Smith
Manager, Environmental Impact Management
Great Barrier Reef Marine Park Authority (GBRMPA)

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the organisations and individuals who willingly collaborated with us in developing the Guidelines. Tourism operators, in particular, Quicksilver Connections, Great Adventures, Sunlover Cruises, Reef and Island Tours, and FantaSea Cruises, provided valuable insights into the planning, installation and operation of their pontoon facilities. Marine engineers, naval architects and other design consultants and marine contractors have assisted with our understanding of the characteristics and behaviour of the pontoon mooring and anchor systems. Staff from the Environmental Impact Management group in the Great Barrier Reef Marine Park Authority, and from Queensland Environment Protection Agency guided us on project assessment and Marine Park management aspects. We also acknowledge the input of researchers who contributed to the work, particularly Dr Stan Massel from the Australian Institute of Marine Science. Lastly, we thank the reviewers of the document, Dr Adam Smith (GBRMPA), Mr Richard Stewart (Stewart Marine Design Pty Ltd) and Mr David Hutchen (FantaSea Cruises) for their valuable contribution to ensuring that the guideline product is useful to tourist pontoon operators, design practitioners and Marine Park managers. This research was funded by CRC Reef Research Centre Ltd.

Mr Ross Kapitzke

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1 INTRODUCTION

	Summary
1.1	Purpose and scope
1.2	History of pontoon development in the Great Barrier Reef Marine Park
1.3	Modern tourist pontoon installations
1.4	Using these <i>Guidelines</i> in tourist pontoon planning, design and implementation
1.5	Recommended reading

Summary

- Tourism **operators/proponents, designers** and environmental **managers** should use this chapter to gain an overview of tourist pontoon development in the Great Barrier Reef region.
- Tourist pontoon facilities must provide for the protection and wise use of the natural environment. They must withstand severe tropical cyclones, meet stringent structure, function and safety requirements, protect cultural heritage, and mitigate impacts on the Reef.
- These *Guidelines* provide a systematic planning, design and implementation procedure to meet the multipurpose requirements for new or upgraded tourist pontoon projects.
- The *Guidelines* provide a framework and procedure for tourism operators/proponents and designers to undertake a development, and they provide a basis for managers and reviewers to assess the proposed projects.

The Great Barrier Reef region, comprising the Great Barrier Reef (GBR) and adjoining mainland coastline and continental islands, has great natural, cultural, aesthetic and economic importance for Australia (Figure 1.1). From a conservation viewpoint, declaration of the Great Barrier Reef World Heritage Area (GBRWHA) in 1981 provided recognition of its outstanding universal value and integrity as a self-perpetuating ecological system. Placement on the register of the National Estate in 1982 further recognised the special values of the Reef for the present community and for future generations in Australia. From a development viewpoint, the region is one of Australia's premier tourist destinations, it supports major fishing and shipping industries, and it encompasses a wide range of infrastructure within and adjacent to the Great Barrier Reef Marine Park (GBRMP).



Figure 1.1 The Great Barrier Reef Region

Source: State of the Great Barrier Reef World Heritage Area (GBRMPA 1999)

Infrastructure developments such as marinas, jetties, tourist pontoons and moorings in coastal, island and offshore environments in the GBR region must be carefully undertaken within this context of conservation and development. The objectives for management of the Reef are to balance its protection and wise use, and to provide for ecologically sustainable development. That is, Reef management aims to protect natural values and ecological processes, whilst providing for a range of uses that are consistent with the conservation of these natural features and processes.

The demand for sustainability within the Great Barrier Reef region applies particularly to the planning, design and implementation of offshore facilities such as tourist pontoons. These pontoons are semi-permanently moored floating structures supporting tourist activities, operated by shore-based tour companies, and normally located at outer reef sites. They must withstand harsh environmental loading such as severe tropical cyclones, and meet stringent requirements for structure, function and safety. Designs must also protect cultural heritage, and mitigate impacts on the sensitive coral reef environment.

Limited guidance has historically been available for the planning, design and implementation of reef and coastal infrastructure projects such as tourist pontoons. Tourist pontoons are unconventional installations, for which design criteria for tropical cyclone loading, and mooring configuration and design techniques have not been clearly established. Few designers have the relevant experience and expertise with this type of facility, and limited information is available on design inputs for winds, waves etc. The requirements for reef facilities differ from those applying in many other marine environments. Standardised coastal engineering analyses and assumptions may not apply to coral reefs, which are living substrates with unusual growth patterns that respond to wave action, currents, cyclones and other climatic variables (Plate 1.1).



Plate 1.1 The coral reef environment: Lady Musgrave Island Reef

The CRC Reef Research Centre (CRC Reef) was established in 1993 through the Australian Government's Cooperative Research Centres Program. CRC Reef is a knowledge-based partnership of coral reef managers, researchers and industry, whose purpose is to address and to develop approaches to sustainable development in the region.

These *Reef Infrastructure Guidelines: Tourist Pontoons* have been developed by CRC Reef to meet the needs of tourism operators, who own and operate tourist pontoons in the Marine Park, as well as the needs of the Great Barrier Reef Marine Park Authority (GBRMPA), which manages and regulates development activities in the region (Box 1.1). An interdisciplinary approach is used, embracing the fields of coastal and ocean engineering, environmental science and conservation management.

Box 1.1 Activities involved in development of Reef Infrastructure Guidelines: Tourist Pontoons

- assessment of reefal and coastal processes and environmental conditions for the GBR
- analysis of natural processes and environmental conditions that affect infrastructure development on the Reef
- analysis of infrastructure response and behaviour when subjected to severe climatic conditions and environmental loading such as during tropical cyclones
- evaluation of infrastructure design layouts and configuration for sustainable development
- development of a project planning and design methodology to account for physical, biological and socio-economic factors
- examination of case study projects in the region
- collaboration with marine park managers, tourism industry operators, designers, and researchers

1.1 Purpose and scope

These *Guidelines* have been prepared to assist tourism operators/proponents, designers, managers and reviewers in the planning, design, implementation, monitoring and management of tourist pontoon projects on the GBR (Box 1.2). They provide **proponents** and **designers** with a basis for understanding and applying sound engineering and environmental practice to pontoon development in coral reef regions. They also provide a basis for **environmental managers** in GBRMPA and other agencies, and expert **reviewers** engaged by GBRMPA, to apply these consistent principles when evaluating and assessing projects.

Both the experienced operator, who already has one or more pontoons in operation, and the not-so-experienced operator, who is proposing a pontoon development for the first time, will use these *Guidelines*. Planners and designers involved in these projects should have a good understanding of the requirements for development of structures in the marine environment, and previous experience with coral reefs in particular. Individual users, trained in engineering, naval architecture, ecology and conservation management etc., will require specialist input in areas outside their expertise.

Box 1.2 Objectives for Reef Infrastructure Guidelines: Tourist Pontoons

- Present an approach to planning and design in the coral reef environment that acknowledges function and safety requirements, as well as protection of coral reef ecosystems, and maintenance of social and cultural values.
- Provide a framework and procedure for tourism operators, developers or their representatives to undertake a tourist pontoon development on the GBR.
- Provide technical guidance for trained professionals (eg. engineers, environmental scientists, ecologists), with specialist input as required, to undertake the planning, design, implementation and monitoring of a tourist pontoon project.
- Provide a basis for management and regulatory agency staff and expert reviewers to assess proposed projects.
- Provide a reference document for policy makers, tourism operators, consultants, researchers, trainers, educators, students, contractors and others involved in infrastructure development in the coral reef environment.

The complexities of natural systems do not allow rigid rules or completely deterministic procedures for infrastructure development projects such as tourist pontoons to be set down in a cookbook type of approach. Prescriptive guidance is neither achievable nor appropriate because of the variety of conditions and circumstances encountered. The approaches and techniques presented here complement, but do not substitute for, professional experience or judgement based on site-specific evaluation and design. They are not intended as a design code requirement or standard. The characteristics of some complex projects may require more comprehensive investigation and design approaches than those outlined here. On the other hand, provided

conservative approaches are used and no adverse consequences and effects are likely to result, investigation and design methods for simple projects may be abridged in order to keep these costs low in relation to overall project costs. Users should understand the full scope of issues and procedures involved in pontoon projects and should approach the planning and design activities in a manner appropriate to the particular project.

The *Guidelines* are not intended to prevent enterprising and innovative solutions. Alternative approaches and techniques will be considered, but pontoon operators and designers should recognise that innovative alternatives may require greater investment of resources in research and development to demonstrate their suitability. Techniques may change over time as a result of new research, proven methods and modern technology. The *Guidelines* provide for this. For example, the information on hydrodynamic design and modelling presented in Chapter 5 and in the *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Hardy et al. 2001) may be updated as hydrodynamic modelling results are developed. A more sophisticated dynamic mooring design approach may be introduced as an alternative to the simplified method presented in Chapter 7, and improved mooring and anchor systems may be developed as alternatives to those described in Chapters 7 and 8.

These *Guidelines* apply both to new tourist pontoon developments and to existing facilities that are to be upgraded or retrofitted to meet updated requirements. The document may also be used as a guide for other, smaller pontoon-type structures, such as swim platforms, helicopter pontoons, and floating decks for reef and jetty access, which are often used in the Reef environment in conjunction with the tourist pontoons. Many of the principles and details presented here for planning, design and implementation will apply to such auxiliary structures, even though their function, configuration and detail differ from tourist pontoons. Although developed for tourist pontoons on the Great Barrier Reef, much of the *Guideline* material will be relevant to other Reef facilities and coastal developments, and to other areas in the wider Pacific region and beyond.

1.2 History of pontoon development in the Great Barrier Reef Marine Park

Various structures such as boat harbours, jetties and underwater observatories existed within or adjacent to the GBRMP at the time of its declaration in 1975. Since the early 1980s, GBRMPA has grappled with the need for a comprehensive policy to manage new infrastructure developments and to regulate existing facilities. Over this period GBRMPA has progressively developed draft policies and guidelines for installations such as pontoons, mariculture, marinas, artificial reefs and sewage outfalls. Guideline users (project proponents, designers and marine park managers), however, have sought updated guidelines that can be applied to all infrastructure development applications. These calls for new guidelines have been heightened by the complex technical issues involved in infrastructure developments, the failure of several structures, an increase in the number of development applications, and the need for streamlining of, and consistency in, assessment.

A number of proposals were put forward in the early 1980s to develop stable, permanently moored tourism facilities on the Reef. The intent was to enhance visitor experience to the outer reef and to relieve pressures on the reef islands, which were under considerable stress from high levels of visitation. (The first tourist pontoon was installed on John Brewer Reef near Townsville in 1983.) These early installations were relatively simple platforms, providing activities such as snorkelling, scuba diving, fish feeding and glass-bottomed boat trips.

The *Four Seasons Floating Hotel* (FSFH) was installed on John Brewer Reef in 1988 as a major pontoon-type venture. Serious attempts were made to adequately consider environmental conditions in design, but few relevant planning and regulatory instruments to guide assessment of this type of offshore structure were available at the time. The venture folded after only a few years of operation, due to poor commercial performance and some technical inadequacies. Nevertheless, the project helped in developing an understanding of the requirements for design and installation of offshore structures on the Reef. It also provided a major milestone in policy development for tourism facilities on the Reef by addressing such things as the uncertainties surrounding the legal status of offshore structures located outside, what was at that time, Australia's three nautical mile declared territorial sea.

The tourist pontoon concept from the 1980s has subsequently grown to the point where a large proportion of first time and return visitors to the GBR now see the Reef from pontoons located from Lady Musgrave Island near Bundaberg to the Agincourt reefs near Port Douglas. Concerns raised by environmental groups, who initially opposed some aspects of the early installations, have largely been resolved, and pontoons have developed into bigger and more complex structures as a result of increasing markets, competitive innovation and technological advances.

Nevertheless, a number of installations have failed in some way, leading either to damage to the structure or to environmental damage to the coral reef in the immediate vicinity. One of the first attempts at a purpose-made pontoon installation (*Fantasy Island* on John Brewer Reef) sank at its moorings shortly after installation in 1988 and was salvaged from the reef after more than 18 months. Over the ensuing decade, a number of pontoons and ancillary facilities broke free from their moorings and were grounded on nearby reefs, damaging coral colonies and causing visual scars. Mooring chains have shifted, damaging coral colonies under and adjacent to the pontoon facilities in many installations. Operators, designers and managers have improved their understanding of technical aspects of the installations by examining the failures, and this has been reflected in some way through revised policies and guidelines for pontoon facilities.

In spite of this, many of the fundamental issues relating to design loading and criteria, and mooring design methods have remained unresolved. Draft pontoon guidelines, introduced by GBRMPA in 1989 and subsequently modified in 1991 and 1992, adopted a simple, precautionary approach. The *Draft Guidelines* stipulated a conservative Category 4 tropical cyclone design criterion to guard against failure or excessive movement of the moorings, which might endanger passenger or shipping safety or damage coral at the site. GBRMPA justified the conservative design criteria on the basis of the high value of the installations, their potential liability for human life and property losses resulting from mooring failure, and their obligation to protect the environmental integrity and the natural and cultural resources of the GBRWHA. GBRMPA further justified the conservative criteria on the basis of the uncertainties in hydrodynamic design, and difficulties in the accurate determination of wind-wave characteristics and design loadings in the coral reef environment.

On the other hand, many marine park tourism industry pontoon operators and designers have considered the design criteria to be excessive both in terms of safety and environmental protection, claiming that the criteria for pontoon mooring safety are not consistent with those for terrestrial installations. With regard to environmental protection of the reef, they have claimed it is futile to provide such conservative criteria for pontoon-related damage when the reef itself is damaged by cyclonic conditions. The argument here is that it is inconsistent and over rigorous to further limit the damage caused by the mooring chains for the same event.

Pontoon operators and marine park managers have improved practices for environmental protection of the pontoon site through monitoring programs, which have examined the effects of the pontoons on the local coral and fish populations. Whereas the first attempts to monitor the potential impacts of pontoons were initiated by tour guide companies in the 1980s, monitoring programs have since become obligatory for new pontoon projects.

1.3 Modern tourist pontoon installations

Modern tourist pontoons (Plate 1.2) are normally located on outer reef sites up to 60km from the coast. Serviced by fast catamarans, the typical large pontoon, takes up to 450 visitors per day, making a 1.5 to 2.5 hour journey from the coast, and staying 3 to 4 hours at the pontoon.

Pontoon facilities, structures and mooring arrangements have changed significantly over time. Whereas the first pontoons were simple, barge-like structures less than 20 metres long with very basic facilities such as covered areas and tables, the latest pontoons are purpose-made, multi-level structures in excess of 50 metres long. Improvised mooring systems on the original installations, incorporating chains attached to miscellaneous concrete and steel anchors, are now replaced with elaborate systems, carefully configured to protect the coral substrate. Difficulties in berthing experienced by service craft at the original pontoons have generally been alleviated at the new installations.

Modern tourist pontoons provide a range of activities, including snorkelling, scuba diving, underwater viewing, fish feeding, reef viewing and guided reef walks (Plate 1.3). In addition to the pontoon structure and moorings, the pontoon installation usually includes a variety of ancillary craft and facilities (Plate 1.4, Box 1.3). Dedicated access platforms are provided for scuba diving and snorkelling, and detached platforms are often provided for helicopters and seaplanes. As well as providing a berthing facility for the transit vessels, the pontoons house semi-submersible craft, glass-bottomed boats and dive tenders.



Plate 1.2 Tourist pontoon: Great Adventures, Norman Reef



Plate 1.3 Pontoon activities: snorkelling



Plate 1.4 Pontoon installation on the Great Barrier Reef
Source: State of the Great Barrier Reef World Heritage Area (GBRMPA 1999)

Box 1.3 Typical auxilliary craft and facilities

- catamaran for day trip service from coastal ports
- miscellaneous service craft (eg. dive tender, runabout, research vessel)
- semi-submersible craft
- swim pontoon
- helicopter and pontoon
- seaplane
- single point moorings for service craft

Aesthetics and physical comfort are important features for tourist pontoons, as they are for all recreational facilities located in coral reef areas. Structures must provide access to the surrounding water and coral, and the facilities must be easily installed and, under present Marine Park regulations, must be able to be completely removed. Floating platforms are most suitable for this purpose as they provide good access to the water, are installed in their complete condition and can be readily removed or relocated.

Extensive facilities are commonly built into the pontoon structure (Box 1.4). The most recently installed structures are multi-level platforms with underwater observatories, barbecue and dining areas, freshwater showers and overnight accommodation for caretaker staff. The components, layout and configuration of a pontoon installation depend on the function of the facility and the characteristics of the site (Chapter 6). Layout planning for pontoon installations has been refined in recent large projects, such as the Agincourt III pontoon near Port Douglas. Quicksilver Connections used an integrated resort-planning approach for this project, creating a physical model of the site and structure to assist in project planning and design (Plate 1.5).



Plate 1.5 Model of Quicksilver tourist pontoon for Agincourt Reef

Box 1.4 Pontoon facilities commonly provided

- docking facilities for craft (catamaran, semi submersible, miscellaneous)
- access platforms for snorkelling
- access platforms for scuba diving (introductory and experienced)
- underwater observatory
- catering area (barbeque, food preparation, food storage, servery)
- dining and lounge areas
- tables and seating areas
- souvenir and sales area
- sun deck
- canopy and sun awnings
- freshwater showers
- change rooms
- machinery space
- storage facilities (diving equipment, souvenirs, galley equipment)
- fresh water tanks
- grey water holding tanks
- overnight accommodation
- communication facilities and other instrumentation
- access ramps and stairwells
- miscellaneous protection devices (eg. bird netting)

If they are appropriately designed and managed, tourist pontoons are likely to have minimal adverse impact on the Reef. At the same time, they offer many benefits for reef-based tourism activities, providing effectively for high demand and high intensity use. They provide enhanced visitor appreciation compared with other offshore tourism operations, and an unparalleled opportunity for tourists to view and learn about the Reef. The comparatively unobtrusive nature of the large capacity installations causes conceivably less disturbance to a 'wilderness experience' than a large number of smaller vessels or structures.

Very few sites are available, however, in any particular area on the GBR that meet the strict criteria for suitability for pontoon installations. Protection of these sites is vital to the continued viable operation of the facility. Site selection criteria for pontoons are based on Marine Park policy and management provisions, as well as, operational, safety and customer considerations (Chapter 6). The characteristics of the pontoon site not only affect operational viability, but also constrain the design and construction of the installation. Sites may differ markedly in exposure to winds, waves and currents; in water depth and foundation conditions; and in coral cover and condition. These factors affect, for example, mooring type, configuration and capacity.

The type and configuration of the pontoon moorings and anchors are governed not only by the site characteristics, but also by the need to withstand tropical cyclonic loadings and to satisfy operating conditions (Chapters 6 to 8). Pontoons are normally located in shallow water, typically less than 20 metres deep. Prevailing weather conditions are predominantly calm, but severe conditions occur during tropical cyclones. The pontoons are moored over and adjacent to corals, hence the moorings and anchors must be strategically placed. Coral is sometimes relocated to provide clearance for mooring lines and anchors. This is a fragile environment, which may be subject to damage during installation and operation.

A multi-point mooring system, comprising a mooring line and anchor connected to each of, at least, four points on the pontoon, has conventionally been used. Various supplementary *cyclone mooring* arrangements, such as a single-point, cyclone swing mooring connected to the primary multi-point mooring system, have been employed for extreme conditions in some installations. This system usually incorporates lightweight mooring lines that hold the pontoon aligned into the prevailing winds under normal conditions. These lines are designed for release during cyclone conditions, allowing the pontoon to weathervane off the single-point mooring line and align with the cyclonic wind, sea, swell and current forces.

Various alternative *cyclone mooring* arrangements have been considered, in which the pontoon would be moved to an adjacent deep water sheltered mooring site prior to the onset of excessive weather conditions. Under this system, a manually operated winch or an automatic system would be used to relocate the pontoon to and from the cyclone mooring. It is not logistically possible to mobilise craft at short notice to rehook the pontoon to alternative moorings at the site, or to relocate the pontoon back to the mainland through rough seas.

The mooring lines and anchors for the multi-point mooring system usually comprise a conventional heavy mooring chain attached to one or more anchors on the seabed for each mooring leg. Conventionally, dumper blocks, clump weight sinkers and line buoys have been used in an attempt to dampen the dynamic effects of the mooring forces on the anchors and to reduce the likelihood of the mooring lines coming in contact with and damaging the corals. Recent modelling studies have shown that the manner in which dumper blocks and buoys have been used in the past has rendered them somewhat ineffective under severe conditions, exacerbating reef damage caused by movements of mooring lines (Chapter 7). More effective use of dumper blocks is required, in conjunction with heavier chains and consideration of innovative systems incorporating elastic elements (eg. bungy cords).

Various anchor types are used in the coral reef environment, including the dead weight, drag embedment, grouted screw and driven pin cluster anchors. Anchor types must be carefully chosen to provide the capacity appropriate to the environmental loading and substrate condition, to suit the ecological conditions, and to minimise construction disturbance. Various anchor types and methods for anchor design are discussed in Chapter 8.

Although only moored floating pontoon systems have conventionally been used on the GBR, fixed systems mounted on piles or caissons on the sea floor could be considered. To alleviate excessive forces on the structure from wave action associated with tide and storm surge induced water level fluctuations, the underside of these platforms would need to be six metres or more above low tide levels. Such a structure would require substantial foundations and would significantly detract from the amenity value of the Reef. A variation to this, which allows the structure to jack up and down with water levels, would be expensive and difficult to construct, operate and maintain in the harsh offshore environment. A possible compromise would be to fix most of the structure well above water levels, with a smaller adjustable (or floating) portion that would be lowered (or float) to cater for water-based recreation. Although offering security under adverse wave conditions, with reasonable foundation requirements, this type of facility has many drawbacks related to the poor visual impact, access difficulties to the water-based activities area, and generally poor amenity value in the marine environment.

One configuration that may provide for structural integrity while meeting the requirements for environmental protection, amenity and recreation access, is to moor a floating pontoon to fixed piers or caissons with short elastic mooring lines. This arrangement would avoid long mooring lines and minimise the area of the seabed affected, while complying with the need for flexible mooring systems, which withstand severe loading conditions.

1.4 Using these *Guidelines* in tourist pontoon planning, design and implementation

These *Guidelines* provide the framework and procedures for development of a tourist pontoon project from the **concept phase**, through **feasibility**, **design** and **installation**, to **monitoring** and **operation** (Box 1.5). The document helps tourism **operators/proponents**, **designers**, **reviewers**, **environmental managers** and other users to:

- understand the concept of sustainable development, and thus provide both for human use and for protection of natural ecosystem function
- understand the marine environment (in particular, the coral reef) and how it relates to pontoon installations
- follow a systematic project planning, design and implementation procedure meeting multi-purpose requirements

Box 1.5 Framework, procedures and elements presented and described in these *Guidelines*

- the prevailing **policy, legislative and management regime** for reef facilities
- a project **planning, design and implementation procedure**
- **guiding principles** for planning, design and implementation
- planning and design **steps and tasks**
- planning and design **tools**
- **techniques** for implementation of the facility and its components
- best practice **guides** and **checklists**
- **references** to relevant literature for detailed procedures or parameter values
- **examples** to illustrate analysis and evaluation

Chapter 2: Sustainable infrastructure development on the Great Barrier Reef provides tourism **operators/proponents**, **designers** and environmental **managers** with an overview of sustainability as it applies to tourist pontoon projects in the GBR. The core principles for sustainable development are presented, and the prevailing policy, legislative and management regime for the GBR is outlined. The desired approaches to multiple objective planning and design, project management and stakeholder consultation are presented.

Chapter 3: Project planning, design and implementation presents a 10-Step procedure, incorporating four phases from (1) **Concept**, through (2) **Feasibility**, and (3) **Implementation**, to (4) **Operation, monitoring and review**. The procedure provides a common basis for **proponents**, **designers** and **managers** to use in the planning, design and implementation of a tourist pontoon project. The GBRMPA permit assessment process is outlined and the manner in which this fits into the planning, design and implementation procedure is described. A summary of the component planning and design steps and tasks within each of the project phases is provided for **designers** and **managers**; the relevant personnel, planning and design tools, input and output data and other information are described, and links with other sections of the *Guidelines* are established.

Chapter 4: Site investigation and characterisation is an integral part of project planning, design and implementation, providing a framework for assessment of site conditions, and outlining site investigations that the **proponents** and **designers** may undertake. The likely data sources and methods of acquisition are described for each of the principal data areas that may be needed, and likely data acquisition needs through various phases of the project are noted.

Chapter 5: Design environmental loads outlines the environmental loading conditions that apply for a pontoon facility, and provides **designers** with a basis for determining design load components resulting from waves, winds and water levels. A risk-based approach is presented as the basis for **proponents, designers and managers** to determine the appropriate loading conditions associated with tropical cyclones. The manner in which the design loads are used in subsequent chapters to ensure the adequacy of the pontoon mooring system, the structural integrity of the pontoon elements, and the overall stability, buoyancy and safe operation of the facility is explained.

Chapter 6: Pontoon siting, layout and configuration provides the basis for **proponents, designers and managers** to determine the site, layout and configuration of the pontoon facility, which must meet multi-purpose requirements related to function, safety, environmental protection and amenity. The scope and method of the tasks, the objectives and criteria to be met, and the relevant personnel, planning and design tools, input and output data and other information are described.

Chapter 7: Mooring design presents detailed procedures for **designers** to use in the selection and design of the pontoon mooring systems, which is one of the most technically demanding and complex tasks covered in these *Guidelines*. Using design load data from Chapter 5, and based on the siting, layout and configuration features selected from Chapter 6, methods of analysis are described for determining forces and movements in the mooring system and for designing mooring components.

Chapter 8: Anchor design is to be used by **designers** in the selection and design of the anchors to be incorporated into the pontoon mooring system. Site data, design loading, siting, layout, configuration, and mooring design information from Chapters 4, 5, 6 and 7 are used to determine anchor loads and to assess capacities for various anchor types and configurations.

Chapter 9: Pontoon body and ancillary facilities provides basic information for **proponents and designers** to use in the configuration, design and specification of the pontoon body and other miscellaneous aspects of the pontoon facility. Principles and recommended practice for selection and design of materials, coatings, storage vessels, waste management and other facilities are provided.

Chapter 10: Pontoon installation, operation, maintenance and monitoring provides a guide for **operators, designers and managers** to use in post-design aspects of the pontoon project. The scope and provisions for installation, operation and maintenance are presented, and the manner in which these aspects are incorporated into project planning and design tasks and management plans is described. The requirements for monitoring both the facility and the environment throughout the above phases are also described.

The *Guidelines* address major issues and limitations that have conventionally applied to planning, design, implementation, maintenance and monitoring practices in tourist pontoon projects. The major issues identified by tourism operators, designers, managers, researchers and others, and the manner in which they are addressed in this document are summarised in Box 1.6. Further detail is provided in subsequent chapters.

Box 1.6 Major issues in pontoon planning, design, implementation, maintenance and monitoring	
Issue	How addressed in these Guidelines
Inadequate links between policy and practice to ensure sustainability for pontoon projects.	Links between policy, legislation and management planning, and project planning, design and implementation are established in the framework for sustainable infrastructure development (Chap 2).
Uncertain path of project assessment by GBRMPA.	The systematic planning, design and assessment procedure clearly outlines project requirements and provides an early indication of project suitability (Chap 3).
Inadequate project management for integration of planning, design and implementation activities by proponents and designers.	The integrated planning, design and implementation procedure reduces project delays and overall costs (Chaps 2, 3 & 4).
Incomplete consideration of multiple project purposes related to function, safety, environmental protection and amenity, by proponents, designers and GBRMPA managers.	Multiple project objectives are achieved through an interdisciplinary approach and the systematic procedure for project planning, design and implementation (Chaps 2, 3 & 4).
Over-conservative and irrational design criteria for tropical cyclone loadings.	A risk assessment approach is used to define design criteria for prevailing and severe conditions (Chap 5).
Inadequate calculation of the intensity of environmental loads due to winds, waves and currents.	Designers will use the <i>Atlas of Tropical Cyclone Waves in the Great Barrier Reef</i> for waves, and simplified approaches for winds and currents (Chap 5).
Deficient analysis and design of pontoon moorings.	A conservative but simplified approach is presented and reference is made to more sophisticated approaches if warranted (Chap 7).
Inadequate construction supervision and maintenance provisions for structural components.	Improved specification and quality control for installation, site testing and maintenance (Chap 10).

1.5 Recommended reading

Atlas of Tropical Cyclone Waves in the Great Barrier Reef. Available at:

<http://tsunami.jcu.edu.au>

Great Barrier Reef Marine Park Authority. 1994. *A 25 year Strategic Plan for the Great Barrier Reef World Heritage Area*.

Great Barrier Reef Marine Park Authority. 1999. *State of the Great Barrier Reef World Heritage Area*.

Hardy TA, McConochie JD, Mason LB. 2001. Great Barrier Reef Tropical Cyclone Wave Database. In *Proceedings of Coasts and Ports Conference 2001*. Institution of Engineers Australia.

Inglis GJ. 1996. Science and tourism infrastructure on the Great Barrier Reef: Learning from experience or just 'muddling through'?. In *Proceedings of The Great Barrier Reef Science, Use and Management, A National Conference*, Townsville, November 1996, pp. 319-333.

2 SUSTAINABLE INFRASTRUCTURE DEVELOPMENT ON THE GREAT BARRIER REEF

	Summary
2.1	Core principles for sustainable reef infrastructure development
2.2	Policy, legislative and management regime
2.3	Multiple objective planning and design
2.4	Project management
2.5	Stakeholder consultation
2.6	Recommended reading

Summary

- Tourism **operators/proponents, designers** and environmental **managers** should use this chapter to gain an overview of sustainability as it applies to tourist pontoon projects in the GBR.
- Core principles for sustainable infrastructure development relating to multiple objectives, an interdisciplinary approach, and a hierarchical project planning, design and implementation procedure, are presented.
- The prevailing policy, legislative and management regime for the GBR, including institutional arrangements, Marine Parks permits and impact assessment, are outlined.
- The desired approaches to multiple objective planning and design, project management and stakeholder consultation are presented.

The concept of sustainable development (Box 2.1) has significantly influenced thinking and practice in infrastructure planning and development in recent years. Sustainable development involves meeting present needs without compromising capacity to meet future needs. It provides a means of achieving sustainability, which, according to the Institution of Engineers, Australia *Policy on Sustainability* (1994), is “the ability to maintain a high quality of life for all people, both now and in the future, whilst ensuring the maintenance of the ecological processes on which life depends, and the continued availability of the natural resources needed”. In simple terms, this means providing for human use and natural ecosystem function, now and in the future.

Box 2.1 Principles for ecologically sustainable development *Source: Report of the World Commission on Environment and Development - Brundtland Report (WCED 1987).*

- decision-making processes should effectively integrate both long-term and short-term economic, environmental, social and equity considerations
- if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent it.
- the principle of inter-generational equity—that the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations
- the conservation of biological diversity and ecological integrity should be a fundamental consideration in decision-making
- improved valuation, pricing and incentive mechanisms should be promoted

The philosophies and principles of sustainable development are now well established in international treaties and protocols, and in national government policies and legislation (see, for example, Australia’s *National Strategy for Ecologically Sustainable Development* and the *Environment Protection and Biodiversity Conservation Act*). These principles are reinforced in professional and industry guides and codes of practice, such as the *Coastal Engineering Guidelines* (NCCOE 1998) and *Environmental Guidelines for Tourist Developments* (ATIA 1990). The challenge for practitioners and managers involved in coastal and ocean engineering and other resource management projects, however, is to bridge the gap between sustainable

development goals at the broad planning level, and sustainable outcomes at the project level. This means translating the general principles of sustainability from well-established policy, legislation and management regimes into a practical basis for project planning, design and implementation.

This chapter aims to establish that link for tourist pontoons on the GBR. Three core principles for sustainable projects are first presented. Key policy, legislation and management aspects for the GBR are then described, and the integrated planning and design approach for multi-purpose infrastructure projects such as tourist pontoons is presented. Essential project management aspects for project staffing, timing and costs, documentation and communication, and quality assurance are then presented. Finally, requirements for stakeholder consultation are discussed.

2.1 Core principles for sustainable reef infrastructure development

Three core principles underlie the integrated planning and design approach for sustainable reef infrastructure development projects, and provide a means for proponents, designers and managers to link the management regime for the Reef (Section 2.2) with planning, design and implementation activities for tourist pontoons (Chapter 3). These core principles do not replace the requirement for detailed investigations, planning and design outlined elsewhere in this document, but provide a good basis for sustainable outcomes.

Firstly, **multiple objectives** that recognise human use and natural ecosystem function are adopted through all stages of the project (Section 2.3). Environmental evaluation is integrated into the project planning and design tasks, which address objectives related to ecological protection and amenity, in conjunction with requirements for function and structural integrity etc. Considering broad issues and adopting multiple objectives for these tasks avoids a reductionist approach and narrow design outcomes, which may lead to project redesign or rejection. For example, the designer should consider the location of valuable coral bommies in determining the mooring layout and configuration in the design phase, to avoid project redesign or coral relocation, which may cause delays and other complications during installation.

Secondly, an **interdisciplinary approach** is used to integrate physical, biological and socio-economic considerations through all stages of the project (Section 2.4). A project team with appropriate experience is established, and the scope, method and responsibilities for planning and design activities are defined. The interdisciplinary approach involves linked investigations of issues or processes by various practitioners, who are encouraged to consider fundamental issues outside their area of expertise, and to clearly communicate the fundamentals on which they base their interpretation. For example, in choosing a pontoon site, an interdisciplinary team is more likely to appreciate the interrelationship of human utility factors (eg. travel distance from port and visual amenity) and environmental factors for the site (eg. protection of coral from shading and snorkelling damage), than a hydrodynamics engineer working alone, who may focus principally on sites with minimal exposure to waves.

Thirdly, the **hierarchical project planning, design and implementation procedure** breaks the project into phases, steps and tasks (Chapter 3). The sequence, scope and method for these activities provide the bases for the proponent, designer and manager to progressively develop proposals, undertake designs and make decisions throughout the project. Project outcomes are enhanced by clearly defining responsibilities for project team members. Appropriate sequencing helps ensure that tasks are not undertaken before appropriate information is available, stakeholder consultation undertaken, suitable preliminary assessments performed, or necessary decisions made. For example, a designer should investigate alternatives and ensure compliance with regulatory requirements prior to undertaking detailed design of a scheme component.

2.2 Policy, legislative and management regime

The management regime for infrastructure development on the GBR embodies various global and local policies and programs, legislation, institutional arrangements, and management planning provisions (Box 2.2). The management goal is conservation and wise use of the Reef, or in other words, sustainable development.

Box 2.2 Policy, legislation and management planning definitions and examples

The **policies and programs** for sustainable development provide the principles, goals, management instruments and funding initiatives that govern and direct development activities at a global, national and regional level. Examples of policies and programs affecting reef and coastal development are *United Nations Agenda 21 on Sustainable Development*, Australia's *National Strategy on ESD*, *World Heritage Convention*, and *Commonwealth Coastal Policy*.

Legislation at a national and state level establishes the regulations and provisions that govern reefal and coastal development. Legislation is closely linked with policies and programs. Within the GBR region this includes the *Great Barrier Reef Marine Park Act 1975*, *Environment Protection and Biodiversity Conservation Act 1999*, *Native Title Act 1993*, *Sea Installations Act 1987*, *Marine Parks Act 1982 (Qld)*, *Beach Protection Act 1968 (Qld)*, *Coastal Protection and Management Act 1995 (Qld)*, and the *Integrated Planning Act 1997 (Qld)*.

Institutional arrangements relate to the regulation, management and ownership of resources in the region, and to the mechanisms for coordination and cooperation among agencies and stakeholders. This includes government management agencies such as the GBRMPA and the QPWS, both of which regulate activities and are responsible for conservation and wise use of the region. Industry groups, such as the Association of Marine Park Tourism Organisations, Queensland Commercial Fishing Organisation and Regional Marine Resources Advisory Council provide an industry voice. Non government organisations and community groups, such as the Marine and Coastal Community Network, North Queensland Conservation Council, and Sunfish, represent other stakeholder interests.

Management planning provides strategies and controls for development and conservation of the region. This usually involves a tiered framework, which integrates environmental protection measures with planning and resource management functions at a range of spatial scales, from regional to local and site. This includes *The 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area*, and Zoning Plans and Statutory Plans of Management for the Great Barrier Reef Marine Park at various scales. These plans are complemented by a State Coastal Management Plan, Regional Coastal Management Plans, Regional Landuse and Biodiversity Plans and Local Authority Planning Schemes for coastal and hinterland areas.

Legislation

Various Commonwealth and Queensland legislation apply to infrastructure development in the GBR region. The areas of jurisdiction of those acts relevant to tourist pontoons are summarised in Appendix A. Several of the principal acts are outlined briefly below.

The *Great Barrier Reef Marine Park Act* (GBRMP Act) and the Great Barrier Reef Marine Park were established in 1975, signifying commencement of formal management of the Great Barrier Reef (Box 2.3). The GBRMP Act was one of the first pieces of legislation in the world to deal comprehensively with management of a marine ecosystem, emphasising the linkages between sites and activities within the GBR, and between the GBR and the adjacent mainland.

Box 2.3 Objectives for management of the Marine Park under the GBRMP Act

- conservation of the Great Barrier Reef
- regulation of use in the Marine Park in order to protect the Great Barrier Reef, while allowing the reasonable use of the Great Barrier Reef region
- regulation of activities that exploit the resources of the Great Barrier Reef in order to minimise the effect of those activities on the Great Barrier Reef
- reservation of some areas of the Great Barrier Reef for its appreciation and enjoyment of the public
- preservation of some areas of the Great Barrier Reef in its natural state, undisturbed by humans except for the purposes of scientific research

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) applies to actions likely to have a significant impact on World Heritage properties such as the GBR. It complements the GBRMP Act and strengthens Australia's capacity to protect biodiversity in the GBRWHA, formally requiring that the principles of ecologically sustainable development (ESD) be taken into account when considering project approvals. All actions that are likely to have a significant impact on the World Heritage property will be subject to an environmental assessment and approval regime under the EPBC Act, unless the action is within the Marine Park or is authorised under the GBRMP Act by either a zoning plan, a plan of management, a permission, an authority, an approval or a permit.

Aboriginal and Torres Strait Islander interests are considered in the assessment of infrastructure developments on the Reef. The GBRMP Act Regulations require that GBRMPA consider the cultural heritage values of the traditionally affiliated Aboriginal and Torres Strait Islander people in making decisions relating to the granting of permits. Planning and management of installations may also be affected by the *Native Title Act 1993*, which may impose conditions that prevent extinguishment or erosion of native title over areas of land and sea used for infrastructure developments.

Institutional arrangements

The Great Barrier Reef Marine Park Authority (GBRMPA) is a Commonwealth statutory body responsible for conservation and wise use of the Reef. GBRMPA manages the GBRMP through partnerships with Commonwealth and State governments, and with coastal communities and other stakeholder groups. GBRMPA is responsible for the management, planning, policy, programs and general oversight of the Park, and has ultimate responsibility for all matters below Mean Low Water. Day-to-day management of the region is conducted primarily through joint management arrangements with QPWS, which has ultimate responsibility for the intertidal zone, advises GBRMPA on local factors and administers Queensland Marine Parks, located adjacent to the GBRMP.

Apart from the legislative framework, GBRMPA is guided in its management approach by policy directives of the government of the day, the concerns of the various stakeholder interests and broader public interest. The Great Barrier Reef Consultative Committee, nominated by the Commonwealth and Queensland governments, provides a strategic advisory role for GBRMPA, while expertise-based Reef Advisory Committees provide technical advice on conservation, biodiversity and World Heritage, fisheries, tourism and recreation, and water quality and coastal development issues. GBRMPA encourages stakeholders to be active partners in marine park management. For example, the tourism industry has adopted self regulation through Codes of Practice, education, training and accreditation in order to comply with best environmental practices.

Public participation plays a big part in management of the GBR. The GBRMP Act and other legislation require public participation through various means including the consultative committee, the zoning process, and assessment and issue of permits for infrastructure development. A formal process for community consultation is now established through the Local Marine Advisory Committees (LMAC), which advise GBRMPA on specific issues affecting the GBRMP. LMACs are established at various centres along the Queensland coast adjacent to the marine park and comprise representatives from various stakeholder groups.

Management planning

A tiered management planning framework applies for the GBR at a range of spatial scales from regional planning to local area and site planning. The philosophy embodied in the management plans is outlined in Box 2.4.

Box 2.4 Management philosophy for the Great Barrier Reef

- management at the ecosystem level to achieve overall protection of the ecosystem
- conservation and reasonable use so that, while the ecosystem is protected, opportunities are still provided for sustainable use and enjoyment of the GBR
- public participation or community involvement in the development and implementation of management
- monitoring and performance evaluation of management

The 25 Year Strategic Plan for the Great Barrier Reef World Heritage Area demonstrates ecologically sustainable use at the regional scale. Released in 1994 following extensive consultation, this plan develops a shared vision and goal for management of the Reef across the broadest range of stakeholders. A range of ‘Shared Principles’ have been developed in the strategic planning process to ensure Australia's obligations are met in relation to World Heritage Listing. The plan sets out broad-scale long-term objectives for management in relation to cultural, heritage and environmental values.

Strategic management of the Marine Park is underpinned by zoning plans, which attempt to resolve conflicts between the dual goals of preservation and multiple use of the natural ecosystem. The plans provide a spatial framework to manage, regulate and control use of the Reef through closures and separation of activities. (Refer to Appendix A for the individual objectives, use and entry provisions of each of the Marine Park zones). Activities or structures that may or may not be carried out or installed in an area are identified, along with those activities or structures requiring a Marine Parks permit (see below). Some restrictions may also apply to the location of structures within zones. Tourist pontoons are allowed in all zones except the scientific and preservation zones, and certain other locations designated in local area or site management plans (introduced below).

The management framework provided through the zoning plans is augmented by area and site management plans designed to manage tourism and recreation for particularly sensitive or heavily used areas. Statutory Plans of Management are commonly used to control access and use of some sites and to protect and conserve identified natural, cultural and scientific values. The plans complement and follow the general intent of the relevant zoning plan for an area, addressing specific issues in greater detail. They may be used in conjunction with other management mechanisms to control the location and operating conditions of tourist pontoons, and to control the placement of, and access to, moorings at pontoon sites. For example, the *Cairns Plan of Management* restricts the number of pontoon installations at the Agincourt Reefs and at Low Island, and restricts the installation and operation of private moorings at several other locations. Site plans may be developed for some pontoons and private moorings in order to achieve an appropriate balance of private and public access opportunities.

Marine Park permits and impact assessment

Marine Parks permits, issued for particular activities in the Marine Park, are used to protect the values and amenity of the Reef by separating conflicting activities and by controlling environmental impacts (Box 2.5). The permit process allows monitoring of potentially damaging activities and provides data for planning and managing the Marine Park. By limiting the number of permits, Marine Park managers are able to minimise the cumulative impact of activities on the environment and on other users.

Box 2.5 Activities requiring a Marine Parks permit

- most commercial activities including tourist operations
- installation and operation of structures such as jetties, marinas, pontoons and mariculture facilities
- any works such as repairs to structures, dredging and dumping, placement and operation of moorings
- anchoring or mooring for an extended period
- waste discharge from a fixed structure
- research
- education programs
- traditional hunting

Activities and installations, such as tourist pontoons, which require a permit are considered on a case-by-case basis. The suitability of each proposal is assessed with respect to the objectives of the relevant zoning and management plans and according to the predicted individual or cumulative impacts. A permit is granted to a nominated company or person/s for a specified length of time, and specifies the activities that are permitted, the location where they may be conducted and any conditions that may apply. New applicants are granted a permit for one year, which allows time to establish the operation, and provides the applicant and the Marine Park managers an opportunity to review performance. Subsequent renewal of the permit is usually for a further six year period, depending on the activities to be conducted, and subject to performance review and reassessment of the facility.

If an operation changes in any way, an application must be submitted to vary the conditions of the existing permit or to seek a new permit. Changes may include adding or changing a vessel, undertaking different activities, or operating in different locations. A Marine Parks permit is transferable from one owner to another as long as the permit is still valid and permission is given by GBRMPA. A permit may also be suspended or revoked. This may happen when speculative operations are not commenced within a specified time, when the permitted activity causes damage to the Marine Park, or when the permit holder fails to comply with a permit condition or fails to pay fees that are due. All permits for commercial operations include a Deed of Agreement, which binds the permit holder to certain obligations, such as indemnifying GBRMPA, maintaining adequate insurance, and the payment of a bond for structures other than vessel moorings. Penalties apply for failing to comply with a Marine Parks permit.

The environmental impact of infrastructure developments, such as tourist pontoons are assessed under Regulation 18 AC(4) of the GBRMP Act (refer to criteria in Appendix A). Impact assessment considers the likely effects of the development on the biophysical environment, on public health and safety, and on social and cultural values (Box 2.6). For projects with potentially significant environmental effects, further assessment may be required under the EPBC Act, which requires either a Public Environment Report (PER) or an Environmental Impact Statement (EIS). The EPBC Act is not commonly triggered for tourist pontoons.

Box 2.6 Matters to be addressed in impact assessment under GBRMP Regulation 18AC(4)

- appropriateness of the project with respect to the zoning
- effect of the proposal on orderly and proper management of the Marine Park
- effect of the project on future options for the Marine Park
- effects of the proposal on existing uses and amenity and on potential future uses or desirable uses and amenity of the area and nearby areas
- effects of the project on the environment
- effects of the project on the conservation of natural resources
- adequacy of safety to visitors
- adequacy of provisions for removal of any associated hardware

2.3 Multiple objective planning and design

A multiple objective planning and design approach that recognises human use and natural ecosystem function is more likely to achieve sustainability goals for tourist pontoon developments on the GBR than an alternative approach based on narrow objectives (Box 2.7). The multiple objective approach gives credence to environmental objectives as well as to physical and economic objectives, which may otherwise dominate design of the facility. The multiple objectives are integrated into the planning, design and implementation procedure in all phases of the project. This provides all the advantages of an environmental impact assessment (EIA), well-integrated with planning and design activities in the early stages of a project. It has a distinct advantage over an EIA process conducted late in a project, which is likely to be less well-integrated, raising environmental issues after the project has been defined.

Box 2.7 Benefits of multiple objective planning and design for tourist pontoon developments

- more environmentally sustainable design
- better siting of the installation
- reduced risk of environmental degradation
- avoidance of expensive mitigation measures or environmental problems
- reduced capital and operating costs
- better compliance with policies, legislation and management planning strategies
- reduced time and costs of approvals of development applications
- increased project acceptance by stakeholders

Proponents/operators, designers and managers must meet a range of objectives in the planning, design and implementation of tourist pontoon projects (Box 2.8). These objectives reflect policy, legislative and management provisions as well as the requirements of the various stakeholders (eg. tourism operators, visitors, environmental managers and the general community). They include, for example, function, safety and structural considerations relating to integrity of the mooring system under cyclonic loadings, capacity of the anchor system, and operation of the facility under normal conditions. Environmental impacts resulting from shading by the pontoon, movement of mooring chains, diver impact, and waste disposal must also be considered in design, along with social and cultural issues such as amenity and aesthetic values relating to pontoon siting and operation. Chapter 6 outlines the manner in which these multiple objectives are addressed in particular planning and design tasks such as site location, and pontoon layout and configuration.

To achieve the desired outcomes for tourist pontoon projects, the designer should understand the following planning and design elements and their application to all project phases, steps and tasks (Box 2.9; Box 2.10). The project **need or aspiration** leads to identification of **development**

objectives relating to **human use** and protection of natural values. **Development pressures** associated with the project cause **failure risk** due to **environmental impacts** on **natural reef and ocean processes**. Natural processes contribute to **failure risk** through **environmental loads** that affect structure integrity and safety. Facility designs and **mitigation measures** to deal with environmental impacts must relate to the **environmental loads, environmental impacts, development pressures, development objectives** and **human use**, and must be established within the context of the **natural reef and ocean processes**.

Box 2.8 Examples of objectives for tourist pontoon project

Serviceability, function and safety	Provide adequate space and facilities for operation. Ensure ease of installation, maintenance and salvage. Ensure visitor comfort and safety in transit to the site and while on the pontoon. Ensure safety and comfort of swimmers, snorkellers and divers.
Structural integrity	Ensure adequate mooring system strength. Limit pontoon drift and interference with the reef or other structures. Provide adequate pontoon stability and buoyancy. Ensure integrity of pontoon body and above water structures.
Environmental protection	Ensure protection of coral from shading, mooring movement or failure. Ensure protection from pollution. Maintain conservation values.
Amenity and cultural heritage	Provide for aesthetic values. Protect cultural heritage.

Box 2.9 Essential planning and design elements for pontoon projects

Definition	Example
Need or aspiration Concepts or ideas outlining the scope and purpose of a development project.	Develop a tourist pontoon in an offshore location within 2 hours travel of port.
Development objectives Desired outcomes for the development project related to environmental, social and cultural values, and structural, functional and safety requirements.	Withstand severe cyclonic and prevailing weather conditions and maintain a 'high quality' environment.
Human utility Utilitarian values of the reef environment such as recreational boating, fishing, snorkelling and diving, sight seeing, conservation, education and research, and shipping.	Provide coral viewing, snorkel, dive and other facilities at the site for 400 visitors daily.
Development pressures Human activities or developments affecting the marine environment such as disturbance due to mooring installation, movement of mooring chains, snorkeller and diver contact with corals, and waste water disposal.	The pontoon footprint shades the ocean floor and the mooring installation moves in severe conditions.
Natural processes Reefal and coastal processes including hydrodynamics (eg. waves, tides and currents); geomorphology (eg. sedimentation and cementation); and ecology (eg. benthic flora and fauna characteristics).	The facility and surrounding site is subject to hydrodynamic processes associated with winds, waves, tides and currents, and ecological processes associated with coral and fish communities.

Environmental impacts Impacts of development pressures on the marine environment, including direct (local) impacts such as coral damage, alteration to fish communities, and increased turbidity; and indirect (remote) impacts such as loss of amenity and degraded water quality.	Coral damage due to shading and mooring movement are direct impacts. Indirect impacts are negligible.
Environmental loads Wind, wave and current loads on the pontoon facility under severe weather conditions occurring during tropical cyclones as well as under normal operating conditions.	The pontoon is subject to wind, wave and current loads in severe weather conditions occurring during tropical cyclones.
Failure risk The risk of coral degradation from shading and mooring line movement, or the risk of damage to the pontoon facility and adjacent coral communities as a result of mooring failure in severe weather conditions.	Excessive coral degradation occurs from shading and mooring line movement, or severe weather causes mooring failure that results in damage to the facility and adjacent coral communities.
Mitigation measures Alteration to development projects to minimise environmental impacts and meet project objectives, such as structure reconfiguration, coral relocation, and waste minimisation.	The pontoon is located over sand, the mooring configured, and coral relocated to minimise environmental impacts.

An understanding of reefal and ocean processes, such as wave hydrodynamics and coral reef morphology and ecology, and the manner in which they interact with the structure, is particularly important. These natural processes provide the link between development pressures and environmental impacts, and help explain the causes of impacts and the risks of adverse environmental consequences (eg. coral damage due to shading). Natural processes also define environmental loads on the structure and failure risks related to its integrity and safety (eg. wind and wave loads in severe conditions). Facilities must be designed to withstand environmental loads due to natural processes, and mitigation measures must address natural processes and the causes of environmental impacts.

Box 2.10 Basis for sustainable design for tourist pontoon projects

- an understanding of natural reef and ocean processes
- clear development objectives relating to human use and natural ecosystem function
- an awareness of present and proposed future human uses
- knowledge of development pressures affecting the environment
- identification of environmental impacts and understanding of their causes
- assessment of failure risks associated with environmental impacts or threats to structure integrity and safety
- a range of mitigation measures that account for the impacts, pressures, objectives, human uses and natural processes

2.4 Project Management

Tourist pontoon projects are most successful in meeting project goals and objectives when project management arrangements (eg. organisational structure, staffing, scheduling and operational procedures) are clearly established and understood by all those involved. Members of the project team established by the proponent should interact closely within their own group and with various agencies, organisations, and individuals. This interaction should continue throughout the project planning, design and implementation procedure. Project timing and costs should be carefully scheduled to avoid delays and cost overruns. Project outcomes should be clearly documented and communicated to relevant parties, and a quality control program should be implemented to ensure that the project fulfils all its planned uses and meets all required provisions and standards.

Box 2.12 Proponent's project team <i>Comprising some or all of the following personnel</i>		
Proponent delegate ^E	Representing the proponent's management group or board, the delegate initiates the project, establishes the necessary resources, and oversees project management.	
Project officer/manager ^E	Manages the project on behalf of the proponent, puts together the project team, co-ordinates project activities, and liaises with the management agency on project assessment and approval.	
Operations manager/resort planner ^O	Develops concepts and arrangements for the pontoon resort to meet recreational and operational requirements.	
Environmental engineer/scientist ^O	Establishes potential environmental impacts due to development pressures and incorporates appropriate mitigation measures.	
Naval architect/marine engineer ^E	Designs the marine engineering components of the facility, such as the moorings and the pontoon body, and defines maintenance requirements.	
Hydrodynamics engineer ^E	Establishes the wind, wave and current conditions at the site for the adopted design criteria.	
Geotechnical engineer ^O	Establishes the foundation capacity of the seabed, and the anchor requirements to resist mooring loads.	
Structural engineer ^O	Works in consultation with naval architect, to determine loads on the structure and design structural components such as shade canopy structures and other superstructure.	
Marine biologist ^E	Assesses the ecological characteristics and conditions of the site and evaluates the effect of the development on the site.	
Marine technician / diver ^O	Assists the proponent with marine activities associated with project planning, underwater investigations, and installation.	
Construction superintendent ^O	Represents the proponent's interests, ensuring contractors meet contractual requirements during construction and installation – the project manager may play this role.	
Construction and installation contractors ^E	Manufactures and installs components of the facility such as the pontoon body, moorings and recreational facilities.	
Other specialists as required ^O	Other specialists may be engaged by the proponent for technical, social, cultural or economic aspects of the project.	
Note	E Essential team members	O Optional team members

Although the full project team will not be permanently required throughout the project, members of the team should be accessible at various stages to provide the required knowledge and skills from the different disciplines, experiences and backgrounds. Planning and design activities may occur in a number of ways. Specialist tasks such as wave hydrodynamic studies, mooring design and biological site surveys may be undertaken by one person or a group of people in a particular discipline, working through the required activities in a logical sequence. Other tasks involving interdisciplinary activities such as pontoon siting, pontoon layout, or impact prediction may require a different forum to access, discuss and evaluate the required information, and to develop options to address the issues. This may involve a workshop or joint field inspection, for example, where the multiple inputs and viewpoints of the project team and specialist advisors are brought together for a more informed and reasoned assessment, particularly of complex issues. The project team commonly interacts as a group, but interchange of information in an informal manner is also important.

Each project requires a project manager or project officer, representing the proponent, who has central responsibility for all project activities. This person plays a key role in successful project outcomes, undertaking most of the work in smaller, straightforward projects, or coordinating a multidisciplinary team in larger or more sensitive projects. He/she should seek external advice on the project as required, briefing specialists from relevant disciplines and consulting with practitioners to address specific project requirements. The project manager should arrange for acquisition of much of the general data, maintain the appropriate level of quality control, provide opportunities for the project team to meet and work together, and co-ordinate joint site visits, office meetings and stakeholder consultation.

Management agency role

Marine management agencies, that is GBRMPA and QPWS, each have a role in the regulation and management of a tourist pontoon project. Management agency representatives are responsible for liaison with the proponent, assessment of project planning and design proposals, supervision of installation of the facility, ensuring compliance with operation and maintenance provisions, and undertaking specialist monitoring and review roles (Box 2.13). In addition to management agency representatives assigned to the project, GBRMPA may engage specialist assistance for assessment or review of technical matters related to tropical cyclone design loading, mooring design, environmental impacts and others. Essential and optional team members are indicated in the table.

Box 2.13 Management agency representatives <i>Personnel usually representing the management agencies</i>		
GBRMPA delegate ^E	Initiates project assessment on behalf of GBRMPA, and approves or refuses the permit application.	
Project manager – planning and design ^E	GBRMPA project officer who manages the project, liaises with the proponent, and co-ordinates project assessment and other regulatory matters.	
Environmental supervisor – construction ^E	QPWS project officer who supervises environmental aspects of installation of the facility, and ensures compliance with operation and maintenance provisions.	
Environmental monitoring contractor ^O	Engaged by GBRMPA on behalf of the proponent to prepare and undertake the environmental monitoring program.	
Other specialists as required ^O	Other specialists may be engaged by GBRMPA for design audit and for review of technical, social, cultural or economic aspects of the project.	
Note	E Essential team members	O Optional team members

Technical Advisory Group

An interdisciplinary Technical Advisory Group (TAG) may be established for assessment or review of significant pontoon projects. The TAG will guide the project team and the management agency in important technical matters relating to the proposed facility, and will provide a forum for stakeholders to discuss the proposal and to provide technical input. It comprises representatives from the management agency and the proponent, stakeholder representatives, and technical experts in specialist areas from the CRC Reef Research Centre and other groups as necessary (Box 2.14).

The role of the TAG will normally be limited to those activities that cannot be readily handled by the GBRMPA project manager, who will have the principal responsibility for project assessment and review. Depending on the complexity of the proposed facility, the TAG role may extend throughout the planning and design phases, and may include post installation and post operation evaluations of the facility. Prospective requirements and responsibilities for the Technical Advisory Group during the various phases of the 10-step planning, design and implementation procedure (Chapter 3) are summarised in Box 2.15.

Box 2.14 Technical Advisory Group <i>Comprising some or all of the following personnel where established for significant projects</i>	
GBRMPA delegate	Initiates TAG involvement in the project, represents GBRMPA and QPWS interests to the TAG.
GBRMPA project manager	Co-ordinates TAG meetings, liaises with the proponent on technical review issues, and assists with terms of reference and project assessment on behalf of GBRMPA.
Proponent delegate	Represents the proponent's interests to the TAG, and liaises with the management agency on technical review issues.
Proponent project officer/manager	Co-ordinates project planning and design, and provides technical data to the TAG on behalf of the proponent.
Stakeholder representatives	Represent the interest of stakeholders such as conservation and industry groups.
CRC Reef technical expert	Provides technical assistance to the TAG on specialist topics such as hydrodynamics, environmental impacts and mooring design.
Other specialists as required	Other specialists may be involved in the TAG for technical, social, cultural or economic aspects of the project.

Box 2.15 Prospective role of Technical Advisory Group, where established for significant projects <i>(refer 10-Step Planning, Design and Implementation Procedure in Chapter 3)</i>	
Phase 1 - Concept	Convene at an early stage to identify principal stakeholders and key issues, to set the terms of reference for the project investigation, and to identify the particular information that is to be provided for GBRMPA preliminary assessment. Assist GBRMPA in preliminary assessment of the project, which may include a review of key issues for principal stakeholders, and preliminary consideration of tropical cyclone design loading, mooring design and environmental impacts.
Phase 2 - Feasibility	Set the terms of reference for design studies and evaluations (possibly including PER or EIS), and identify the particular information that is to be provided for GBRMPA detailed assessment. Assist GBRMPA in detailed assessment of the project, which may include consideration of tropical cyclone design loading, mooring design and environmental impacts.
Phase 3 - Implementation	Consider issues that may arise during installation, such as anchoring techniques, or disturbance and relocation of coral. Post installation evaluations and review undertaken by the TAG will be useful to the proponent and GBRMPA in continued operation of the facility and in the development of other pontoon projects.
Phase 4 – Operation, monitoring and review	Consider issues that may arise during operation, maintenance and monitoring of the facility, such as mooring and anchor performance under severe weather conditions, and environmental impacts such as coral disturbance. Post operation evaluations and review undertaken by the TAG will be useful to the proponent and GBRMPA in continued operation of the facility and in the development of other pontoon projects.

Project timing and costs

Planning, design and implementation of a tourist pontoon project involves many activities, which may require years to complete. The proponent should prepare a timetable and budget for project development that schedules, sequences and estimates the cost of all tasks, from the concept phase studies through to monitoring and review of the completed facility. Schedules must anticipate the duration of specific tasks, the lead-time necessary to prepare for those tasks, and the consequences of delays. Delays in project schedules may increase project costs, and project budgets should include a contingency allowance for unexpected costs associated with these delays, for unresolved technical matters, or for other matters. The budgets should be progressively updated as the scope of work is refined during the project.

Project budgets should make appropriate provision for planning and design costs, including site investigations and other analyses. The costs of undertaking the necessary investigations for reef and coastal engineering projects is usually only a small proportion of total project costs, although environmental complexity or uncertainty in some projects may require relatively more costly investigations. Reducing the effort and cost of these investigations may lead to false economy, as capital or maintenance costs of projects may increase because poor designs may result from inadequate knowledge of reefal and coastal processes. This may adversely affect the facility or the environment in ways not fully understood at the time of the decision to proceed. Inadequate designs may also inhibit project approval, further increasing costs, and possibly bringing about rejection of worthwhile proposals.

Communication and documentation

A management framework, including project team meetings and joint site inspections where necessary, should be established to facilitate open communication and decision-making among relevant parties in the tourist pontoon project. Each step in the planning, design and implementation of the project should be clearly documented in an administrative record or technical report, which may be used in communication with others. The analyses that are undertaken, the assumptions that are made, the investigation results that are obtained, the decisions that are given, and the post construction details of the project should be recorded during the planning, design and implementation process. This documentation assists with transferring knowledge between proponents, practitioners and managers. It also facilitates project evaluation and approvals through regulatory bodies such as GBRMPA, and assists in resolving disputes that may arise over technical or administrative matters.

Technical documents may include a pre-feasibility planning report, a stakeholder survey, site condition survey, impact assessment, hydrodynamic study, mooring design report, feasibility study, design report, detailed design drawings, contract specification, post construction drawings, operations and maintenance manuals, and monitoring reports. Administrative documents may include written instructions, memos, letters, graphics and recorded conversations.

Quality assurance and technical review

A quality assurance (quality control) program should be built into the project to ensure a sufficiently high standard of workmanship is achieved for all aspects of the project, from the planning and design phase to implementation and monitoring. This is especially important if a large number of design professionals, contractors, and other people are involved. Quality assurance may add some cost to each project phase but will save much more in terms of getting the right result first time, rather than having to undertake remedial actions on parts of the project.

Project planning and design is to be undertaken by qualified professionals with demonstrated competence and experience in their particular field. The proponent and the designers should internally review project planning, design and implementation activities as part of the quality assurance process. Unless in conflict with the provisions of these *Guidelines*, designers should adopt recognised design standards and codes of practice and follow best practice guidelines wherever they are available. For example, Standards Association of Australia AS Codes specify requirements for particular design aspects, such as wind loading, and individual components of the facility, such as structural members. It is not possible to prescribe any one standard or code of practice that may be universally specified and applied in all instances to ensure a guaranteed level of performance for tourist pontoon projects.

A project quality plan, with associated checklists for each project phase, step and task, provides a basic quality control mechanism. Checklists help ensure all tasks and activities relating to achievement of objectives for the project are adequately taken into account. Checklists for a tourist pontoon project can be developed on the basis of the *How To Do* segments presented within the project steps (Chapter 3) and the planning, design and implementation tasks (Chapters 4 to 10).

A quality assurance system for designers and others involved in a tourist pontoon project assists regulators and managers (such as GBRMPA or its nominated agent, independent accredited expert or review panel) in technical review of specialist areas of the design, such as environmental impacts, hydrodynamic and mooring design. Comprehensive planning and design by the proponent and designers, evidenced by completed checklists and other quality control techniques enables reviewers to readily check compliance with established criteria, recommended procedures and best practice guidelines.

2.5 Stakeholder Consultation

Consultation with stakeholders (government agencies, local authorities, industry groups, community groups and others) is essential for successful planning, design and implementation of multi-purpose projects. The requirements for formal consultation with stakeholders for reefal and coastal infrastructure projects are set out in the appropriate Commonwealth and State government environmental regulations. For tourist pontoons, the GBRMPA permit assessment process provides for formal stakeholder consultation in the feasibility phase by means of public advertising and public submissions (Chapter 3). Where projects are likely to have a significant environmental impact, more extensive stakeholder consultation may be undertaken as part of the environmental impact assessment process.

Stakeholder consultation provides an opportunity for the proponent to achieve early contact with affected individuals or groups, to liaise with and satisfy the requirements of government agencies, and to maintain close interaction with decision-makers. It allows the practitioners and managers to seek input, provide advice and seek feedback on project proposals. All groups with a perceived interest in the project have an opportunity to become involved. This may include the local community, special interest groups connected with the project, indigenous people, local government, and state government agencies charged with specific responsibilities relating to the reefal and coastal environment.

Stakeholder consultation has many benefits for the proponent, practitioner and manager (Box 2.16). It provides the proponent with useful sources of local information, otherwise unavailable or only obtainable at considerable cost. Costly design modifications late in the project can frequently be avoided by adequate two-way consultation, and the short-term costs of public involvement is invariably offset by longer term goodwill. Properly undertaken consultation is good business practice and provides good insurance against failure of a project.

Box 2.16 Object of stakeholder consultation

- define the scope and type of project
- identify related social and economic issues
- identify and understand project needs
- obtain information on the history of development and use in the region
- determine community expectations of the development
- provide input to the development of objectives for the project
- identify the history and magnitude of natural events such as cyclones
- obtain feedback about project designs and review of objectives
- facilitate review of project performance and maintenance requirements
- exchange information, facilitate good working relationships and understanding, reconcile differences

2.6 Recommended reading

Association of Tourism Industry Authorities 1990. *Environmental Guidelines for Tourist Developments*.

Great Barrier Reef Marine Park Authority 1994. *A 25 year Strategic Plan for the Great Barrier Reef World Heritage Area*.

National Committee on Coastal and Ocean Engineering of the Institution of Engineers, Australia 1998. *Coastal Engineering Guidelines*.

National Committee on Environmental Engineering of the Institution of Engineers, Australia. 1994. *Policy on Sustainability*.

World Commission on Environment and Development. 1987. *Report of the World Commission on Environment and Development - Brundtland Report*.

3 PROJECT PLANNING, DESIGN AND IMPLEMENTATION

	Summary
3.1	The 10-Step project planning, design and implementation procedure
3.2	GBRMPA permit assessment process
3.3	Phase 1 – Concept: Steps 1 – 3
	Step 1 Initial concepts
	Step 2 Concept design
	Step 3 GBRMPA preliminary assessment
3.4	Phase 2 – Feasibility: Steps 4 – 5
	Step 4 Feasibility design
	Step 5 GBRMPA detailed assessment
3.5	Phase 3 – Implementation: Steps 6 – 8
	Step 6 Detailed design
	Step 7 Baseline monitoring
	Step 8 Construction and installation
3.6	Phase 4 – Operation, Monitoring and Review: Steps 9 – 10
	Step 9 Performance monitoring
	Step 10 GBRMPA performance review
3.7	Recommended reading

Summary
• Proponents, designers and managers should use this chapter in the planning, design and implementation of a tourist pontoon project. • A 10-Step planning, design and implementation procedure, incorporating four phases from (1) <i>Concept</i>, through (2) <i>Feasibility</i>, and (3) <i>Implementation</i>, to (4) <i>Operation, monitoring and review</i>, is presented. • The GBRMPA permit assessment process is outlined and the manner in which this fits into the planning, design and implementation procedure is described. • A summary of the component planning and design steps and tasks within each of the project phases is provided; the relevant personnel, planning and design tools, input and output data and other information are described; and links with other sections of the <i>Guidelines</i> are established.

Sustainable infrastructure development projects such as tourist pontoons are seldom so simple or clearly defined that they can be undertaken without a formal problem-solving procedure. The systematic procedure presented in this chapter provides a means for proponents, designers and managers to move from sustainable development goals at the broad policy and planning level to sustainable outcomes at the project level. This procedure compliments and incorporates the other core principles for sustainable Reef infrastructure development relating to multiple objectives (Section 2.3) and interdisciplinary planning and design (Section 2.4). The GBRMPA permit assessment process is also introduced in this chapter, and the manner in which it is integrated with the planning and design procedure is described.

The planning, design and implementation procedure for tourist pontoons can logically be broken into four phases (*Concept; Feasibility; Implementation; Operation, monitoring and review*), and a sequence of ten project steps. An hierarchical structure and ordered sequence of activities leads from **project phases**, through **project steps** to **planning and design tasks**. The systematic procedure and the structured sequence, scope and method assists proponents, designers and managers in project development and decision-making (Box 3.1).

3.1 The 10-Step project planning, design and implementation procedure

The *10-Step Project Planning, Design and Implementation Procedure* for tourist pontoons is presented in Box 3.2. Box 3.3 provides a generic schedule of major planning and design tasks that may apply within the various project phases and steps outlined in the following sections. This schedule may be modified in scope and sequence depending on specific project requirements.

Project phases and **project steps** in the *10-Step Planning, Design and Implementation Procedure* are described in Sections 3.3 to 3.6. The project step descriptions in these sections outline the following planning and design elements, and provide a link to other sections of these *Guidelines* (Chapters 4 to 10):

- **scope** and **purpose** of each step
- list and brief description of suggested **planning, design and implementation tasks**
- **planning and design tools** that may be used
- **input data** that will be required, and **outputs** from the step
- list of **personnel** who are likely to undertake the associated tasks
- special mention of **site investigations**, and **GBRMPA and other stakeholder consultation**

The procedure applies both to new pontoon facilities and to existing pontoons that are to be retrofitted or upgraded with, for example, new moorings. The step descriptions presented in the following sections relate principally to new projects, and therefore include tasks such as site selection, which will not apply to existing projects. For modifications to existing pontoons, proponents, designers and managers should adapt the procedure and step outlines according to the scope of the retrofit or upgrade.

3.2 GBRMPA permit assessment process

Box 3.4 shows how the GBRMPA permit assessment process for major new or upgraded tourist pontoon projects in the GBRMP is integrated with the phases and steps in the *10-Step Project Planning, Design and Implementation Procedure*. This structured approach, incorporating progressive development of the proposal, submission to GBRMPA, and assessment in accordance with GBRMPA policy and regulations, complements the hierarchical structure and ordered sequence of project phases, steps and activities, and assists proponents, designers and managers in project development and decision-making (Box 3.5).

Major activities in the GBRMPA permit assessment flowchart are briefly outlined in Box 3.5 for each of the project phases. More extensive descriptions of these activities and the roles of the various participants are provided in the project planning, design and implementation step descriptions (Sections 3.3 to 3.6). Some activities in the assessment flowchart, such as *Terms of Reference for PER or EIS*, and the *Assessment Review*, are only triggered under particular conditions that apply in complex projects with significant impacts, or in appeals on GBRMPA decisions.

Box 3.1 Merits and characteristics of the 10-Step planning, design and implementation procedure

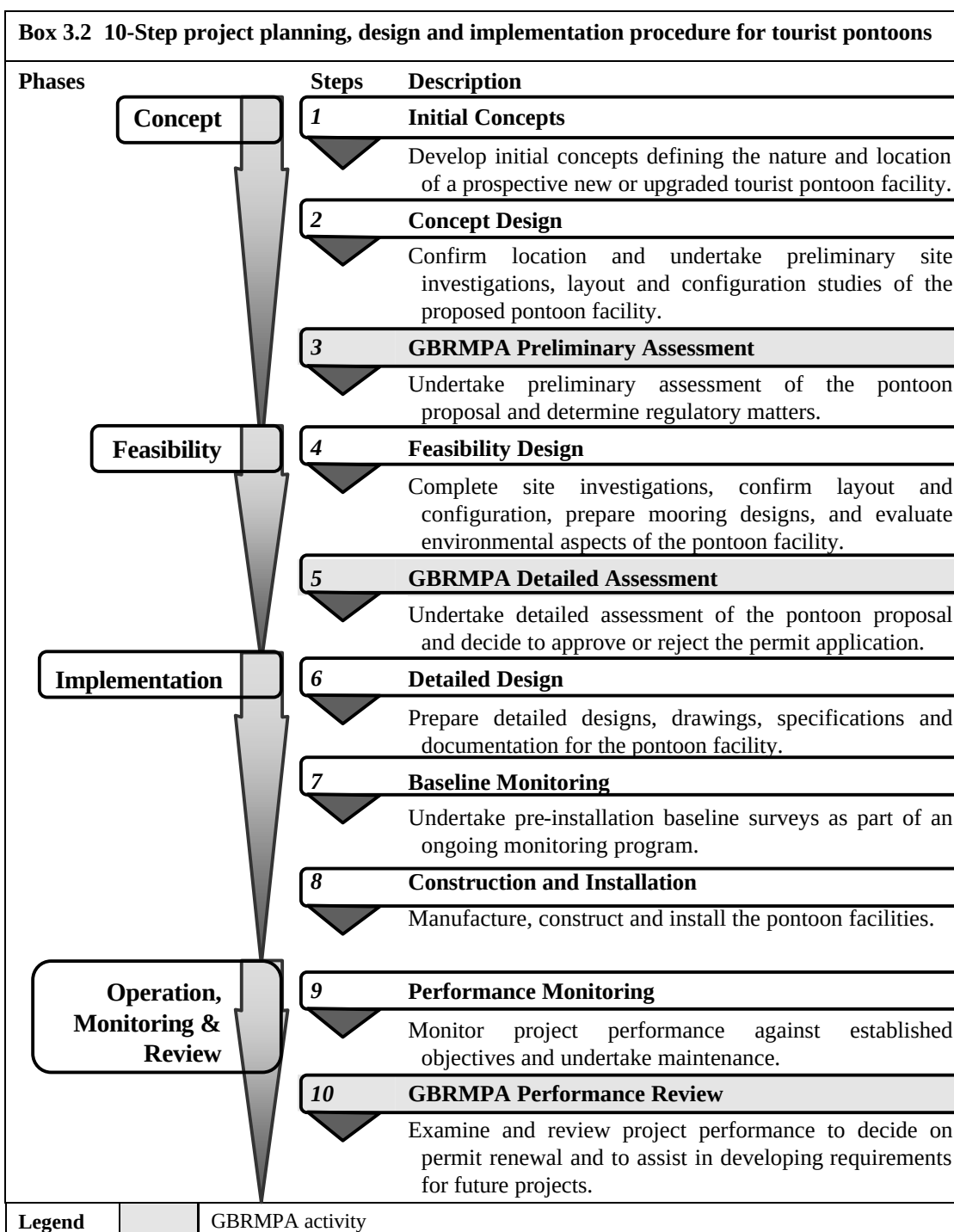
The systematic ***planning, design and implementation procedure***, and the structured sequence, scope and method for project activities provides the basis for progressive development of proposals, technical studies and designs, and a series of decisions on whether the proposal should proceed directly to the next stage, or whether it should be amended or abandoned. The procedure readily incorporates project technical issues, complies with policy, legislative and management requirements, and integrates multiple objectives and interdisciplinary provisions into all project phases. It provides a straightforward yet rigorous process that ensures the required broad range of issues are appropriately addressed.

Breaking the project into ***phases*** offers a number of advantages. It allows the proponent and designer to progressively develop concepts and submit information to GBRMPA for assessment and approval. Site investigations and design requirements are minimised in the early project stages, reducing unnecessary financial commitment to projects that may not proceed to implementation. Time delays and uncertainties in information supply, project assessment and approval are reduced. Site characterisation and other activities such as stakeholder consultation can be undertaken progressively through the project phases as decisions are progressively made. Whilst the distinction between phases is less well defined for smaller projects, proponents, designers and managers will, nevertheless, benefit by following the sequential phases and steps in the design, assessment and approval process.

Project steps and ***planning and design tasks***, although presented here in sequential linear order, commonly overlap in practice and are often carried out simultaneously. Many phases and steps are linked to their predecessors in feedback loops as designers use an iterative process to rework previous analyses with refined or revamped inputs. Information flows in both directions among activities during any particular stage of a project, and the lines between the end of one activity and the start of another are often blurred.

Practitioners and managers will use a range of ***planning and design tools*** to address various issues, investigate problems, or evaluate solutions that meet the multi-purpose requirements of tourist pontoon projects. This may include quantitative analysis methods such as formulae and models; qualitative evaluation techniques such as checklists, matrices, ranking, overlays and system diagrams; specialist input through expert systems or expert opinion; and standardised procedures for prediction, analysis and design. Site characterisation and condition assessment methods, multiple criteria analysis, predictions of environmental loadings and environmental impacts and structural analysis are examples of tools that may be used.

The ***10-Step Planning, Design and Implementation Procedure*** provides a consistent approach that will streamline project outcomes. It is not intended as a cookbook solution, however, and should be applied purposively to suit the particular project and issues, flexibly selecting steps and tasks so suit the scope of work required. The procedure and methods are not intended to be prescriptive, or inflexible to enterprising alternative solutions or approaches. Where innovative alternatives are proposed, an investment of resources in research and development beyond the scope of activities outlined here will generally be required to demonstrate their suitability.

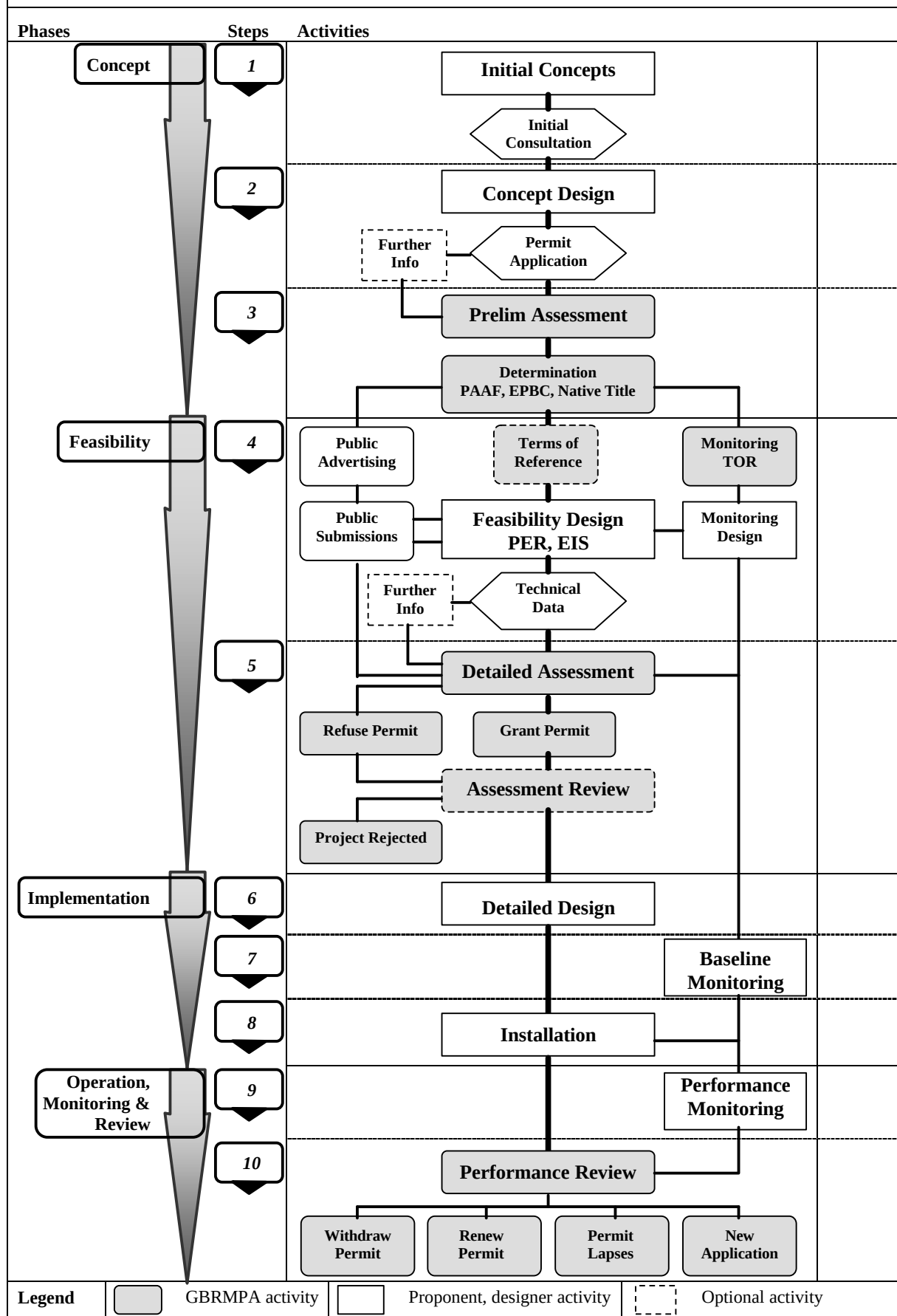


Box 3.3 Project planning and design task schedule for major tasks

This generic schedule of major tasks may be modified in scope and sequence depending on specific project requirements

Phases	Steps	Site Investigation and Characterisation				Consultation		Planning and Design								
		Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & management	Socio-cultural / economic assessment	Permits, licences & approvals	Tender documentation
Concept	1 Initial Concepts	Ö	Ö	Ö		Ö		Ö	Ö					Ö		
	2 Concept Design	Ö	Ö	Ö	Ö	Ö ♦	Ö	Ö	Ö	Ö	Ö		Ö	Ö		
	3 GBRMPA Prelim Assess	•				Ö				•			•			
Feasibility	4 Feasibility Design	Ö	Ö	Ö	Ö	Ö ♦	Ö		Ö	Ö	Ö	Ö	Ö	Ö	Ö	
	5 GBRMPA Detail Assess	•				Ö	Ö			•		•	•		Ö	
Implementation	6 Detailed Design									Ö	Ö	Ö •	Ö	Ö		Ö
	7 Baseline Monitoring		Ö	Ö		Ö ♦							Ö			
	8 Construction & Installation		Ö			Ö ♦							Ö		Ö	Ö
Operation, Monitoring & Review	9 Performance Monitoring		Ö	Ö									Ö			
	10 GBRMPA Perform Rev					Ö ♦							Ö	Ö		
Legend	GBRMPA activity	Ö	likely planning and design task			♦	possible joint GBRMPA / proponent site inspection			•	possible expert assistance for design audit and technical review					

Box 3.4 GBRMPA permit assessment flowchart for major new and upgraded pontoon projects



Box 3.5 Merits, characteristics and scope of the GBRMPA permit assessment process for tourist pontoons

The structured **permit assessment** approach to proposal development, submission to, and assessment by GBRMPA allows all participants to clearly see what is expected at each step of the process. This helps proponents and designers understand what information is required without having to repeatedly consult with, and supply information to GBRMPA. Although GBRMPA is unable to approve the proposal or grant a permit for the installation until comprehensive information is provided for assessment, the preferred arrangement is for GBRMPA to undertake progressive assessments and decisions, which provide a flow in project activities without the need to return to steps and decisions already made. Critical issues are established at each step and, where appropriate, unresolved issues and options are carried over to subsequent steps for more detailed examination.

Cost outlays are minimised early in the project as only preliminary information need be developed and submitted in the concept phase proposal. Overall project costs and uncertainties are minimised through the progressive development and assessment of proposals. The systematic planning, design and assessment procedure also minimises the likelihood of inconsistencies in project assessment by management agency personnel.

By presenting well-defined **packages of information** that meet the planning and design requirements of these *Guidelines*, proponents can expect a more streamlined and straight forward permit assessment process with fewer problems. However, compliance with the *Guidelines* does not automatically mean approval of the project, nor does it remove the capacity of GBRMPA to reject or refuse a proposal on policy grounds. Compliance does not remove the proponent's obligations regarding safe operation, repair of damage, or salvage of the facility in the case of failure.

The permit assessment process is constrained by strict **statutory requirements** relating to payment of fees and periods for submissions, decisions, notifications, etc. Where proponents fail to comply with these requirements they may forfeit deposits and be forced to start the submission exercise over again. Estimated time periods for major project activities for straightforward and complex projects, including allowances for statutory requirements, can be obtained from GBRMPA on request.

Phase 1 Concept (refer Box 3.4)

The proponent develops **initial concepts** for the project in the *Concept Phase* and holds **initial consultations** with GBRMPA to establish critical issues that may affect the proposal. The GBRMPA project officer will be assigned to the project on initial consultations.

The proponent then prepares project **concept designs** and submits a **permit application** for a marine parks permit for the installation. GBRMPA undertakes a **preliminary assessment** and **determination** on the project proposal to:

- ensure the application conforms with zoning plans and guideline requirements
- assess the scope of impacts of the proposal, the applicability of the *Environmental Protection and Biodiversity Conservation Act 1999* (EPBC Act), and the need for an Environmental Impact Statement (EIS) or Public Environment Report (PER)
- establish if the *Native Title Act 1993* applies to the proposed development
- determine the applicability and scope of the Permit Application Assessment Fee (PAAF) according to the value of the installation and the anticipated level of impacts
- assess the requirements for public advertising

GBRMPA may request **further information** to assist with clarification and review of the proposal prior to completing the assessment. The EIS or PER impact assessment studies are triggered if the project is likely to cause significant environmental impact.

Phase 2 Feasibility (refer Box 3.4) Public advertising of project proposals is undertaken in the <i>Feasibility Phase</i> where reasonable use of the Marine Park by the general public is likely to be affected. Advertising is commonly part of a new pontoon project but is not required for renewal of a pontoon permit. Public submissions are invited for advertised projects. These submissions provide input to the feasibility studies and to the GBRMPA assessment and may affect project approval. The proponent should address the terms of reference (TOR) for the PER or EIS if these studies are required. On completion of the project feasibility design, the proponent submits more detailed technical data, including the proposed environmental monitoring design, which forms part of the environmental management plan for the facility. GBRMPA then undertakes a detailed assessment for a marine parks permit for the installation. Where impact assessment studies are required, the proponent is required to submit the EIS or PER for assessment and review. GBRMPA may request further information to assist with clarification and review of the proposal prior to finalising their assessment. They may grant the permit, allowing the project to proceed, or alternatively refuse the permit. Granting of a permit is notified in the government gazette, and granting or refusal is subject to appeal and assessment review. The review will either reject the project or allow it to proceed to implementation.
Phase 3 Implementation (refer Box 3.4) The <i>Implementation Phase</i> includes detailed design and installation of the facility, by or on behalf of the proponent/operator. Approvals for construction are sought from GBRMPA, and the proponent conducts baseline monitoring to provide a quantitative description of the physical and biological environment prior to installation.
Phase 4 Operation, monitoring and review (refer Box 3.4) The <i>Operation, Monitoring and Review Phase</i> includes operation and maintenance of the facility by the operator and performance monitoring and review of performance by GBRMPA. The objective of the monitoring is to determine impacts on the Marine Park and to confirm whether modifications should be made for continued operation of the facility. Performance review is based on monitoring results, mooring maintenance performance and operational matters. Review may result in renewal of the permit if satisfactory, the permit may be withdrawn for non-compliance, or alternatively the permit may lapse and a new application will be required.
Project abandonment A tourist pontoon project may be abandoned at any time from the initial planning stages through to the review of facility operations. The operator may abandon the project due to financial difficulties or unforeseen failure under cyclonic conditions. Alternatively, GBRMPA may force abandonment if the project fails to comply with Marine Park regulations. The operator is required to salvage the pontoon structure, remove all components of the installation from the site, and rehabilitate any environmental damage if the project is abandoned in the operational phase. GBRMPA requires the operator to make provisions for abandonment as part of project planning and design, and to post a bond to cover this contingency.

3.3 Phase 1 – Concept: Steps 1 – 3

The Concept Phase represents Steps 1 to 3 of the *10-Step Planning, Design and Implementation Procedure* for tourist pontoons. This phase takes the project from *Initial Concepts* through *Concept Design*, to *GBRMPA Preliminary Assessment*. The proponent formulates the overall purpose and significant requirements of the project and prepares initial concepts and plans to meet these requirements. GBRMPA undertakes a preliminary assessment of the proposal to check basic compliance with relevant policy, legislative and management provisions. Preliminary investigations and analyses are undertaken in the concept phase, prior to the proponent undertaking more detailed studies and submitting the full application for formal assessment in the subsequent feasibility phase.

Step 1 Initial Concepts														
Scope and purpose Develop initial concepts defining the nature and location of a prospective new or upgraded tourist pontoon facility. The proponent will develop basic proposals for the pontoon development to meet project requirements, check compliance with regulatory provisions using a self-assessment approach and hold initial discussions with GBRMPA. The proposal may relate to either a new pontoon facility in a particular area or to an upgrade of existing facilities, eg. with new moorings.														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
Ö	Ö	Ö		Ö		Ö	Ö					Ö		
Ö planning and design task				◆ joint site inspection				● expert assistance for design audit and technical review						

Step 1 - Overview

The proponent will have some concept of the type, size, configuration and method of operation of the proposed pontoon facility at this early stage in the project. Information on the expected number of visitors, the pontoon facilities to be provided, and the operating range for craft will guide initial economic assessments. Marine Park zoning, shelter provisions, coral conditions, and options for mooring arrangements will guide the search for suitable sites for new pontoon projects. Several alternative sites may be identified and their suitability investigated against broad criteria (Chapter 6). The preferred site will be chosen during *Concept Design* (Step 2).

The initial concepts for the pontoon facility may be based largely on existing projects, although the features of one project can rarely be satisfactorily transferred to another site. Very preliminary sketches of the prospective facility and components will be useful in developing options and in conveying ideas to others. Entrepreneurial activities that introduce new concepts to the Marine Park may be considered at this stage.

Step 1 - Site investigation and characterisation (Chapter 4)

A reconnaissance survey of the region and prospective sites should be undertaken by boat or by plane to confirm suitable reef condition, access routes and water depths for new projects, or to re-evaluate site conditions for project upgrades. An initial assessment of wind and wave characteristics should be undertaken to consider exposure conditions for the various sites. Basic site bathymetric information (such as depth to coral and other substrate) should be obtained, and a location marker (eg. buoy) should be placed at the likely preferred site. The proponent will need to obtain some basic information on the type and extent of coral cover, and other ecological characteristics of the alternative sites.

Step 1 - GBRMPA and other stakeholder consultation

The proponent and project manager should hold initial discussions with GBRMPA as soon as possible in order to define the scope of work involved in the project, and to identify critical issues that may affect the proposal. GBRMPA will note the proponent's intent, outline the policy, legislative and management regime for the region, and direct the proponent to relevant criteria, procedures and best practice guidelines for the type of pontoon development proposed. The GBRMPA project manager will be assigned to the project on the initial consultations. A joint site reconnaissance would be beneficial, although this is not essential.

How to do Step 1 - Initial Concepts

Suggested tasks

1. Consider the need for and the economic viability of tourist pontoon operations in the vicinity.
2. Collect information on available sites, access routes, coral conditions and shelter for new projects.
3. Undertake a reconnaissance survey of prospective sites for new projects and identify alternative sites for the facility (Chapters 4 and 6).
4. Obtain basic site bathymetric information and place a location marker, eg. buoy, at the likely site(s) (Chapter 4).
5. Consider the size and configuration of the facility and prepare initial sketches, including modifications for existing facilities (Chapter 6).
6. Consider specialised features such as innovative mooring arrangements (Chapter 7).
7. Discuss proposals with GBRMPA.

Inputs

- market reports on regional tourism activities
- configuration and layout of existing pontoon installations
- Marine Park zoning plans, marine charts, aerial photographs and bathymetric charts
- tropical cyclone, wind and wave characteristics for the region
- details of existing facilities, in the case of projects that are to be upgraded

Tools

- economic models to assess various options
- *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Chapter 5)

Personnel

- coordination by the proponent's project manager
- close involvement from the proponent's management group and delegated representative
- involvement from the operations manager / resort planner
- specialist support from an economist, hydrodynamics engineer, naval architect, marine biologist or others as required
- management agency's interests represented by the GBRMPA delegate and project manager

Outputs

- initial concepts for a prospective new facility, identifying the port location, prospective reef and access routes
- preferred pontoon site, size and configuration options, including preliminary sketches
- other special considerations such as innovative mooring systems
- initial concepts for an upgraded facility identifying the prospective means of upgrade for moorings or other components
- initial estimates of project costs and market returns

Step 2 Concept Design														
Scope and purpose Confirm location and undertake preliminary site investigations, layout and configuration studies of the proposed pontoon facility. The proponent will identify various alternative schemes or scheme components, and develop conceptual designs for the preferred scheme that broadly satisfy the multiple project objectives. The conceptual designs should define what the proponent wishes to establish for the pontoon facility, and should address GBRMPA requirements and regulatory provisions in sufficient detail for submission to GBRMPA for preliminary assessment.														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
○	○	○	○	○ ◆	○	○	○	○	○		○	○		
○ planning and design task				◆ joint site inspection				● expert assistance for design audit and technical review						

Step 2 - Overview

Concept design has a large intuitive component that draws heavily on experience. Multiple objectives relating to serviceability and function, structural integrity and safety, environmental protection, and social and cultural values must be incorporated into the project during the concept design (Section 2.3). It is unlikely that the scheme options considered in the concept phase will fully meet all objectives or satisfy all constraints. Design proposals may need to be re-assessed against objectives as the project proceeds.

Concept designs should define the scope and nature of the preferred scheme and any alternative schemes that are being considered. This will include the expected level of use, the facilities to be provided, and the type of activities to be conducted. The level of detail will vary between projects but the types of outputs from a conceptual design may include development plans, schematic diagrams of the facility, environmental assessment analyses and processes, measures for environmental impact mitigation, project timelines, preliminary estimates of cost, and other flow charts of processes and procedures. The schematic diagrams will usually include a layout plan of the scheme showing approximate location of components, example elevations and sections illustrating features of the design, and estimated sizes and characteristics of various components. Concept designs will also normally consider installation and salvage methods and equipment access to site, and environmental disturbance during installation (Chapter 10).

Step 2 - Site investigation and characterisation (Chapter 4)

Site investigations and assessments in the concept phase may include preliminary calculations of prevailing and extreme hydrodynamic conditions. Information on wind and wave climate, water levels, tides and currents is used in site selection and choice of facility type for new projects, and in initial assessments of mooring systems for upgraded projects. Estimates of frequency, magnitude and direction information for waves at the project site can be obtained from the *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Chapter 5). For complex conditions, GBRMPA may engage expert assistance to review the tropical cyclone design loadings.

Basic characteristics of the site (including water depth, seafloor physiography, ecological condition and coral characteristics, substrate geotechnical conditions, and archaeological and cultural issues) should be obtained in the concept design step. This information is necessary for site selection, preliminary configuration and layout of the facility, and to assess ecological effects such as shading or disturbance to coral. Survey control markers and buoys should be established at the preferred site to identify the location and orientation of the pontoon, moorings, anchors and other facilities.

Step 2 - GBRMPA and other stakeholder consultation

A joint site inspection of the preferred site(s) should be undertaken by boat, involving the proponent, members of the interdisciplinary project team, GBRMPA, and other regulatory personnel. This preliminary inspection should take place early in the concept phase, as soon as possible after the initial concepts for the pontoon facility are formulated. The purpose is to familiarise all parties with the site and with GBRMPA requirements for pontoons, and to enable discussion and clarification of matters prior to extensive commitment of resources.

The proponent and the designers should discuss concept designs with GBRMPA in order to comply with the policy, legislative and management regime, and to meet technical requirements for the project. Clarification should be sought on the terms of reference for information to be supplied to GBRMPA for preliminary assessment. The GBRMPA project manager should be contacted for guidance with the permit application and submission of technical data.

Step 2 - Site selection (Chapter 6)

Site selection is a major planning and design task undertaken in the concept phase of new projects. An hierarchical approach to site selection is usually adopted, based on Marine Park management provisions, operational, safety and customer considerations. Multiple project objectives relating to the following matters are addressed:

- Marine Park zoning and management planning
- (preferably) outer reef location with viable transit distance to port
- protection from prevailing and severe sea conditions
- good quality coral with good cover and variety for viewing
- adequate area for pontoon and ancillary facilities
- sufficient clear sand substrate for placement of mooring lines
- suitable access and water depth for service craft
- protected swimming and snorkelling areas

Step 2 - Preliminary pontoon and mooring layout and configuration (Chapter 6)

In this task, the designers further develop the initial concepts and prepare a preliminary layout and configuration of the pontoon facilities and moorings to suit the site and planned operations, and to address multiple project objectives. Facility components such as viewing chambers, snorkelling platforms and vessel berths are arranged to suit site characteristics such as coral cover, water depth and bottom clearance for the facilities and tender craft. The preferred orientation of the pontoon on the site is chosen to suit the facility components, the site physiography, and the prevailing and severe wind and wave directions. Alternative types, layouts and configuration options for the mooring system are considered, and potential mooring line corridors and anchor locations are identified.

The preliminary studies and layouts will be based on preliminary data for the site, as outlined above. The underwater conditions relating to access, swimming, snorkelling etc will be studied, and preliminary layouts incorporating all site features and facility components will be prepared. Designers are unlikely to undertake significant calculations of forces on mooring systems and other facility components in this conceptual phase study, relying mostly on preliminary estimates and previous experience. These detailed studies will be undertaken in the feasibility phase. In situations where complex innovative mooring arrangements are proposed, GBRMPA may engage expert assistance to review the proposal.

Step 2 - Quality assurance and technical review

The proponent and designers should adopt a quality assurance system to record relevant data and procedures, and critical decisions and assumptions incorporated in the concept design studies. For complex proposals, GBRMPA may engage other regulatory bodies or specialist advisors to review particular technical aspects, such as tropical cyclone design loading, mooring design and environmental impacts (Step 3).

Step 2 - Submission to GBRMPA

The proponent shall prepare and submit a package of information describing the proposal in sufficient detail for GBRMPA preliminary assessment (Appendix B). Only preliminary information, sufficient to determine whether the proposal can proceed to the feasibility phase, need be incorporated in the concept phase submission. Well-defined packages of information that meet the planning and design requirements of these *Guidelines* will be most readily assessed, thereby minimising delays and uncertainties.

How to do Step 2 - Concept Design

Suggested tasks

1. Determine the size of the pontoon operation, the level of use, the facilities to be provided, and the type of activities to be conducted for new projects.
2. Select the preferred pontoon site and identify any alternative sites for new projects (Chapter 6).
3. Determine the means of access to the site.
4. Undertake preliminary hydrodynamic studies for the site (Chapters 4 and 5).
5. Undertake preliminary bathymetric surveys, geotechnical and ecological assessments of the site (Chapter 4).
6. Establish survey control markers and buoys at the preferred site to identify the location and orientation of the pontoon, mooring, anchors and other facilities (Chapter 4).
7. Prepare conceptual layouts and configurations of the pontoon facility, showing upgraded components for existing facilities (Chapter 6).
8. Prepare conceptual mooring and anchor designs (Chapters 6, 7 and 8).
9. Examine measures to mitigate the effects of the facility on ecological, social and cultural values.
10. Consider methods for installation and salvage of the facility.
11. Estimate project costs and examine the economic viability of the tourist pontoon operation.
12. Discuss proposals with GBRMPA.
13. Document information required for GBRMPA preliminary assessment.
14. Submit information to GBRMPA.

Inputs

- initial concepts of pontoon operation, location, access, size, configuration and mooring arrangements (Step 1)
- Marine Park zoning plans, marine charts, aerial photographs and bathymetric charts
- tropical cyclone, wind and wave characteristics for the region

Tools

- *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Chapter 5)
- product data and other literature to assess mooring requirements (Chapter 7)
- product data and other literature on anchors (Chapter 8)
- GBRMPA application form and technical data requirements for infrastructure developments

Personnel

- coordination and preparation of required information by the proponent's project manager
- close involvement from the proponent's management group and delegated representative
- involvement from the operations manager / resort planner
- specialist support from an environmental engineer / scientist, marine engineer / naval architect, hydrodynamics engineer, geotechnical engineer, marine biologist or others as required
- input from the marine technician, particularly in site investigations
- management agency's interests represented by the GBRMPA project manager

Outputs

- conceptual design of the preferred scheme defining the site and access arrangements for new projects
- configuration and layout of the facility, indicative sizes of key components, and preliminary assessment of impacts on coral and marine biology for new and upgraded projects
- brief outline of any alternative schemes
- preliminary estimates of project costs
- submission to GBRMPA with required information in the designated format

Step 3 GBRMPA Preliminary Assessment														
Scope and purpose Undertake preliminary assessment of the pontoon proposal and determine regulatory matters. Preliminary assessment in the concept phase has minimal technical content and serves mainly an administrative purpose. Regulatory requirements are determined for those projects that can proceed to the feasibility phase, and projects that fail to meet basic technical requirements are screened out. Although GBRMPA is unable to approve the proposal or grant a permit for the installation at this stage, preliminary assessment brings technical issues forward and identifies complex issues early in the project. The proponent can address these issues in the subsequent planning and design activities, thereby minimising delays and unexpected costs at a later date.														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
•				Ö				•			•			
Ö planning and design task				◆ joint site inspection			• expert assistance for design audit and technical review							

Step 3 - Overview

In this step GBRMPA registers the permit application and undertakes preliminary assessment and determination of the proposal in order to:

- identify major regulatory requirements and constraints for the installation
- ensure the application conforms with zoning plans and general siting constraints
- identify major technical anomalies in the project related to such things as siting and mooring types, which the proponent will be required to resolve in the feasibility phase

Step 3 - Regulatory requirements

GBRMPA determines regulatory requirements for the proposal at the preliminary assessment stage by:

- assessing the scope of impacts of the proposal and determining if the project should be designated under the *Environmental Protection and Biodiversity Conservation Act* (EPBC Act)
- determining if the proposal invokes the provisions for an Environmental Impact Statement (EIS) or Public Environment Report (PER)
- determining if the proposed project site is listed under the provisions of the *Native Title Act*
- identifying other Commonwealth and Queensland legislation that may apply to the facility
- determining the applicability and amount of the Permit Application Assessment Fee (PAAF) according to the value of the installation and the anticipated level of impacts
- assessing the requirements for public advertising and notice of the proposal through the Commonwealth of Australia Gazette, a local and Queensland newspaper

Step 3 - Environmental Protection and Biodiversity Conservation Act 1999

GBRMPA may have a pontoon development designated under the EPBC Act where it is likely to have a significant impact on the World Heritage property as a result of:

- loss of one or more of the World Heritage values, or
- degradation or diminution of one or more of the World Heritage values, or
- diminution of the integrity or authenticity of one or more World Heritage values

The EPBC Act specifies a formal process for assessment of impacts of the pontoon proposal and allows for assessment through public review. GBRMPA and affiliated government agencies will determine if an Environmental Impact Statement (EIS) or Public Environment Report (PER) is to be prepared under the Act, and will establish the terms of reference for these studies, to be undertaken during *Feasibility Design* (Step 4).

Step 3 - Native Title Act 1993

GBRMPA will seek advice from affiliated government agencies on whether the provisions of the *Native Title Act* apply to the project. Where they do, Marine Park permits are classified under the act as Category D future permissible actions, and will only be issued on the condition that they do not extinguish or erode native title. A statutory 28 day period applies from the time the Native Title notification is established until a decision is given on whether the site is subject to Native Title claims.

Step 3 - Permit Application Assessment Fee - PAAF

In line with the user-pays principle, which attempts to recover GBRMPA or QPWS assessment costs, all applications for a Marine Park permit to establish, continue or vary a program or facility such as a tourist pontoon, are charged a Permit Application Assessment Fee (PAAF). The fee varies depending on the type and size of operation and potential for environmental impacts (refer GBRMPA for current schedule of fees). It is only determined definitely when a firm application is submitted, and may be waived where assessment is minimal. An "initial fee" is charged for applications for a new facility or one in which significant changes are made to an existing operation. A lesser "continuation fee" is charged for applications to continue an existing operation substantially as before. The PAAF can be refunded if the application is withdrawn within a statutory period, but is otherwise not refundable regardless of whether the permit is granted or refused.

Step 3 - Public advertising of proposal

GBRMPA preliminary assessment determines if public advertising of the proposal is to be undertaken in the subsequent *Feasibility Phase*. The requirement for advertising depends on whether or not reasonable use of the Marine Park for the general public is likely to be affected. The GBRMPA determination will outline requirements on what to include in the advertisement and where to publish.

Step 3 - Preliminary technical review

In addition to Marine Park matters relating to zoning etc., the GBRMPA project manager, assisted as necessary by specialists, will conduct a preliminary technical review of the project concept designs to check compliance with established criteria, recommended procedures and best practice guidelines. Expert review may be necessary to assess specialist aspects of the complex proposals relating to tropical cyclone design loading, mooring design etc. For routine projects, however, GBRMPA project managers should be able to undertake this technical review in terms of the basic provisions outlined in these *Guidelines*. These reviews will identify major technical anomalies and potential problem issues such as sheltering or mooring type, requiring attention prior to, or during, the feasibility design phase.

Step 3 - Further information

GBRMPA may request further information on the project from the proponent to assist with review of the proposal prior to completing the preliminary assessment.

Step 3 – GBRMPA preliminary assessment report

GBRMPA will prepare a report on the preliminary assessment, which will either reject the application and state the grounds for rejection, or identify major technical anomalies in the project related to such things as siting and mooring types, which the proponent will be required to resolve in the *Feasibility Phase* if the project is to go ahead.

How to do Step 3 - GBRMPA Preliminary Assessment
Suggested tasks 1. GBRMPA determines regulatory requirements for the proposal. 2. GBRMPA undertakes preliminary assessment to screen out unacceptable projects. 3. GBRMPA may engage other experts for technical review of complex proposals to assess specialist areas such as tropical cyclone design loading, mooring design, and environmental impacts. 4. GBRMPA may seek further information from the proponent to clarify aspects of the proposal. 5. GBRMPA prepares preliminary assessment report and provides comments on projects that may proceed to the next stage. Inputs • project information prepared by the proponent in Step 2 • GBRMPA assessment reports for similar projects Tools • GBRMPA assessment procedures Personnel • preliminary assessment by the GBRMPA project manager • specialist input as required to ensure compliance with established criteria, recommended procedures and best practice guidelines Outputs • determination of regulatory requirements relative to the <i>EPBC Act</i>, <i>Native Title Act</i>, permit assessment fee and requirements for public advertising • GBRMPA preliminary assessment report on the project • identification of major technical anomalies related to such things as pontoon siting and mooring types, to be resolved in the feasibility phase

3.4 Phase 2 – Feasibility: Steps 4 – 5

The Feasibility Phase takes the project through Steps 4 and 5, *Feasibility Design* and *GBRMPA Detailed Assessment*. Following preliminary assessment and an indication of compliance of the concept designs from Phase 1, project proposals are further developed to meet the proponent's requirements, and to comply with GBRMPA regulations. This involves detailed investigation and analyses of the project, evaluation of alternatives against project objectives and design criteria, and judgements and decisions on project suitability. The proponent determines the preferred layout, configuration, installation, operation, maintenance and monitoring arrangements for the installation, and GBRMPA undertakes detailed assessment for a Marine Parks permit.

Step 4 Feasibility Design														
Scope and purpose														
Complete site investigations, confirm layout and configuration, prepare mooring designs, and evaluate environmental aspects of the pontoon facility. The proponent will advance the proposed scheme from a concept level to a feasibility level design. The cost and effectiveness of the proposals in meeting the various project objectives and design criteria, and regulations under the GBRMP Act and other legislation are assessed. These evaluations form the basis for decision-making by the proponent and project assessment by GBRMPA. Environmental impact assessment procedures such as the Environmental Impact Statement (EIS) or Public Environment Report (PER) may be included if these are required.														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
○	○	○	○	○ ◆	○		○	○	○	○	○	○	○	
○ planning and design task				◆ joint site inspection			● expert assistance for design audit and technical review							

Step 4 - Overview

Feasibility design and evaluation should provide the basis for decisions on whether the scheme will proceed. As for earlier project steps, multiple objectives relating to serviceability and function, structural integrity and safety, environmental protection, and social and cultural values must be incorporated into the feasibility design (Section 2.3). Various design options are identified, comparisons are made between alternatives if necessary, and the preferred layout, configuration, installation and operation of the facility are determined. Full feasibility design will usually only be required for the preferred scheme, as alternative schemes will normally be eliminated early in the evaluation process. The proponent will be required to address the terms of reference for the EIS or PER if ordered, and account for stakeholder input and public comment when public submissions are invited for advertised projects.

Feasibility designs will normally incorporate development plans for the project, specialist studies on reef processes, environmental assessment analyses, measures for environmental impact mitigation, and detailed estimates of cost. The development plans will be more detailed than those supplied for the concept design, and will usually show layout and configuration of the scheme, elevations and sections through the facility, and sizes and characteristics of major components. Proposals for installation and later salvage of the facility will be prepared, including site preparation, construction and removal methods and equipment, access to site, and methods of avoiding environmental disturbance. The proponent will prepare operation and maintenance schedules and proposals for environmental monitoring, and will submit necessary applications for permits and licences, incorporating relevant technical and regulatory data for the project.

Step 4 - Site investigation and characterisation (Chapter 4)

Feasibility design will usually incorporate significant site investigation and assessment activities, additional to those undertaken in the concept phase. Whereas initial site investigations provided preliminary information for concept level studies, the assessments at this stage are focused on more detailed requirements for designing the facility. This will usually include detailed hydrodynamic studies; detailed bathymetric survey; and detailed survey of the ecological condition. Further geotechnical assessment may be undertaken depending on the type of anchor and mooring system proposed. Consideration of relevant archaeological and cultural issues may be included where relevant.

The detailed hydrodynamic assessment examines the magnitude and frequency of winds, waves, water levels and currents for use in the determination of structure loads and movements under prevailing and extreme conditions. Estimates of frequency, magnitude and direction information for waves at the project site can be obtained from the *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Chapter 5). The designer may refine these estimates using fine scale wave modeling that takes account of the structure location relative to the reef, local bathymetry, wave diffraction around the reef, and wave transmission and dissipation over the reef. GBRMPA may engage expert assistance to undertake a design audit and technical review of the tropical cyclone design loadings.

The principal topographic site surveys will normally be undertaken in the feasibility phase, using the survey control established in the preliminary site surveys. Bathymetric information for the site is used to define the configuration and layout of the facility and to ensure the pontoon and mooring location suits coral cover and other substrate conditions. Ecological assessments may include field, laboratory and desk studies related to facility design and baseline monitoring. If extensive geotechnical site assessment is to be undertaken for mooring and anchor design, this will usually be done in the feasibility phase.

Step 4 - GBRMPA and other stakeholder consultation

Further discussions, and perhaps a joint site inspection, between the proponent, members of the interdisciplinary project team, GBRMPA, and other regulatory personnel are likely to be necessary in the feasibility phase to resolve technical matters relating to design of the facility. Extensive consultation with GBRMPA and other stakeholders is essential where formal impact assessment studies (such as EIS or PER) are required under the provisions of the Act.

Public advertising of project proposals is undertaken in the feasibility phase where reasonable use of the Marine Park by the general public is likely to be affected. Advertising is commonly part of a new pontoon project but is not required for renewal of a pontoon permit. Public submissions are invited for advertised projects. These submissions provide input to the feasibility studies and to the GBRMPA assessment and may affect project approval. EIS and PER reports must be available for public comment for specified periods.

The proponent and the designers should discuss feasibility designs with GBRMPA in order to comply with the policy, legislative and management regime, and to meet technical requirements for the project. Clarification should be sought on the terms of reference for information to be supplied to GBRMPA for detailed assessment. The GBRMPA project manager should be contacted for guidance with the permit application and submission of technical data.

Step 4 - Detailed mooring layout, configuration and movement tolerances (Chapter 6)

In this task, the designers prepare a detailed layout and configuration of the mooring system, based on the preliminary layouts prepared in the concept design studies, and detailed site investigations undertaken in the *Feasibility Phase*. The mooring layout and configuration takes account of pontoon facility requirements, such as viewing chambers, snorkelling platforms and vessel berths; site characteristics, such as suitable mooring line corridors and anchor locations; and the prevailing and severe wind and wave loadings. This may involve relocation or sacrifice of specific corals to provide acceptable shading effects from the pontoon footprint or acceptable corridor provisions for mooring lines, vessel access and berthing. Conventional catenary type mooring systems or alternative taut mooring systems attached to fixed piles may be considered, and several iterations of mooring system layouts and mooring designs may be undertaken prior to finalisation.

Designers will define the configuration of the mooring system and specify acceptable movement limits for the pontoon, mooring lines and components. These will be used in the detailed design of mooring system components as part of the mooring and anchor design task. Detailed site layouts incorporating all site features and facility components will be prepared in conjunction with the naval architect's or marine engineer's drawings of the mooring and anchor system, prepared as part of the mooring and anchor design.

Step 4 - Mooring and anchor design (Chapters 7 and 8)

The mooring and anchor design proceeds after the pontoon site and facilities have been defined, and the type, layout and configuration of the mooring system have been determined. Several iterations of mooring system layouts and mooring designs may be undertaken prior to finalisation. The pontoon orientation, and the permissible movements for the pontoon and mooring system under normal operating and severe conditions must be determined prior to undertaking final structural design of the mooring system. Design of the mooring is determined by these movement limits and by the maximum permissible forces in the mooring line and mooring components for the nominated range of load cases.

Forces imposed on the pontoon and mooring system are determined on the basis of design loads determined from hydrodynamic and other studies (Chapter 5), and the geometry and configuration of the mooring system. Designers may follow a simplified mooring design procedure based on the conventional quasi-static design philosophy outlined in Chapter 7. Alternatively, the designer may use a less conservative approach and elect to undertake a more sophisticated study using numerical or physical modeling. Anchor designs are undertaken on the basis of the forces determined in the mooring analysis and the geotechnical properties of the substrate. Various anchor types (such as deadweight, drag embedment, grouted screw or pin clusters) may be used, depending on the site characteristics and the magnitude and nature of the loads, eg. inclined or horizontal. Simplified static analysis methods with generous safety factors are normally used to size anchors.

Mooring line configurations, anchors and other components of the mooring system sized in the above design procedures will be detailed on naval architect or marine engineer drawings and specifications. These details are used for assessment and review of the mooring system, and will be issued to suppliers for fabrication and detailed design of components in the subsequent *Implementation Phase*. GBRMPA may engage expert assistance to undertake a design audit and technical review of the design of the mooring system.

Step 4 - Pontoon body and ancillary facilities (Chapter 9)

The proponent should develop preliminary designs for the pontoon body and ancillary facilities in this step. These should be sufficient to confirm layout and configuration, and to provide an estimate of cost. Detailed designs, including workshop fabrication drawings, will be undertaken in the *Implementation Phase* (Step 6). GBRMPA will require a marine classification approval for the pontoon body design (eg. Lloyds Register of Shipping) in the Implementation Phase, and may engage expert assistance to undertake a design audit and technical review of this component.

Pontoon body design should comply with the rules of an approved marine classification society (eg. Lloyds Register of Shipping) and relevant shipping structures codes (eg. Uniform Shipping Laws Code), for a particular survey class (eg. *Restricted offshore operations* or *Partially smooth water operations*). Pontoon design and construction must meet Queensland Department of Transport survey requirements. The pontoon design is subject to further requirements under Workplace Health and Safety Regulations for use as a dive platform. The facility must be designed by a marine engineer/naval architect of demonstrated competence and experience.

Step 4 - Impact assessment and mitigation (Chapters 6, 9 and 10)

Some environmental impact may result from development pressures associated with the planning and design, installation, or operational phases of the pontoon project. Project proponents and designers should fully identify, examine and provide measures for mitigation of these environmental impacts in the feasibility step, and ensure compliance with Marine Park regulations (Appendix A). Some pressures, impacts and mitigation measures for tourist pontoons are presented in Box 3.6. GBRMPA may engage expert assistance to undertake a design audit and technical review of the environmental impacts of the facility.

Box 3.6 Pressures, impacts and mitigation measures for tourist pontoons		
Pressures	Potential impacts	Possible mitigation measures
<i>Presence of pontoon and facilities</i>		
Allocation of site	Cumulative effects of increasing numbers of structures Social issues of displacement	Social and cultural values managed through Marine Park policy, zoning and permits
Altered seascape and local condition	Loss of amenity for the area Possible aesthetic deterioration due to disturbance and alteration to uniqueness of the site	Modify nature, size and appearance of the facility, or locate at different site
Shading from the pontoon	Coral damage, coral death and decrease in coral cover in footprint underneath structure	Locate pontoons over sand rather than over living coral Relocate coral prior to installation
Fish aggregations due to pontoon presence	Attraction of larger predatory fish and grazing and scavenging fishes that change local fish communities	Manage in conjunction with fish feeding activities
Establishment and operation of pontoon facility	Potential effect on significant habitats or seasonal breeding, feeding and nesting Potential effect on rare or endangered species	Locate to avoid significant sites
<i>Moorings and anchors</i>		
Conflict with coral locations	Disturbance to coral from mooring line or anchor movement Loss of coral along mooring line or under anchor block location	Modify mooring system Relocate coral outcrops likely to be subject to damage Transplant corals
Location within recreational area	Adverse affect on amenity and aesthetic values	Minimise physical effects and visual disturbance of structures
Mooring or anchor failure	Dragging anchors and mooring chains Grounding of pontoon on the reef Break away into shipping lanes	Modify mooring or anchor system
<i>Pontoon installation</i>		
Disturbance due to installation activities	Physical damage to marine organisms Damage to coral or substrate Disturbance to wildlife, seabed and marine life from noise, vibration, craft movements and turbidity	Arrange installation activities to minimise coral damage in placement of the chains, blocks and anchors Relocate corals where necessary
<i>Recreational activities</i>		
Snorkelling and diving	Fin damage to coral communities from inexperienced snorkellers and divers	Modify recreational activities and provide training programs
Fish aggregation due to fish feeding	Increase in predatory fish due to fish feeding	Modify fish feeding practices
<i>Pontoon operations</i>		
Catamaran manoeuvring and docking	Increased turbidity, reduced light, and increased sedimentation due to disturbance of bottom sediments	Define appropriate route and operating regime for craft
Semi-submersible and service craft	Collisions between craft and coral outcrops, reducing coral cover, height and diversity	Define appropriate route and operating regime for craft
Solid waste and wastewater disposal	Impacts of litter and potential changes in water quality, particularly increase in nutrients	Modify waste disposal procedures and wastewater treatment facilities
Pollution from spillage of fuels or other pollutants	Degraded water quality affecting corals and other organisms	Modify fuel and pollutant handling procedures

Step 4 - Environmental Impact Statement (EIS) or Public Environment Report (PER)

An EIS or PER may be required for a new tourist pontoon project under the terms of the *Environment Protection and Biodiversity Conservation Act*. The EIS or PER provides: (i) information for interested people to understand the proposal and its likely impacts; (ii) a forum for public consultation; and (iii) a framework for decision-makers to consider environmental and other aspects of the proposal. The terms of reference (TOR) for these studies will be determined by GBRMPA and affiliated government agencies, and will incorporate social impact and economic needs in addition to physical and biological requirements. Where a PER or EIS is required under the EPBC Act, assessment occurs under both this Act and the GBRMP Act (Step 5).

Step 4 - Proposals for installation and salvage (Chapter 10)

The proponent shall develop proposals for installation of the pontoon facility, and for its removal from the Marine Park either upon expiry of the permit, or on wreckage, abandonment or sinking of the structure. Proposals for installation should consider transportation of the pontoon and mooring system to the site; relocation or removal of designated corals; placement and testing of anchors and mooring lines; and positioning and connection of the pontoon body and associated structures. Salvage proposals should allow for removal of anchors and mooring lines from the site, relocation of the pontoon body and associated structures from the vicinity, and replacement of designated corals. All installation and salvage operations should ensure that the coral and other marine ecosystems at the site are protected from physical disturbance, pollution or other impacts. Proponents will be required to indemnify GBRMPA against loss or damage arising out of the removal of the pontoon infrastructure from the Marine Park, and will lodge a bond to cover the costs of salvage and environmental rehabilitation (Step 5).

Proposals for installation and salvage should be incorporated in the *Management Plan for Installation* of the facility. This Plan should be updated with final design details prior to commencement of installation (Step 8).

Step 4 - Proposals for operation and maintenance (Chapter 10)

The proponent shall describe arrangements for operation and maintenance of the facility, including guidelines for site management and provision for contingency procedures. Proponents will be required to indemnify GBRMPA against claims related to health, safety and damage to the environment, and will lodge a bond to cover the likely costs of damage (Step 5). Proposals for operation and maintenance should identify and describe arrangements relating to, among other things:

- general provisions for the site and operation of the facility
- recreational activities to be conducted in or associated with the facility
- vessels or aircraft, including ancillary vessels, to be used in the operation
- facilities, equipment and procedures including overnight accommodation
- operation and maintenance procedures for miscellaneous pontoon facilities and equipment, and transit and ancillary vessels
- transfer, use and disposal of fuels and other consumables, effluent or waste
- health and safety standards and provisions for emergencies
- contingency plans for safety, communication, and evacuation for adverse weather and other emergencies, eg. tropical cyclone, fire, explosion, collision, fuel and oil spills, equipment failure
- facility and equipment service and maintenance schedules and procedures
- vessel and mooring maintenance surveys, inspections, timings and personnel

Proposals for operation and maintenance should be incorporated in the *Management Plan for Operation and Maintenance* of the facility. This Plan should be updated with final design and installation details prior to commencement of operation, maintenance and performance monitoring (Step 9).

Step 4 - Proposals for environmental monitoring (Chapter 10)

The proponent shall prepare a plan for environmental monitoring of the facility, incorporating proposals for environmental monitoring of the effects of construction and operation. The environmental monitoring program is best conceived in the feasibility phase when the goals and performance criteria are being developed during the planning and design of the facility. The monitoring plan will usually be specific to the pontoon site but may form part of a general monitoring program for the adjacent area. It will incorporate the designs for *Baseline Monitoring* (Step 7) and ongoing short term and long term *Performance Monitoring* (Step 9). The monitoring proposal will be based on terms of reference prepared by GBRMPA and will be subject to independent review prior to adoption. It will be funded by the proponent and undertaken by a consultant contracted to GBRMPA.

The environmental monitoring plan will form part of an overall *Environmental Management Plan* for the facility, and should be updated with final design and installation details prior to commencement of *Baseline Monitoring* (Step 7) and again prior to *Performance Monitoring* (Step 9).

Step 4 - Quality assurance and design audit

The proponent and designers should adopt a quality assurance system to record relevant data and procedures, and critical decisions and assumptions incorporated in the feasibility design studies. GBRMPA or other regulatory bodies and specialist advisors may undertake a design audit and technical review of particular aspects such as tropical cyclone design loading, mooring design, pontoon body design, and environmental impacts (Step 5).

Step 4 - Licences and approvals

In addition to approvals for marine park permits under the GBRMP Act, the proponent must obtain all other necessary licences and approvals required for implementation of the project under other relevant pieces of legislation (Box 3.7). These approvals may relate to any of the three spheres of government or other public regulatory authorities, and will range from overall planning approval to specific approvals for noise, marine discharges, seadumping etc. Most permit and licence applications will be made in the feasibility phase on the basis of technical and regulatory data so far established. Specific applications relevant to construction and installation of the facility may be made in the *Implementation Phase* (Step 8).

Box 3.7 Possible licence and approval requirements for pontoon projects (additional to Marine Parks permit)	
Legislation	Licence or approval
<i>Australian Heritage Commission Act 1975</i>	Clearance under requirements for protection of items of cultural and natural heritage
<i>Environment Protection and Biodiversity Conservation Act 2000</i>	Clearance under requirements for impact assessment
<i>Environmental Protection (Sea Dumping) Act 1981</i>	Licence for disposal of spoil and for construction for artificial underwater structures
<i>Native Title Act 1993</i>	Clearance under requirements to protect native title
<i>Sea Installations Act 1987</i>	Permit to ensure personal safety and environmental protection for the facility
<i>Environmental Protection Act 1994 (Qld)</i>	Licences for disruptive practices causing noise, pollution etc
<i>Workplace, Health and Safety Act</i>	Compliance with design requirements for facility components, and approval for installation
<i>Harbours Act 1955-1987</i>	Permit for fixed structure

Step 4 - Submission to GBRMPA

The proponent shall prepare and submit a package of information describing the proposal in sufficient detail for GBRMPA to make a detailed assessment of the application for the pontoon facility (Appendix B). The information to be supplied will be additional to, or will modify, the information supplied for the *GBRMPA Preliminary Assessment* (Step 3). Where impact assessment studies are ordered to address specific terms of reference, the proponent is required to submit the draft EIS or PER for GBRMPA assessment and external review. Well-defined packages of information that meet the planning and design requirements of these *Guidelines* will be most readily assessed, thereby minimising delays and uncertainties.

How to do Step 4 - Feasibility Design
Suggested tasks 1. Undertake detailed hydrodynamic studies of wind, wave and current conditions for the site (Chapters 4 and 5). 2. Undertake detailed bathymetric surveys, geotechnical and ecological assessments of the site (Chapter 4). 3. Prepare detailed layouts and configurations of the pontoon facility, including moorings and anchors (Chapter 6). 4. Define acceptable movement limits for the pontoon and mooring system under normal operation and severe conditions (Chapter 6). 5. Analyse the structure to determine forces and movements in the pontoon and mooring system, and design mooring components to accommodate wind, wave, current, dead and live loads (Chapter 7). 6. Select and design suitable anchor type, configuration and size to suit substrate conditions and to accommodate design loads (Chapter 8). 7. Assess the stability of the pontoon body, check flotation requirements and undertake preliminary design of pontoon structural members (Chapter 9). 8. Define configuration and layout of pontoon ancillary facilities, including platforms, walkways, water storage, waste storage and disposal as required (principally for new projects). 9. Assess the environmental effects of the facility, including installation and operation, and mitigate ecological, social and cultural impacts (Chapters 6, 9 and 10). 10. Define the installation and salvage arrangements for the facility (Chapter 10). 11. Define the operation and maintenance program for the facility (Chapter 10). 12. Define the environmental monitoring program for the facility (Chapter 10). 13. Estimate project costs and examine the economic viability of the tourist pontoon operation. 14. Prepare EIS or PER where these are ordered. 15. Discuss feasibility studies and designs with GBRMPA. 16. Document information required for GBRMPA detailed assessment. 17. Document EIS or PER if ordered. 18. Seek licences and approvals for the installation from regulatory agencies. 19. Submit information to GBRMPA. Inputs • preliminary site assessments of hydrodynamic, bathymetric, ecological and geotechnical conditions (Step 2) • conceptual design of the scheme operation, location, access, size, configuration and mooring arrangements, and preliminary assessment of impacts (Step 2) • preliminary project cost estimates of the facility (Step 2) • GBRMPA preliminary assessment report on the project and determination of regulatory requirements (Step 3)

Tools

- *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Chapter 5)
- ecological model of disturbance effects on coral
- structural model to assess pontoon mooring loads and movements (Chapter 7)
- structural model for anchor capacity (Chapter 8)
- geotechnical model for foundation design (Chapter 8)
- GBRMPA application form and technical data requirements for infrastructure developments

Personnel

- coordination and preparation of required information by the proponent's project manager
- involvement from the operations manager / resort planner
- specialist support from an environmental engineer / scientist, marine engineer / naval architect, hydrodynamics engineer, geotechnical engineer, structural engineer, marine biologist or others as required
- major input from the marine technician, particularly in site investigations
- environmental monitoring contractor, engaged by GBRMPA on behalf of the proponent, will develop the environmental monitoring program
- management agency's interests represented by the GBRMPA project manager

Outputs

- feasibility designs for the scheme, defining the configuration and layout of the facility, sizes and characteristics of major components, environmental assessment and measures for impact mitigation
- installation, salvage, operation, maintenance and monitoring proposals for the facility
- updated project cost estimates
- licence and permit applications to regulatory agencies
- submission to GBRMPA for Marine Parks permit with required information in the designated format, including the EIS or PER where ordered

Step 5 GBRMPA Detailed Assessment														
Scope and purpose Undertake detailed assessment of the pontoon proposal and decide to approve or reject the permit application. GBRMPA determines whether or not to approve the proposal and issue a Marine Parks permit for the facility. Technical issues relating to tropical cyclone loading, mooring design, environmental impact etc. are addressed. Where applicable, GBRMPA also assesses and co-ordinates external review of the EIS or PER.														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
•				Ö	Ö			•		•	•		Ö	
Ö planning and design task				◆ joint site inspection				• expert assistance for design audit and technical review						

Step 5 - Overview

GBRMPA undertakes detailed assessment of the proposal under Regulation 18AC(4) of the Great Barrier Reef Marine Park Act (Appendix B), which considers the likely effects of the development on the biophysical environment, public health and safety, and other users of the area. Decisions to approve or reject the proposal are appealable by affected persons. The following matters are addressed:

- appropriateness of the project with respect to the zoning
- effect of the proposal on orderly and proper management of the Marine Park
- effect of the project on future options for the Marine Park
- effects of the proposal on existing and potential future uses and amenity of the area
- effects of the project on the environment during construction and operation
- effects of the project on the conservation of natural resources
- adequacy of safety to users, visitors, etc
- adequacy of provisions for removal of any associated hardware
- compliance with established criteria, recommended procedures and best practice guidelines

Compliance with established guidelines does not automatically mean approval of the project, nor does it remove the capacity of GBRMPA to reject or refuse a proposal on policy grounds. Where an EIS or PER is prepared for the project, assessment is based on specified terms of reference.

Step 5 - Stakeholder consultation

Stakeholder input and public comments are taken into account in the assessment when public submissions are invited for advertised projects. GBRMPA is required to publish the notice of decision and provide time for affected parties to appeal or ask for reconsideration once the assessment is completed. Public notice is also required for structure permits granted under the *Sea Installations Act*. EIS and PER reports must be available for public comment for specified periods, and public notice given of their release and where they can be viewed.

Step 5 - Regulatory requirements

GBRMPA determines regulatory requirements for the proposal at the detailed assessment stage by:

- considering the outcomes of an EIS or PER, where applicable under the EPBC Act
- determining if the pontoon requires a permit under the provisions of the *Sea Installations Act*
- determining whether to grant a Marine Parks permit, and preparing deeds of agreement for signature by GBRMPA and the proponent
- undertaking an assessment review when affected persons appeal against either granting or refusal of the permit application
- determining the applicability and amount of the bond to cover costs for salvage of the installation and rehabilitation of the Marine Park

Step 5 - Environment Protection and Biodiversity Conservation Act 1999

Where a pontoon development is designated under the EPBC Act, the project may be assessed under this act as well as under the GBRMP Act. The proponent is required to submit the preliminary draft EIS or PER for internal assessment by GBRMPA. The draft version is circulated to external government agencies and other reviewing bodies, and is made available to the public for comment. GBRMPA makes the decision on whether the project should be allowed to proceed, taking into account the content of the proposal and conformity with the GBRMPA Act and Regulations. Conditions attached to Marine Park permits often contain results and recommendations of EIS and PER reports. If the permit is granted, conditions and restrictions on development may be specified relative to environmental management plans for construction, maintenance and monitoring.

Step 5 - Sea Installations Act 1987

The *Sea Installations Act 1987* (SIA) provides for minimum safety and environmental standards for the design, installation and operation of offshore facilities. The act ensures that sea installations are operated in a manner consistent with the protection of the environment, having regard to the safety of the people using them and the people, ships and aircraft near them. The SIA requires that these installations will not interfere with navigation, fishing or conservation of resources of the sea or seabed, and that unauthorised fixed structures are removed, and damage caused by the installation is rehabilitated.

A permit is required under the act for pontoons with on-board accommodation, located in waters administered by the Commonwealth (outside the Territorial Sea of Australia - 3 nm). An exemption certificate can be issued for pontoons with no on-board accommodation. Depending on the effect the installation would have on the environment and the number of persons likely to be on the installation at any one time, exemption may also be available for pontoons and permanently moored vessels with caretaker accommodation for operating staff. For facilities valued at less than \$5 million, GBRMPA is delegated responsibility for assessing applications, making recommendations, and general administration of the Act. Facilities costing more than this require permits granted by the Commonwealth environment department.

Public notice is given when permits are granted for structures designated under the *Sea Installations Act*. Marine Parks permits and SIA permits or exemption certificates are normally granted in a manner to avoid duplication of information, advertising requirements and payment of fees.

Step 5 - Marine Parks permit

A Marine Parks permit under the *GBRMP Act 1975* is required for pontoon installations within the GBR Marine Park and State Marine Parks of the GBR region. Conditions relating to the planning, design, installation, operation and monitoring of the facility are often attached to the permit as a means of implementing recommendations from the impact assessment process, and to help ensure the protection of the values of the Marine Park and other users. Conditions vary depending on activities and are often contingent upon issue of other State and Commonwealth permits.

The proponent must sign the Deed of Agreement outlining contractual responsibilities between GBRMPA and the proponent. GBRMPA will determine the amount of a bond (see below) and minimum insurance to be provided by the operator to indemnify GBRMPA against claims related to health, safety and damage to the environment. The operator must provide the bond prior to installation of any facilities in the Marine Park, and must observe and perform his/her obligations under and pursuant to the Deed, including cleaning up the Marine Park following damage.

Step 5 - Assessment review

Affected parties have a statutory 21 day period to appeal against and ask for reconsideration of a decision made by GBRMPA to either grant or refuse a permit for the pontoon installation. Public appellants must provide reasons for the appeal. No access to technical material or assessment is provided unless under Freedom of Information (FOI) or legal actions. Appeals are considered in an assessment review process, which will either confirm or reverse GBRMPA's initial decision to grant a permit. An internal assessment review by GBRMPA would reconsider the decision and other matters, and provide a new decision with reasons within a statutory 40-day period. A further right to apply for external review of the reconsidered decision is available if the affected parties are dissatisfied with the outcome. This external review may include the Administrative Affairs Tribunal (AAT) merit and process review.

Step 5 - Bond to cover salvage and rehabilitation costs

Salvage and removal of the pontoon structure and associated infrastructure from the Marine Park may be required where the operator ceases to hold a valid permit to conduct the operation, where the structures are wrecked or abandoned, or where removal is directed by GBRMPA in accordance with the environmental monitoring program. Operators shall indemnify GBRMPA against loss or damage arising out of the removal of a structure and associated infrastructure from the Marine Park. Operators shall also indemnify GBRMPA against loss or damage incurred in rehabilitating the Marine Park as a result of damage associated with the wrecking, abandonment etc.

GBRMPA will define the standard to which the rehabilitation is to be undertaken, and will determine the amount of a bond to be provided by the proponent to cover the costs of salvage and environmental rehabilitation that may be required in the event of damage caused by the structure or its removal. Operators are required to carry and maintain specified insurances against third party liability, rehabilitation and removal. The bond is to be lodged with GBRMPA and maintained during the operating term and a subsequent period. The amount of the bond is to be based on independent salvage quotes obtained by the proponent.

Step 5 - Environmental management charge

An environmental management charge (EMC) will be applied to tourist pontoon operators and other commercial operators who hold Marine Parks permits. The revenue from the EMC will be used to fund research and education projects for ecologically sustainable use of the GBR.

Step 5 - Design audit and technical review

The GBRMPA project manager, assisted as necessary by specialists, will conduct a design audit and technical review of the project designs to check compliance with established criteria, recommended procedures and best practice guidelines. Expert review will not be necessary on all parts of the design, but may be undertaken to assess particular specialist areas of the proposals such as tropical cyclone design loading, mooring design, pontoon body design, and environmental impacts. The review may be used to provide an impartial view of particular issues, and will be used to identify further information that may be required, or mitigation measures that could be included in the project. In a complex project, the review may operate in an iterative manner, whereby issues requiring further research or investigation are identified.

Step 5 - Further information

GBRMPA may request further information on the project from the proponent to assist with clarification and review of the proposal prior to completion of the assessment.

How to do Step 5 - GBRMPA Detailed Assessment
<i>Suggested tasks</i> 1. GBRMPA determines regulatory requirements for the proposal. 2. GBRMPA undertakes detailed assessment of proposals. 3. GBRMPA may engage other experts for design audit and technical review to assess specialist areas such as tropical cyclone design loading, mooring design, pontoon body design, and environmental impacts of the facility. 4. GBRMPA coordinates review of EIS or PER, if applicable. 5. GBRMPA may seek further information from the proponent to clarify aspects of the proposal. 6. GBRMPA either grants or refuses a permit. (The decision is subject to review). <i>Inputs</i> • feasibility design for the scheme defining the configuration and layout of the facility, sizes and characteristics of major components, environmental assessment and measures for impact mitigation (Step 4) • project information prepared by the proponent in Step 4, including the EIS or PER, where ordered <i>Tools</i> • GBRMPA assessment procedures <i>Personnel</i> • GBRMPA delegate and project manager • specialist input as required to ensure compliance with established criteria, recommended procedures and best practice guidelines <i>Outputs</i> • determination of regulatory requirements relative to the <i>EPBC Act</i>, the <i>Sea Installations Act</i>, bond for salvage etc • expert review of particular technical aspects • GBRMPA detailed assessment report on the project • determination whether to issue, or reject the application for the Marine Parks permit

3.5 Phase 3 – Implementation: Steps 6 – 8

The Implementation Phase includes Steps 6 to 8, *Detailed Design*, *Baseline Monitoring* and *Construction and Installation* of the facility. Detailed design proceeds after the main function, safety, environmental protection, social and economic issues are resolved in the feasibility phase, and a decision is made to proceed with the project. Baseline monitoring, undertaken prior to construction, provides a quantitative background description of the physical and biological environment against which environmental impacts can be measured. The construction and installation step must meet all environmental requirements for the project, such as protecting the coral and minimising disturbance to the seafloor and reef flat, as well as function and safety objectives.

Step 6 Detailed Design														
Scope and purpose														
Prepare detailed designs, drawings, specifications and documentation for the pontoon facility. The proponent develops and refines detailed design aspects of the adopted scheme. Detailed design proceeds on the basis of the adopted layout and configuration of the facility and the outcomes of environmental studies undertaken in <i>Feasibility Design</i> (Step 4). Detailed design must conform to the requirements of the permits and licences initiated or obtained in the <i>Feasibility Phase</i> . Typically, all planning and design aspects of the project will have been approved in <i>GBRMPA Detailed Assessment</i> (Step 5), and GBRMPA involvement in detailed design is normally minimal.														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Moorings design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
								Ö	Ö	Ö •	Ö	Ö		Ö
Ö planning and design task				◆ joint site inspection				● expert assistance for design audit and technical review						

Step 6 - Overview

Detailed design usually involves prescriptive analysis of scheme components in accordance with well-defined constraints that are established in the feasibility design. Detailed structural design and scheduling of moorings, anchors, and other structural components such as the pontoon body, is undertaken in this step. The size of scheme components, their materials and construction methods are finalised; and design drawings, project specifications and tender documents are prepared for construction and installation of the facility. Cost estimates for the project will normally be updated as part of detailed design.

Step 6 - Site investigation and characterisation (Chapter 4)

Further limited site investigation and assessment may be required in the detailed design step to supplement investigations undertaken in the concept and feasibility phases. These site assessments will usually be related to specific components of the adopted scheme, and the requirements will usually be very well defined on the basis of decisions taken in the earlier work. The most likely site assessment requirement is additional site inspections to confirm bathymetric, coral and other substrate conditions related to pontoon configuration and mooring and anchor design. Some minor hydrodynamic design may be required to supplement wind, wave and current loads already determined for the structure.

Step 6 - GBRMPA and other stakeholder consultation

Design and specification details should be discussed with GBRMPA and other government agencies in order to comply with legislative requirements.

Step 6 - Pontoon body and ancillary facilities (Chapter 9)

Detailed designs for the pontoon body, including workshop fabrication drawings, will be undertaken in this step. This will be based on preliminary designs prepared in *Feasibility Design* (Step 4). Pontoon body design should comply with marine classification society, relevant shipping structures code, and other marine survey requirements. GBRMPA will require marine classification approval for the structure (eg. Lloyds Register of Shipping), and may engage expert assistance to undertake a design audit and technical review of the pontoon body design.

Detailed designs for ancillary facilities, including platforms, walkways, water storage, waste storage and disposal should be prepared, and drawings and tender documents prepared for manufacture and construction.

Step 6 - Drawings, specification and tender documentation

Design drawings and technical specifications should be prepared for the manufacture and installation of the mooring system, anchors and other components of the facility (Chapters 7, 8 and 10). Where construction and installation of the facility is to be let out to tender, these drawings and specifications should be incorporated in tender documents, which provide for tender evaluation, contract administration, supervision of construction etc. The documentation should provide an integrated specification of the physical and ecological requirements of the project, incorporate best practice guides for construction and installation, and comply with management plans for installation and monitoring. Detailed drawings are to show all dimensions and aspects of the project in sufficient detail to communicate the design to the client, approving authorities, potential contractors and the community in general. Drawings should include setting out details for construction, refer all elevations to the same datum, and give examples of conversions from one datum to another (e.g. Australian Height Datum-AHD to Chart Datum).

Tender documents for pontoon projects should take account of special factors that affect work in the reefal and coastal environment. In addition to the contractor's responsibility to ensure minimal disturbance to the site, the documents should incorporate a mechanism to handle variations that arise from downtime and delays in construction project schedules. These delays may occur as a result of environmental influences, such as unfavourable wave conditions, strong or unfavourable currents, strong winds, elevated water levels and excessive rainfall. Provisions should be made for contractors to comply with all relevant approvals and licence conditions. Technical specifications relating to removal or reinstatement of the facility should also be included where appropriate.

Step 6 - Quality assurance and design audit

The proponent and designers should adopt a quality assurance system to record relevant data and procedures, and critical decisions and assumptions incorporated in the detailed design studies. GBRMPA will require a marine classification approval for the pontoon body design (eg. Lloyds Register of Shipping), and may undertake a design audit and technical review of this component.

How to do Step 6 - Detailed Design

Suggested tasks

1. Confirm bathymetric and substrate conditions, if necessary, to finalise mooring and anchor design.
2. Undertake supplementary hydrodynamic studies, if necessary, to determine wind, wave and current loadings on the structure (Chapters 4 and 5).
3. Undertake detailed design analyses to finalise sizes, material requirements and construction methods for moorings, anchors and other structural components such as the pontoon body.
4. Prepare and submit details for the pontoon body design to an approved marine classification society (eg. Lloyds Register of Shipping).
5. Finalise designs for ancillary pontoon facilities such as platforms, water storage, waste disposal etc.
6. Prepare detailed drawings and specifications for the installation.
7. Prepare tender documents in readiness for awarding construction contracts.
8. Update project cost estimates for the facility.
9. Discuss detailed designs and specifications with GBRMPA and other agencies.

Inputs

- detailed site assessments of hydrodynamic, bathymetric, ecological and geotechnical conditions (Step 4)
- feasibility design of the scheme, defining the configuration and layout of the facility, sizes and characteristics of major components, environmental assessment and measures for impact mitigation (Step 4)
- project cost estimates of the facility (Step 4)
- GBRMPA detailed assessment report on the project and determination of regulatory requirements (Step 5)
- requirements for permits and licences (from regulatory agencies)

Tools

- structural models to design pontoon, mooring and anchor components (Chapters 7, 8 and 9)
- procedures for adaptation of standard specifications and tender documentation

Personnel

- coordination by the proponent's project manager
- majority of the work undertaken by the marine engineer / naval architect and structural engineer, preparing detailed designs, drawings and specifications for installation of the facility
- management agency's interests represented by the GBRMPA project manager

Outputs

- detailed design drawings, specifications and tender documents suitable for construction and installation of the facility
- marine classification society approval of pontoon body design
- updated project cost estimates

Step 7 Baseline Monitoring														
Scope and purpose														
Undertake pre-installation baseline surveys as part of an ongoing monitoring program. The survey provides a quantitative description of the physical and biological environment at the site prior to installation and operation of the facility. Baseline monitoring forms part of an overall <i>Environmental monitoring plan</i> , prepared in <i>Feasibility Design</i> (Step 4) in accordance with GBRMPA terms of reference. It provides a baseline for short term or long term <i>Performance Monitoring</i> , which may extend throughout and beyond the life of the project (Step 9).														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
	Ö	Ö		Ö ♦							Ö			
Ö planning and design task				♦ joint site inspection				● expert assistance for design audit and technical review						

Step 7 - Baseline monitoring (Chapter 10)

The baseline (pre-installation) monitoring usually has to be in place for at least three months before pontoon installation commences or modifications are made to existing facilities. Although baseline monitoring is normally conducted after *GBRMPA Detailed Assessment* and approval of the marine parks permit application (Step 5), the proponent may choose to do this earlier in the project as part of *Feasibility Design* (Step 4), particularly where insufficient time is likely to be available after permit approval and prior to *Installation* (Step 8). Site investigations and condition assessment undertaken in the *Feasibility Phase* can usually be readily modified to incorporate the requirements for baseline monitoring (Chapter 4).

Baseline monitoring will be funded by the proponent and undertaken by a consultant contracted to GBRMPA. It will be based on terms of reference prepared by GBRMPA and will be subject to independent review prior to adoption. The monitoring should be undertaken in accordance with the requirements of the *Environmental monitoring plan* for the pontoon facility prepared in the feasibility phase. The EMP should be updated with final design details for the facility prior to commencement of monitoring.

Step 7 - Site investigation and characterisation (Chapter 4)

Baseline monitoring activities should be closely integrated with, and use appropriate information from, the site bathymetric, substrate and ecological surveys undertaken as part of site assessment in the concept and feasibility phases.

Step 7 - GBRMPA and other stakeholder consultation

Baseline survey proposals should be discussed with GBRMPA to ensure compliance with the agreed environmental monitoring program for the facility. A joint site inspection with GBRMPA personnel and the environmental monitoring contractor would be beneficial.

Step 7 - Physical and biological monitoring (Chapter 10)

Monitoring of the physical and biological environment will concentrate on the direct impacts of the pontoon on benthic assemblages (mostly corals), fishes and water quality. The baseline survey should encompass areas of the reef adjoining the pontoon that will be used for intensive snorkelling and diving activities, as well as, at least, two control locations away from the influence of pontoon-based activities. Hard corals retained in the pontoon footprint (the shaded area beneath the pontoon body) are expected to die after installation due to shading and, in normal circumstances, no special attention is given to monitoring coral decline in this area as a result of this effect.

Step 7 - Baseline monitoring report (Chapter 10)

The results of the baseline monitoring should be presented in a report describing the general objectives and scope of the monitoring program, the methods used and the results obtained. The standards for the various environmental parameters, against which GBRMPA will determine whether changes to the environment that may be detected in subsequent performance monitoring are within acceptable levels, should be presented.

How to do Step 7 - Baseline Monitoring
<i>Suggested tasks</i> 1. Review environmental monitoring program proposals developed in the feasibility phase and update EMP with final design details for the facility. 2. Develop detailed plan for physical and biological baseline monitoring. 3. Discuss proposals for baseline monitoring with GBRMPA. 4. Conduct baseline monitoring. 5. Prepare and submit the baseline monitoring report to GBRMPA. <i>Inputs</i> • layout and configuration plans of the facility (Step 4) • environmental assessment studies and measures for impact mitigation (Step 4) • environmental monitoring program proposals (Step 4) • bathymetric, substrate and ecological surveys for the site obtained during site investigations (Steps 2 and 4) <i>Tools</i> • protocols for physical and biological monitoring of reef sites <i>Personnel</i> • coordination by the proponent's project manager • major work undertaken by the environmental monitoring contractor engaged by GBRMPA on behalf of the proponent • on-site assistance from the marine technician • activities co-ordinated on behalf of the management agency by the GBRMPA project manager, consulting with the GBRMPA delegate, the QPWS environmental manager, and other specialists as required <i>Outputs</i> • baseline survey of the physical and biological condition of the site • Baseline monitoring survey report

Step 8 Construction and Installation														
Scope and purpose Manufacture, construct and install the pontoon facilities. The proponent undertakes and manages the construction and installation of a new pontoon facility or the upgrade of an existing facility, in accordance with project designs and environmental management provisions. The layout and configuration of the pontoon structure and associated facilities, and the environmental management provisions for installation and monitoring will have been established as part of <i>Feasibility Design</i> (Step 4). Design drawings and specifications for the pontoon body, moorings, anchors and other components will have been developed in <i>Detailed Design</i> (Step 6).														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Moorings design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
	Ö			Ö ♦							Ö		Ö	Ö
Ö planning and design task				♦ joint site inspection				● expert assistance for design audit and technical review						

Step 8 - Overview

The pontoon structure and associated mooring hardware will be manufactured and assembled off site in a ship building facility or manufacturing plant. Manufacture and construction of these facilities should be in accordance with the design drawings and specifications prepared in *Detailed Design* (Step 6). All mooring chain, cable or other anchor lines, and all anchors and associated mooring system fittings must comply with classification society requirements for manufacture and testing. Factory certificates or other satisfactory evidence of grade and proof testing must be provided for new or reused mooring and anchor components.

Site installation typically involves several stages, which lead from site preparation, through construction, testing and monitoring, to clean up and post-installation inspection. Site installation requirements are defined by the layout and configuration of the pontoon structure and associated facilities, and the environmental management provisions for installation and monitoring established in *Feasibility Design* (Step 4). All installation activities should be undertaken in accordance with project design plans and specifications prepared in *Detailed Design* (Step 6), or approved variations of these plans or specifications that comply with the original design intent.

Step 8 - Site investigation and characterisation (Chapter 4)

Apart from the specialist field testing and record of ‘as-constructed’ details outlined below, limited site investigation and assessment may be required in the installation step. This may include control surveys to set out the components of the facility, and more detailed bathymetric information to assist the installation contractor, the contract supervisor and the environmental manager in finalising the location of moorings and other hardware.

The environmental supervisor will record the physical condition of the site during installation, and note any modifications made to the pre-existing condition. This may include relocation of corals or alterations to substrate undertaken as part of the project plan, or other alterations to the coral or other substrate that occur as a direct result of the on-site activities. All such modifications should be tied in to the baseline survey and reconciled with the environmental monitoring program.

Step 8 - GBRMPA and other stakeholder consultation

All manufacture, construction and installation activities should be coordinated with personnel from GBRMPA and other appropriate management agencies, some of whom may be involved in contract supervision and site inspections.

Step 8 - Management plan for installation (Chapter 10)

Careful environmental management is required during installation of the facility to protect the coral and other marine ecosystems at the site from physical disturbance, pollution or other impacts. Most potential environmental impacts associated with construction will have been identified during the concept, feasibility and detailed design steps. The construction step is principally concerned with effective implementation of environmental safeguards already established in the *Environmental Management Plan (Installation)*. This Plan should be updated with final design details prior to installation. Environmental monitoring is undertaken during installation to ensure compliance with these plans.

Step 8 - Site testing (Chapter 10)

Site testing will normally entail test loading of installed anchors and mooring lines in accordance with design load conditions. Care should be taken to avoid damage to the coral substrate from chain tensioning, and other physical damage from the test equipment. Most pontoon ancillary facilities, such as platforms, electrical, water and waste systems, will be factory tested prior to transport to site. Some equipment testing may be undertaken on site prior to commissioning of the facility, eg. raising and lowering of the swim and divers platform, and operation of the freshwater system.

Step 8 - Construction contractors, construction management and site supervision (Chapter 10)

Site installation and salvage are usually undertaken by contractors on behalf of the pontoon proponent/operator. The proponent will engage a construction superintendent to coordinate and supervise installation of the pontoon and mooring system, as well as the manufacture, construction and installation of all components of the facility. For environmental matters relating to the site installation, the superintendent will liaise with the QPWS environmental supervisor, who will supervise installation activities on behalf of GBRMPA. Significant site activities associated with the installation or relocation of the facility, such as the siting and manner of installation and placement of the moorings, must be undertaken in the presence of the QPWS environmental manager. The operator and his/her agents must comply with any directions of the QPWS environmental manager that are reasonably necessary for the conservation, protection and preservation of the Marine Park.

Step 8 - 'As constructed' details

The location, configuration and size of all components of the facility should be recorded on the design drawings after installation has been completed. Any variations from the design should be noted. This record of as-constructed conditions will provide the basis for future investigations and activities associated with the operation, maintenance, monitoring or future modification of the pontoon facility.

Step 8 - Quality assurance and construction audit

The proponent should adopt a quality assurance system to record relevant data and procedures, and critical decisions and assumptions incorporated in the manufacture, construction and installation of the facility. Contractors should adopt recognised construction standards and codes of practice, comply with established criteria and recommended procedures, and follow best practice guidelines wherever they are available. GBRMPA, QPWS or other regulatory bodies and specialist advisors may undertake an audit of particular manufacture and construction activities such as anchor manufacture and mooring installation.

Step 8 - Licences and approvals

In addition to Marine Park permits and other approvals obtained in the *Feasibility Phase* (Step 4), the proponent and the contractors should ensure that all relevant licences and approvals for workplace, health and safety; noise; marine discharges; sea-dumping etc. are sought and obtained prior to construction and installation of the facility.

How to do Step 8 - Construction and Installation
Suggested tasks 1. Seek and obtain all outstanding licences and approvals prior to construction and installation of the facility. 2. Call tenders and appoint appropriate contractors for the various contracts tasks associated with manufacture, construction and installation of the facility. 3. Manufacture and construct pontoon structure, mooring system components and associated hardware off- site. 4. Review and update the <i>Environmental Management Plan (Installation)</i> with final design details for the facility. 5. Transport pontoon, mooring system and other components to the site in readiness for installation. 6. Prepare the site and set it out prior to installation. 7. Remove or relocate designated corals and clear away unwanted obstructions. 8. Install anchors and test to ensure design strength is achieved. 9. Connect mooring lines to the anchors, position pontoon and connect to mooring lines. 10. Complete installation, assembly and testing of the pontoon and associated facilities. 11. Remove all construction equipment and materials and clean corals and substrate after construction complete. 12. Record 'as-constructed' details of the installation. 13. Inspect the physical condition of the site and note any modifications to the pre-existing condition. Inputs • marine charts, aerial photographs and bathymetric charts for the site • environmental management provisions for installation and monitoring (Step 4) • layout and configuration plans of pontoon and associated facilities (Step 4) • detailed drawings and specifications for manufacture, construction and installation (Step 6) • tender documents for manufacture and construction contracts (Step 6) • environmental monitoring program and baseline survey results (Steps 5 and 7)

Tools

- contract administration documents and materials
- ecological models for coral damage
- field test performance certificates for anchors and mooring components

Personnel

- co-ordination of activities and contract supervision for the manufacture, construction and installation of the facility by the proponent's project manager, construction superintendent and marine technician
- specialist support from a marine engineer, geotechnical engineer, marine biologist or others as required (preferably those involved in design of the project)
- co-ordination of activities on behalf of the management agency by the QPWS environmental manager - construction, consulting with the GBRMPA delegate and other specialists as required

Outputs

- facility components manufactured and transported to site, and pontoon and associated facilities installed in readiness for operation
- factory certificates and site test reports for manufacture and installation of mooring, anchor and other components
- 'as constructed' details of the facility and information on alterations to the site condition as a result of the installation

3.6 Phase 4 – Operation, Monitoring and Review: Steps 9 - 10

In Phase 4 the project moves from Implementation through *Performance Monitoring* (Step 9) to *Performance Review* (Step 10). This includes monitoring and review of performance of the installation to determine environmental impacts and to decide whether or not modifications should be made to the facility. Performance monitoring usually examines the impact of movement of mooring chains and anchor blocks on coral, the effect of pontoon shading etc. on the coral substrate and the effect of snorkellers and divers on the coral. Environmental monitoring is undertaken in conjunction with facility monitoring to assess functional and structural aspects as part of pontoon operation and maintenance. The maintenance program systematically replaces, repairs or adjusts deficient mooring components. The performance review examines project performance and reviews success or failure in meeting goals for the project and for the marine park.

Step 9 Performance Monitoring														
Scope and purpose Monitor project performance against established objectives and undertake maintenance. Performance monitoring, undertaken during operation of the pontoon, forms part of an overall <i>Environmental monitoring plan</i> , prepared in <i>Feasibility Design</i> (Step 4) in accordance with GBRMPA terms of reference. The object is to describe the physical and biological environment at the site, examine environmental impacts and changes to the facility, and provide a basis for developing mitigation strategies to minimise further impact on a short or long term basis. The environmental performance of the facility is determined by comparison with baseline or pre-existing conditions established in <i>Baseline Monitoring</i> (Step 7).														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
	Ö	Ö									Ö			
Ö planning and design task				◆ joint site inspection				● expert assistance for design audit and technical review						

Step 9 - Outline

Performance monitoring assesses the impact on coral or substrate, marine organisms, wildlife, seabed and marine life of day-to-day activities such as craft movements, visitor recreation and waste disposal in terms of the objectives set out in the project planning and design phase. Performance monitoring is conducted immediately post-installation and during pontoon operation, in association with facility monitoring and maintenance activities associated with replacement and repair of facility components.

The monitoring should be undertaken in accordance with the requirements of the plan for environmental monitoring prepared as part of the *Environmental Management Plan* in the *Feasibility Phase*, and updated with final design details for the facility prior to commencement of monitoring. In a similar manner to the baseline environmental survey, the detailed performance monitoring surveys will be undertaken by an environmental monitoring contractor, employed by GBRMPA and funded by the proponent. Detailed performance monitoring surveys by the environmental monitoring contractor will be undertaken as part of an overall performance monitoring program. That will usually involve the following:

- site inspection by GBRMPA as soon as practical after installation
- subsequent site inspections and reports by GBRMPA once a year
- detailed survey if annual inspections indicate significant human-induced changes since the baseline survey
- subsequent detailed surveys at approximately 5 year intervals, depending on the term of the marine parks permit

Step 9 - Site investigation and characterisation (Chapter 4)

Performance monitoring activities should be closely integrated with, and use, appropriate information from the site bathymetric, substrate and ecological surveys undertaken as part of site assessment in the concept and feasibility phases (Chapter 4). Biophysical surveys undertaken during performance monitoring should conform to those undertaken during the baseline surveys and installation monitoring.

Step 9 - GBRMPA and other stakeholder consultation

The performance monitoring program should be undertaken and developed in close consultation with GBRMPA and QPWS personnel, who will conduct post-installation and annual site inspections to determine the requirements for detailed monitoring surveys and associated management responses.

Step 9 - Physical and biological monitoring (Chapter 10)

Monitoring of the physical and biological environment will comply with the current GBRMPA protocol for tourist pontoons, and will usually concentrate on the direct impacts of the pontoon on benthic assemblages (mostly corals), fishes and water quality. Performance monitoring will follow the design of the baseline survey, and include areas of the reef adjoining the pontoon used for intensive snorkelling and diving activities, as well as at least two control locations away from the influence of pontoon-based activities. Hard corals retained in the pontoon footprint (the shaded area beneath the pontoon body) are expected to die after installation due to shading and, in normal circumstances, no special attention is given to monitoring associated coral decline in this area.

Step 9 - Performance monitoring report (Chapter 10)

The results of the performance monitoring should be presented in a report describing the general objectives and scope of the monitoring program, the methods used, the results obtained, and the proposed management responses. The standards for the various environmental parameters, against which GBRMPA will determine whether or not changes to the environment that may be detected are within acceptable levels, should be presented. The report should discuss options to address deficiencies, such as modification of mooring lines, if impacts exceed a particular level.

How to do Step 9 - Performance Monitoring

Suggested tasks

1. Review environmental monitoring program proposals developed in the feasibility phase and update EMP with installation details for the facility.
2. Review baseline monitoring results and significant performance issues.
3. Consult with GBRMPA to determine the scope and nature of the performance monitoring.
4. Develop detailed plan for physical and biological performance monitoring.
5. Conduct performance monitoring.
6. Prepare and submit the performance monitoring report to GBRMPA.

Inputs

- layout and configuration plans of the facility (Step 4)
- environmental assessment studies and measures for impact mitigation (Step 4)
- environmental monitoring program proposals (Step 4)
- bathymetric, substrate and ecological surveys for the site obtained during site investigations (Steps 2 and 4)
- baseline monitoring report (Step 7)

Tools

- protocols for physical and biological monitoring of reef sites

Personnel

- coordination by the proponent's project manager
- major work undertaken by the environmental monitoring contractor engaged by GBRMPA on behalf of the proponent
- on site assistance from the marine technician
- activities co-ordinated on behalf of the management agency by the GBRMPA project manager, consulting with the GBRMPA delegate, the QPWS environmental manager, and other specialists as required

Outputs

- performance monitoring results of the physical and biological condition of the site
- Performance monitoring survey report

Step 10 GBRMPA Performance Review														
Scope and purpose Examine and review project performance to decide on permit renewal and to assist in developing requirements for future projects. The intention is to determine impacts on the Marine Park due to the presence of the structure or associated activities, to check that any unacceptable level of change has not taken place, and to confirm whether or not modifications should be made to allow continued operation of the facility. Performance review considers possible actions that may be taken where significant impacts occur to the Marine Park as a result of actions taken by the operator, including non-compliance with licensing provisions for the installation.														
Site Investigation and Characterisation				Consultation		Planning and Design								
Oceanography / hydrodynamics	Bathymetry / site set out	Ecology	Geotechnical / substrate	GBRMPA	Other stakeholders	Site selection	Layout & configuration	Mooring design	Anchor design	Pontoon body & other facilities	Environmental impact & manag.	Socio-cultural / economic assess.	Permits, licences & approvals	Tender documentation
				Ö	◆						Ö	Ö		
Ö planning and design task				◆ joint site inspection				● expert assistance for design audit and technical review						

Step 10 - Overview

Performance of the facility is reviewed with respect to the objectives and predicted performance of the facility when the Marine Parks permit was approved. Review is based on the results of the performance monitoring, mooring maintenance performance and operational matters (Chapter 10). The review should examine the history of the project and assess how well it has met the planning, design and operational objectives, including those outlined in the *Management plan for operation and maintenance*. Consideration should be given to how operations have changed during the project as a result of monitoring the performance of the works, and recommendations for improving similar projects in the future, should be made.

Performance review is undertaken annually or as defined in the Marine Parks permit. An initial review on completion of installation can deal primarily with planning and implementation aspects. Subsequent reviews should be undertaken at intervals designated in the Marine Parks permit and whenever something notable occurs (eg. damage from a cyclone). Review may result in *renewal* of the permit if satisfactory. The permit may be *withdrawn* for non-compliance when the permitted activity causes damage to the Marine Park, or when the permit holder fails to comply with a permit condition or fails to pay fees that are due. Alternatively the permit may *lapse* and a *new application* will be required.

Step 10 - GBRMPA and other stakeholder consultation

Close consultation between GBRMPA and the pontoon operator is required during the performance review and subsequent activities. A joint site inspection should be undertaken.

Step 10 - Removal and salvage of the pontoon facility (Chapter 10)

If a permit is not renewed following the performance review process, GBRMPA can order removal of the installation from the Marine Park in accordance with provisions established in earlier project approvals. The operator is required to salvage the pontoon structure, remove all components of the installation from the site, and rehabilitate any environmental damage if the project is abandoned in the operational phase.

How to do Step 10 - GBRMPA Performance Review

Suggested tasks

1. GBRMPA undertakes detailed assessment of the facility.
2. GBRMPA may engage other experts to assess specialist areas, such as environmental impacts of the facility.
3. GBRMPA prepares assessment report and recommends appropriate action.
4. Permit either renewed, withdrawn, or allowed to lapse, in which case a new application will be required.

Inputs

- project designs and construction details of the facility
- Management plans for *Installation* and *Operation and maintenance*
- Baseline and performance monitoring reports (Steps 7 and 9)
- GBRMPA review assessment reports for similar projects

Tools

- GBRMPA review assessment procedures

Personnel

- performance review initiated by the GBRMPA delegate
- review co-ordinated by the GBRMPA project manager
- proponent's interests represented by the proponent's delegate and project manager
- specialist input obtained as required to consider complex issues related to environmental impact etc.

Outputs

- GBRMPA review assessment report on the project
- determination of review requirements related to the Marine parks permit for the facility
- identification of issues to be addressed prior to renewal of the Marine Parks permit
- identification of requirements for salvage of the facility, where applicable

3.7 Recommended reading

Atlas of Tropical Cyclone Waves in the Great Barrier Reef. Available at:
<http://tsunami.jcu.edu.au>

4 SITE INVESTIGATION AND CHARACTERISATION

	Summary
4.1	Site assessment framework
4.2	Meteorology, physical oceanography and hydrodynamics
4.3	Site bathymetry
4.4	Ecology
4.5	Geotechnical/substrate aspects
4.6	Recommended reading

Summary

- **Proponents** and **designers** should use this chapter to identify the site investigations and characterisation activities that may be undertaken as part of the planning, design and implementation of a tourist pontoon facility.
- A framework for assessment of site conditions is provided, outlining project phasing, data acquisition and limitations.
- The likely data sources and methods of acquisition are described for each of the principal data areas that may be needed, and likely data acquisition needs through various phases of the project are noted.

Site investigation and characterisation (or site assessment), refers here to field investigations and office studies, undertaken by or on behalf of the proponent, to describe the physical and biological characteristics of the site within the local and regional context. Site assessment is an integral part of the planning, design and implementation procedure for a tourist pontoon project. It provides proponents, designers and managers with knowledge of natural processes for the site in pre- and post-development conditions, and helps develop an understanding of how the pontoon facility interacts with the surrounding environment. Regional oceanographic conditions are important for siting the pontoon, whilst local bathymetric and environmental conditions influence the configuration of the facility. Hydrodynamic and geotechnical/substrate conditions determine loads and capacities for design of the structure, mooring and anchoring system, whilst ecological conditions are used to assess ecosystem function and the environmental impacts of the installation.

This chapter provides a framework for site assessment that recognises the spatial and temporal context of reefal and ocean processes and related data. It identifies the general data requirements that proponents, planners and designers may be expected to acquire. Likely data sources and methods of acquisition are described for each of the principal data areas: meteorology and physical oceanography, site bathymetry, ecology, and geotechnical aspects. Prospective data requirements within these data areas are then described for the major site investigation and characterisation tasks in the *10-Step Project Planning, Design and Implementation Procedure* (Chapter 3, Box 3.2) and *Project Planning and Design Task Schedule* (Chapter 3, Box 3.3). These site investigation and characterisation data are used in the determination of design environmental loads and in facility design, installation and monitoring (Chapters 5 – 10). The scope of the site investigations will be tailored to the scope and nature of the project, and will commonly be less extensive for pontoon upgrades or retrofits than for new installations.

4.1 Site assessment framework

Spatial and temporal context

Investigation and characterisation of natural processes at the pontoon site should be undertaken within a broad spatial and temporal framework that encompasses local, regional, short-term and long-term conditions. The recommended site assessment framework uses a spatial hierarchy that considers the local (fine) scale conditions and processes (such as hydrodynamics, bathymetry and ecology) within the context of broader regional scale characteristics, such as oceanography and geomorphology. The geographical boundaries for data acquisition and technical assessment should reflect the various scales at which the relevant processes influence the site, or are influenced by the project. The extent of the natural system to be considered will also depend upon the size and nature of the project, the likely magnitude of its impact, and socio-cultural issues related to natural or cultural heritage. The temporal context identifies changes over time in response to ongoing natural or human-induced processes and disturbances. Baseline data, derived from pre-development conditions at the site or from other sites, provide a base from which to compare and measure future changes.

Local processes such as wave hydrodynamics and changes to coral reef morphology must be considered within the regional context. For tourist pontoons, both regional (100 km) and local (100 m) scales are important for hydrodynamic conditions relating to winds, waves and currents. Environmental loads on the facility due to waves, for example, are governed by ocean conditions at a regional scale and by coral reef bathymetry at a local scale. Environmental impacts from the development, such as coral damage, may apply at a local scale, while regional scale impacts from a pontoon are unlikely to apply (cf. pollution from land runoff). The local scale is significant for ecological and water quality issues, which relate mostly to local habitat degradation, species disturbance and pollution impacts directly associated with the pontoon installation. Other ecological issues relating to, for example, conservation of biodiversity are more relevant to process impacts at broader, regional scales. These impacts are not usually relevant to tourist pontoons. Site bathymetry and geotechnical conditions are local scale issues.

The temporal context identifies past and present variations in the behaviour of natural reefal and coastal processes, and allows prediction of the expected severity of natural events with a particular likelihood of occurrence. Long-term and short-term data are useful in understanding variations in environmental conditions, and in evaluating the likely effect of natural processes on the development, and the effect of the development on the natural system. Likely changes in development pressures and environmental impacts over time, and the likely success of designs and mitigation measures in withstanding environmental loads or minimising environmental impacts, can also be predicted. Where it is available for the region or locality, long-term historical information on wind, wave and current characteristics, provides some context for the hydrodynamic conditions that apply for design of the pontoon facility (Chapter 5). Ecological and bathymetric information, obtained over the life of the facility, provides a short-term data record, from which to monitor, assess and manage the environmental impacts of the pontoon (Chapter 10).

Project phases

The site investigation and characterisation activities, undertaken by or on behalf of the proponent, should be phased throughout the project in conjunction with other project activities, in the manner described in Chapter 3 (Boxes 3.2 - 3.4). Whereas the **Concept Phase** assessment would normally relate to issues such as proximity to port, sheltering, ecological integrity and aesthetic value, the **Feasibility Phase** would relate to facility requirements for moorings, waste treatment etc. The **Implementation Phase** may involve more detailed or supplementary

investigations related to detailed design and installation of the facility, while the physical and biological condition of the site after installation will be important in the ***Operation, Monitoring and Review Phase***.

The phased approach to site investigation and characterisation allows the proponent's project manager to carefully scope and schedule site assessment activities within each of the principal data areas. This produces a better administrative and technical outcome for the project. Progressive site assessment can minimise early project costs, which is particularly important when a project does not proceed to implementation, and when extensive site investigations are required for a complex project. A phased assessment can provide technical information at the most relevant time in a project, thereby minimising the likelihood of having to repeat site visits and assessments that may have been undertaken before the full assessment requirements were known. On the other hand, where the logistics for repeat establishment on site are particularly difficult, or where minimal overall investigations are required for simple projects, it may be best to undertake the site investigation and characterisation in a concerted manner without phasing.

Data acquisition, limitations and priorities

Site assessment activities and site investigation methods, undertaken by or on behalf of the proponent, will vary according to the project. They may include a review of historical data and previous studies, primary data collection from field investigations, and physical or mathematical modelling. Site visits and inspections are important. Joint inspections involving the proponent, the marine management agency representative (GBRMPA or QPWS), and members of the interdisciplinary project team, can be particularly valuable. Aerial inspections or inspections by boat may be undertaken.

Interdisciplinary input from hydrodynamic and geotechnical engineers, marine engineers/naval architects, marine biologists, planners and other practitioners is often necessary in site investigation and characterisation. The site assessment program is likely to contain some specialist activities and data acquisition that must be undertaken only by these trained professionals. Nevertheless, the proponent's project manager will be able to acquire much of the information required for general multidisciplinary needs across the project. Aerial photographs and bathymetric surveys, for example, will commonly be used by several disciplinary groups within the various planning and design tasks. The project manager should sequence data acquisition activities and analyses to ensure that results are available for project team members at the appropriate time, thereby avoiding duplicated effort. Joint site inspections involving the proponent, designers, GBRMPA and QPWS or others should be scheduled, where possible, to coincide with acquisition of key site data (eg. bathymetry, ecology). The range of general data requirements, and alternative sources and methods of acquisition are presented in Box 4.1.

Data will be available in various formats and may be assembled from many sources at different times with varying reliabilities. Examples are old documents, microfilm or fiche, computer disc, and the Internet. The quality of data is important for the planning and design of tourist pontoons. Users should assess the suitability of available data and consider the possibility and cost of replacing or expanding them with more reliable or more extensive information. Investment in quality data and long-term data programs is an investment in reducing project uncertainty or risk, resulting in more appropriate design criteria and parameter selection, and a reduction in capital costs and the likelihood of expensive failures. Where original data are to be acquired for a project, the proponent and designer should consider the long-term value of the data for future public or private uses and ensure that the appropriate scientific method is applied, incorporating adequate quality control and archival procedures.

In recognition of budget limitations and technical constraints that often apply to the amount and types of data that can be collected, site assessment should focus on the most important issues. Provided the reliability of the data and the predictability of the impact are clearly identified, the amount of information should be limited to manageable levels, sufficient to allow planning, design and implementation to meet project objectives. In prioritising data collection, the minimum requirement is to obtain the data necessary to explain the mechanisms or processes that affect site conditions. For example, in smaller projects at low conservation value sites that are well protected from severe wind and wave conditions, it may not be necessary to conduct sophisticated ecological or hydrodynamic studies.

Common sense and practical considerations should guide selection of the quantity of data and the extent of data analysis required for a pontoon project. Assessment requirements are very site-specific and depend upon the nature of both the project and the local environment. Although no prescriptive guides can be given to suit every situation, the scope of work and the general approach presented below for each of the principal data areas are useful starting points. The scope of these *Guidelines* does not allow detailed procedures for site investigation and characterisation to be defined.

Box 4.1 General data requirements for site assessment	
Data description	Alternative data sources and methods
Aerial photographs and remotely-sensed images	Government mapping agencies (eg. Sunmap) Private mapping agencies Fishing and tourism industry organisations Other pontoon operators
Photographic and video records of the site	Recent site inspections GBRMPA Local library Other pontoon operators Reports on environmental conditions Project development proposals
Oceanographic charts, navigation charts and shipping routes	Government mapping agencies (eg. Sunmap) Fishing and tourism industry organisations Local coast guard or boat club
Bathymetric surveys	Government mapping agencies (eg. Sunmap) GBRMPA Reports on environmental conditions or project development proposals
Historic field inspection reports and other site, local or regional data	GBRMPA Archives and newspapers at the local library Other pontoon operators Reports on environmental conditions Project development proposals
Proximity and type of adjacent installations	GBRMPA Other pontoon operators Project development proposals
Plans and drawings of existing installations	GBRMPA Other pontoon operators Project development proposals
Geographic information systems (GIS) or other data bases	GBRMPA Fishing and tourism industry organisations
Anecdotal information and local knowledge	Other pontoon operators Fishing and tourism industry operators Other stakeholders

4.2 Meteorology, physical oceanography and hydrodynamics

Planning and design of reef and coastal infrastructure projects, such as tourist pontoons requires regional and local scale knowledge of meteorology (eg. wind, rainfall and temperature), physical oceanography/geomorphology (eg. sedimentology, reefal and coastal form and process), and hydrodynamics (eg. waves, water levels and currents). A summary of potential data requirements, and alternative sources and methods of acquisition is presented below (Box 4.2). Box 4.3 indicates the likely site investigation and characterisation tasks related to hydrodynamics for each of the project phases and steps in the *10-Step Planning, Design and Implementation Procedure* (Chapter 3, Box 3.2) and *Project Planning and Design Task Schedule* (Chapter 3, Box 3.3). The manner in which these data are used to determine environmental loading conditions is described in Chapter 5. Some form of predictive modelling is usually necessary to supplement historical data and provide sufficient data for design.

Box 4.2 Potential meteorology, physical oceanography and hydrodynamic data requirements	
Data description	Alternative data sources and methods
Winds Wind velocity and direction over water and land	<i>AS 1170 Wind Code</i> Bureau of Meteorology data files Other published wind data Field observations and measurements
Waves Wave height, period, direction and recurrence interval	<i>Atlas of Tropical Cyclone Waves in the Great Barrier Reef</i> Computer modelling and prediction Historical observations Field observations and measurements
Currents Current speed and direction (local wind; tidal; flood; wave generated; regional; inter-reefal; continental shelf and oceanic)	Reef and ocean charts Computer modelling and prediction Field observations and measurements
Water levels Tides; wave set up; storm surge	Tide tables Charts and atlases Computer modelling and prediction Field observations and measurements

Meteorological information for the site may be required during various phases of a pontoon project, from *Concept* through to *Operation, monitoring and review*. Wind data will be useful in site selection (*Concept Phase*) and in determination of structure loads (*Feasibility Phase*). Rainfall and temperature data may be used in detailed design of facility components (*Implementation Phase*) and in developing operation and maintenance schedules (*Operation, monitoring and review Phase*). Geomorphological assessment may be undertaken during site selection in the *Concept Phase*, although, at most, it is only likely to involve a rudimentary investigation of coral reef composition and stability, and sediment type, distribution and movement. More detailed geomorphological studies of regional and local reef processes may be warranted for major reefal and coastal projects situated in dynamic environments.

Knowledge of waves, currents and water levels for cyclonic, storm and normal operating conditions is fundamental to the design of floating structures, such as tourist pontoons constructed on the GBR. These hydrodynamic characteristics are difficult to determine accurately, and data on the historical occurrence of cyclones are limited in offshore areas and at specific reef sites. Hydrodynamic processes are complex across the continental shelf, the shallow coastal sea and the matrix of coral reefs, where complicated dissipation, refraction and diffraction conditions apply. Waves, tides and currents interact with the coral reefs and are affected by the degree of protection and sheltering, propagation through channels, and transmission over reefs. Bathymetry in the vicinity of coral reefs is very different from that of beaches, and the abrupt change from deep to shallow water over the reef provides a different interaction to that in the sloping, shallow water environment of mainland beaches.

A number of spatial scales are relevant for wave measurement and modelling in the reef environment: 1) synoptic - outside the reef; 2) outer reefal/coastal; 3) reef groups - open reef areas within the reef matrix; and 4) the reef crest/lagoon. The *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Chapter 5) provides statistical data on wave frequency, magnitude and direction down to the third tier, (the open reef area scale). The designer can use outputs from the wave atlas modelling to predict wave conditions for a suite of events likely to affect a proposed pontoon facility. In complex reefal areas, the designer may need to refine predictions of hydrodynamic conditions to take account of the structure's location relative to the reef, local bathymetry, wave diffraction around the reef, and wave transmission and dissipation over the reef. The wave atlas data can be used as boundary conditions for this finer scale wave modelling.

Some hydrodynamic assessment of the magnitude and frequency of waves, water levels and currents will commonly be undertaken in each of the *Concept*, *Feasibility* and *Implementation* phases (Box 4.3). Concept level investigations will usually involve rudimentary estimates of prevailing and extreme conditions for site selection and choice of facility type. Detailed hydrodynamic studies are usually undertaken in the *Feasibility Phase* to determine loads on structures and anticipated movements under prevailing and extreme conditions. These hydrodynamic loads may also be used in detailed design of the pontoon structure in the *Implementation Phase*. The scope of the hydrodynamic investigations and characterisation for pontoon upgrades or retrofits should be tailored to suit the scope and nature of the project.

Box 4.3 Indication of project phasing for Hydrodynamics site assessment tasks <i>refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3, Box 3.2); Project Planning and Design Task Schedule (Chapter 3, Box 3.3); and Design Environmental Loads (Chapter 5)</i>	
Purpose	Task Description
Phase 1 Concept	
Step 1 Initial Concepts Initial assessment of wind, wave and current characteristics to consider exposure and amenity conditions for alternative sites.	Gain initial understanding of hydrodynamic characteristics at the alternative sites from Bureau of Meteorology data files, charts and tables, and the <i>Atlas of Tropical Cyclone Waves in the Great Barrier Reef</i> .
Step 2 Concept Design Preliminary assessment of wind, wave, water level, tide and current characteristics for site selection and choice of facility type for new projects, and for initial assessment of mooring system requirements for new and upgraded projects.	Conduct inspection of the preferred site by boat – possibly a joint visit involving the proponent, designers, GBRMPA and QPWS. Obtain estimates of wave, wind and current frequency, magnitude and direction at the preferred site from the <i>Atlas of Tropical Cyclone Waves in the Great Barrier Reef</i> , the <i>Wind Code</i> etc.
Step 3 GBRMPA Preliminary Assessment Preliminary technical review of concept designs relating to sheltering, tropical cyclone design loading etc.	Confirm wave, wind and current conditions from the <i>Atlas of Tropical Cyclone Waves in the Great Barrier Reef</i> and other sources, engaging expert assistance as required.
Phase 2 Feasibility	
Step 4 Feasibility Design Detailed hydrodynamic studies used to determine structure loads and movements of the facility under prevailing and extreme conditions.	Obtain estimates of wave, wind and current characteristics from the <i>Atlas of Tropical Cyclone Waves in the Great Barrier Reef</i> , the <i>Wind Code</i> etc. Refine estimates for waves, if necessary, using fine scale wave modelling to take account of reef location, local bathymetry, wave diffraction, transmission and dissipation.

Step 5 GBRMPA Detailed Assessment Design audit and technical review of design operating conditions for winds, waves and currents, and for tropical cyclone design loadings.	Confirm wave, wind and current conditions from the <i>Atlas of Tropical Cyclone Waves in the Great Barrier Reef</i> and other sources, engaging expert assistance as required.
Phase 3 Implementation	
Step 6 Detailed Design Limited hydrodynamic design and site assessment related to specific components of the adopted scheme.	Conduct specialist, fine-scale studies of wave, wind and current characteristics, if required. Deploy current measurements on site if critical to design conditions.
Step 7 Baseline Monitoring	No significant activities.
Step 8 Construction & Installation	No significant activities.
Phase 4 Operation, Monitoring and Review	
Step 9 Performance Monitoring	Record wind, wave and current data on site in accordance with monitoring plan.
Step 10 GBRMPA Performance Review	No significant activities.

4.3 Site bathymetry

Bathymetric information for the site is important in site selection of a new facility, and in the configuration, layout, design and installation of a new or modified facility. Rudimentary hydrographic surveys will usually be adequate for preliminary assessment in the *Concept Phase*, whereas control surveys and more detailed bathymetric information will be necessary for detailed studies in the *Feasibility Phase* and for installation in the *Implementation Phase*. A summary of potential data requirements, and alternative sources and methods of acquisition is presented below (Box 4.4). Box 4.5 indicates the likely site investigation and characterisation tasks related to bathymetry and site set out for each of the project phases and steps in the *10-Step Project Planning, Design and Implementation Procedure* (Chapter 3, Box 3.2) and *Project Planning and Design Task Schedule* (Chapter 3, Box 3.3).

Box 4.4 Potential bathymetry and site set out data requirements	
Data description	Alternative data sources and methods
Substrate plan position, elevation and depth – reef scale (1000m) Water depth; water level variation; reef shape and slope	Airborne radar Photogrammetric survey Shipborne sonar Bathymetric chart of surrounding waters
Substrate plan position, elevation and depth – local scale (100m) Water depth; water level variation; reef shape and slope; reef structure and orientation	Tape, staff and rod measurements Compass Triangulation from fixed points Offsets from datum line Underwater video
Structure plan position, elevation and depth – local scale (100m) Fixed structure; underwater hazards or obstructions; investigation pit; test reference point	Tape, staff and rod measurements Compass Triangulation from fixed points Offsets from datum line Underwater video
Site set out Datum lines; control points; marker pegs	Driven steel posts Wire lines Marker buoys
Navigation conditions to site Minimum water depth on waterway; shipping lines and approach lines; underwater obstacles; restrictions on use of waterways	Navigation charts

The basic hydrographic survey will record the water depth at the site and the tidal range. More detailed bathymetric surveys should incorporate topographic details of the ocean floor, existing structures and underwater features, hazards or obstructions. The location and dimensions of particular subsurface ecological and geotechnical features such as coral, seagrass beds and foundations should also be recorded. This will include the type and density of coral, and the seabed type, eg. sand (Sections 4.4 and 4.5). Survey control points with buoy markers should be established for site reference and location.

Various methods and degree of detail may be used in developing site bathymetric information and compiling plans. Depending on the desired scale, this ranges from airborne radar and photogrammetric survey, to shipborne sonar, and underwater grid survey with marker lines for horizontal and vertical control. Video is often used to record the type and extent of coral cover along the location of proposed pontoon mooring legs. In critical locations, a 3-dimensional physical model of the site with the pontoon installed may be constructed to determine the design configuration, and for demonstration purposes.

Proponents and designers will use the hydrographic information to prepare a bathymetric plan for the site. The plan will be used during project planning and design to configure the pontoon and mooring to suit coral cover and other substrate conditions. The marine management agency will refer to the plan for design and installation approvals, and the installation contractor will also use the bathymetric mapping during the installation of moorings and other hardware. The scope of the bathymetric survey and site set out for pontoon upgrades or retrofits should be tailored to suit the project and the suitability of existing information and control surveys.

Elevations for the bathymetric surveys are usually referred to a low water datum such as Mean Low Water Mark (MLW), Indian Springs Low Water (ISLW), Lowest Astronomical Tide (LAT) or Chart Datum (CD). A common elevation datum is essential for each project. Care should be taken when comparing historical elevation data from older maps and charts, which may use various other datums. Consistent map projections and grid coordinate origins should be adopted, as various azimuth datums, such as the true, magnetic or grid north meridian, are sometimes used for projects.

The scope and method of the survey should be chosen to suit the site characteristics and the required level of detail. For example, survey is difficult for deep-water, steep-sided reef conditions compared with shallow, flat-bottom sites. Notwithstanding, the mooring designer should visit the site and inspect the underwater conditions, at least by snorkelling, but preferably by diving. Verbal advice from divers is usually inadequate for design.

Box 4.5 Indication of project phasing for Bathymetry and site set out site assessment tasks <i>Refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3, Box 3.2); and Project Planning and Design Task Schedule (Chapter 3, Box 3.3)</i>	
Purpose	Task Description
Phase 1 Concept	
Step 1 Initial Concepts Confirm basic site bathymetric information at prospective sites for new projects, or re-evaluate site conditions for project upgrades.	Conduct reconnaissance survey of alternative sites by boat. Conduct underwater investigation of alternative sites including rudimentary depth and location measurements for coral and other substrate. Place location marker (eg. buoy) at the preferred site.
Step 2 Concept Design Obtain preliminary bathymetric information for the preferred site, necessary for confirmation of site selection, preliminary configuration and layout of the facility.	Conduct inspection of the preferred site by boat – possibly a joint visit involving the proponent, designers, GBRMPA and QPWS. Establish survey control markers and buoys as reference datum for bathymetric survey data. Conduct preliminary underwater survey over approx. 100m x 100m area, including water depth and seafloor physiography at approx. 20m grid centres, and location and depth of major coral outcrops. Prepare preliminary bathymetric plan showing water depths, basic seafloor physiography and location of major coral outcrops relative to the survey control lines.
Step 3 GBRMPA Prelim Assessment	Examine and use bathymetry and site out data in assessment, where necessary.
Phase 2 Feasibility	
Step 4 Feasibility Design Obtain detailed bathymetric information for the chosen site, necessary to define the configuration and layout of the facility.	Conduct inspection of the chosen site by boat – possibly a joint visit involving the proponent, designers, GBRMPA and QPWS. Confirm survey control markers and buoys established as reference datum for bathymetric survey data and future location and orientation of the pontoon, moorings, anchors and other facilities. Conduct detailed underwater survey over approx. 100m x 100m area (using line transects or grid survey at approx. 5m centres), including water depth and seafloor physiography, and location and size of major coral outcrops. Prepare detailed bathymetric plan showing location and level of all substrate, coral outcrops, structures and other features relative to the survey control lines. Construct physical model of the site and the installed pontoon, if required in special situations.
Step 5 GBRMPA Detailed Assessment	Examine and use bathymetry and site out data in assessment, where necessary.
Phase 3 Implementation	
Step 6 Detailed Design Limited site assessment may be required to confirm bathymetric and substrate conditions related to pontoon configuration and mooring and anchor design.	Conduct supplementary underwater survey, including water depth and seafloor physiography, as required. Update bathymetric plan with supplementary survey data, shown relative to the survey control lines.
Step 7 Baseline Monitoring Obtain baseline bathymetric information in accordance with the requirements of the environmental monitoring program.	Measure and record the existing physical environment that may affect, or be affected by the proposal. Update bathymetric plan with baseline monitoring data, shown relative to the survey control lines.
Step 8 Construction & Installation Limited site assessment to set out the components of the facility, and more detailed bathymetric information to assist in finalising the location of moorings and other hardware.	Conduct supplementary control surveys and mark out the pontoon facility on the sea bed, as required. Record the physical condition of the site during installation, note any modifications made to the pre-installation condition, tie in to the baseline survey, and reconcile with the environmental monitoring program.
Phase 4 Operation, Monitoring and Review	
Step 9 Performance Monitoring	No significant activities
Step 10 GBRMPA Performance Review	No significant activities

4.4 Ecology

Ecological assessment will be relevant during various phases of a pontoon project, from *Concept* through to *Operation, monitoring and review*. The ecological significance of alternative sites will govern initial concepts for the project and determine site selection. Specialist input is required early in the *Concept Phase* to determine the scope of ecological assessment that may be required for the project. For example, an initial site inspection and identification of suitable coral substrate may confirm site suitability, whereas detailed ecological assessment of other aspects may be deferred until the *Feasibility Phase* if that information is not critical to the initial choice of options. A summary of potential data requirements and alternative sources and methods of acquisition is presented below (Box 4.6). Box 4.7 indicates the likely site investigation and characterisation tasks related to ecology for each of the project phases and steps in the *10-Step Project Planning, Design and Implementation Procedure* (Chapter 3, Box 3.2) and *Project Planning and Design Task Schedule* (Chapter 3, Box 3.3).

Box 4.6 Potential ecological data requirements	
Data description	Alternative data sources and methods
Coral condition and cover For impact assessment and other studies	Still photos and videos <i>In situ</i> quadrats Tagged corals Insitu transects, eg. line intercept transects Video belt transects Anecdotal notes from log books
Map of corals under and adjacent to pontoon Spatial distribution of coral type, shape and condition before and after impact to provide qualitative estimates of the change of amenity at the site	Underwater inspection and photographic survey before and after impact Photographs of tagged individual corals Photographs or video of quadrats Video transects – estimate % cover from point intercepts on still video frames
Cover by hard and soft corals Estimates of percent cover of coral types at various taxonomic resolutions	Gross identification as hard or soft corals Identification to species level and genus and life form Lump into families for analysis Size structure of populations of some families Levels of damage and height of corals
Benthic organisms Abundance on main coral outcrops located beneath and adjacent to the pontoon (greater than 95% of all benthic organisms are corals)	Record visible sessile benthic organisms and analyse where appropriate Identify benthic organisms to genus and species level where possible Taxa may be pooled for higher levels of analysis
Fish aggregations Size and composition of fish aggregations at or adjacent to the pontoon, providing a summary of spatial and temporal patterns in fish communities before and after impact	Total counts of fish aggregations Maximum size and composition of aggregations Fish census along transect at pontoon and at control sites Aggregation of large mobile fish (visually obvious species > 15 cm long) beneath immediate pontoon area Small benthic-associated fish on main bommies beneath and adjacent to the pontoon Undertaken on consecutive days on several occasions prior to and after potential impact
Mooring line and anchor block movement Effects of movement on coral substrate over the extent of the mooring line or other mooring component	Use reference nails on hard substrate and steel bar in the sand

The purpose of describing the ecological characteristics of the site is to evaluate the conservation value of the site, to map the distribution and nature of the coral substrate, and to assess the impact of the proposed project on ecological processes and values. These assessments then provide input to the selection of appropriate designs for the site, such as the mooring layout, which is dependent on the local coral reef environment.

Whilst the attention for ecological assessment will often focus on the immediate site, a broad view is necessary to assess the importance of the site in relation to the overall characteristics of the region. Marine ecosystems are large and interconnected and, although the effects of a pontoon installation on regional biology are unlikely to be significant, they must be considered. Ecological investigations should be undertaken within the regional context and should include description of the surrounding region at scales ranging from the immediate vicinity of the site (usually tens of metres) to regional scales of tens of kilometres. The level of detail required will decline with the increase in spatial coverage of the assessment. Biological data is seldom available over any extended period for many sites on the GBR. The *State of the Great Barrier Reef World Heritage Area* report (GBRMPA 1997) provides some baseline data for future comparison, but few reliable data are available at most sites to assess the natural variability of marine ecosystems, let alone their tolerance to disturbance by human activities. Information may be available when facility upgrades are proposed at existing pontoon sites where ecological surveys have been undertaken previously.

The ecological investigations for tourist pontoons are commonly part of an operator-funded monitoring program that includes baseline and performance monitoring of the biological environment affected by the pontoon (Chapter 10). The environmental monitoring program must comply with the GBRMPA protocol for tourist pontoons and will normally concentrate on the direct impacts of the pontoon on benthic assemblages (mostly corals), fishes and water quality.

Box 4.7 Indication of project phasing for <i>Ecology</i> site assessment tasks <i>refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3, Box 3.2); and Project Planning and Design Task Schedule (Chapter 3, Box 3.3)</i>	
Purpose	Task Description
Phase 1 Concept	
Step 1 Initial Concepts Confirm suitable reef condition at prospective sites for new projects, or re-evaluate site conditions for project upgrades.	Conduct reconnaissance survey of alternative sites by boat. Conduct underwater investigation of alternative sites, including some basic information on the type, location and extent of coral cover, and other ecological characteristics.
Step 2 Concept Design Obtain basic ecological characteristics of the preferred site, necessary for confirmation of site selection, preliminary configuration and layout of the facility; and to assess ecological effects such as shading or disturbance to coral.	Conduct inspection of the preferred site by boat – possibly a joint visit involving the proponent, designers, GBRMPA and QPWS.
Step 3 GBRMPA Prelim Assessment	Examine and use ecology data in assessment, where necessary.
Phase 2 Feasibility	
Step 4 Feasibility Design Obtain detailed ecological characteristics of the chosen site related to facility design, including pontoon and mooring location relative to coral cover and other substrate conditions.	Conduct detailed ecological assessments, including field, laboratory and desk studies.
Step 5 GBRMPA Detailed Assessment	Examine and use ecology data in assessment, where necessary.
Phase 3 Implementation	
Step 6 Detailed Design Limited site assessment may be required to confirm coral substrate conditions relevant to pontoon configuration and mooring and anchor design.	Conduct supplementary ecological surveys as required.
Step 7 Baseline Monitoring Obtain baseline ecological data in accordance with the requirements of the environmental monitoring program.	Describe the existing biological environment that may affect, or be affected by, the proposal (Chapter 10).
Step 8 Construction & Installation Limited site assessment, including more detailed ecological data to assist in finalising the location of moorings and other hardware.	Conduct supplementary ecological surveys, as required. Record the biological condition of the site during installation, note any modifications made to the pre-installation condition, tie in to the baseline survey, and reconcile with the environmental monitoring program.
Phase 4 Operation, Monitoring and Review	
Step 9 Performance Monitoring Obtain ecological data relating to operation of the facility in accordance with the requirements of the environmental monitoring program.	Record the biological condition of the site during pontoon operation, note any modifications and tie in to the baseline survey (Chapter 10).
Step 10 GBRMPA Performance Review	No significant activities

4.5 Geotechnical/substrate aspects

Geotechnical investigations are important in determining the design and construction conditions for anchors and foundations for structures in the coral reef environment. Geotechnical/substrate properties of coral reef areas are complex and difficult to predict due to their extremely heterogeneous structural characteristics. In many instances, reefs provide poor foundations for engineering structures, as the coral reef structure frequently incorporates cavities and loosely packed sands and gravels.

Some form of site-specific geotechnical investigations is, therefore, recommended for the planning and design of pontoon projects. These investigations improve the reliability and confidence in determining anchor load capacities, reduce the likelihood of damage to the installation due to mooring failure, improve understanding of the geotechnical characteristics of the reef environment, and contribute to the (presently) very sparse database on reef conditions and engineering properties. A summary of potential data requirements, and alternative sources and methods of acquisition is presented below (Box 4.8). Box 4.9 indicates the likely site investigation and characterisation tasks related to geotechnical aspects for each of the project phases and steps in the *10-Step Project Planning, Design and Implementation Procedure* (Chapter 3, Box 3.2) and *Project Planning and Design Task Schedule* (Chapter 3, Box 3.3). For further information on geotechnical characteristics relevant to anchor design, refer to Chapter 8.

Box 4.8 Potential geotechnical/substrate data requirements	
<i>Note: Data methods denoted '**' may be used for a standard pontoon installation with deadweight, drag embedment or screw anchors; other methods listed are not commonly used but may be employed in projects with major foundation requirements, eg. piles and caissons</i>	
Data description	Alternative data sources and methods
Substrata profiling	Shallow probing or excavations with shovel or bar ** Rotary or cored drilling Seismic refraction
In situ properties	Shallow probing or excavations with shovel or bar ** Standard Penetration Test in conjunction with drilling Heavy dynamic or hand driven penetrometer Static (Piezo) cone
Sampling	Shallow excavations with shovel or grab bucket ** Disturbed samples recovered from returned drill cuttings or test holes Intact samples recovered from undisturbed tubes, core barrels or manually pushed tubes
Material classification Index tests; grain size, mineralogy, carbonate and organic content; % calcareous composition	Particle size distribution, Atterberg limit Particle density test Chemical reaction to sulphuric acid
Strength properties	Triaxial and direct shear tests

A phased assessment approach is recommended, in which the designer obtains some preliminary indication of geotechnical characteristics through preliminary assessments undertaken in the *Concept Phase*. This will usually include some rudimentary underwater investigation that will help identify the need or otherwise for subsequent, more detailed geotechnical investigations. Bathymetric surveys and any geomorphological site assessments undertaken early in the project will assist in the *Concept Phase* assessments. If extensive geotechnical site assessment is to be undertaken in complex projects, this will usually occur in the *Feasibility Phase*. Some specialist field testing and laboratory testing may also be conducted in the *Implementation Phase*. The results of the *Concept Phase* investigations will be useful in determining the subsequent activities, in establishing suitable access methods, in identifying expected material types, in selecting appropriate techniques and equipment, and in choosing the appropriate extent of test holes that may be undertaken.

The scope and method of the geotechnical investigation to be undertaken for a particular project depends on the type of anchor system that is to be used and the approach selected for anchor design (Chapter 8). The **Surface Assessment** method for anchor holding capacity uses a rudimentary investigation without obtaining detailed geotechnical data for the substrate prior to design and installation. This approach is usually appropriate for **deadweight** anchors and **drag embedment** anchors, and is sometimes used for embedded foundations such as **screw anchors**. The **Intrusive Assessment** method involves subsurface foundation investigation and may include geotechnical drilling of the substrate. This approach is usually appropriate for **screw anchors**, **piles** or **driven anchors**.

Whether to undertake extensive substrate geotechnical investigations or to rely merely on conservative estimates of load capacities, is an economic decision for the pontoon operator and designer. This is a trade off between the investigation cost of obtaining the geotechnical information before design and installation, and the increased capital cost of providing a conservative type of anchorage system. The decision depends on the scale and significance of the installation. As with most geotechnical assessments, contingency allowances must be made for unexpected results during investigation and installation.

Box 4.9 Indication of project phasing for Geotechnical/substrate site assessment tasks <i>refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3, Box 3.2); and Project Planning and Design Task Schedule (Chapter 3, Box 3.3)</i>	
Purpose	Task Description
Phase 1 Concept	
Step 1 Initial Concepts	No significant activities
Step 2 Concept Design Obtain basic geotechnical characteristics of the site, necessary for confirmation of site selection, preliminary configuration and layout of the facility.	Conduct inspection of the preferred site by boat – possibly a joint visit involving the proponent, designers, GBRMPA and QPWS. Conduct underwater inspection and undertake rudimentary geotechnical investigation of substrate using hand sampling or probing equipment.
Step 3 GBRMPA Prelim Assessment	No significant activities
Phase 2 Feasibility	
Step 4 Feasibility Design Obtain detailed geotechnical characteristics of the chosen site, where required for mooring and anchor design.	Conduct detailed geotechnical assessments, including subsurface investigations, where appropriate.
Step 5 GBRMPA Detailed Assessment	Confirm geotechnical conditions if necessary, engaging expert assistance as required.
Phase 3 Implementation	
Step 6 Detailed Design	No significant activities
Step 7 Baseline Monitoring	No significant activities
Step 8 Construction & Installation	No significant activities

4.6 Recommended reading

Atlas of Tropical Cyclone Waves in the Great Barrier Reef. Available at: <http://tsunami.jcu.edu.au>

5 DESIGN ENVIRONMENTAL LOADS

	Summary
5.1	Design approach: Acceptable risk
5.2	Design winds
5.3	Design waves
5.4	Design currents
5.5	Design water levels
5.6	Recommended reading

Summary

Engineers and marine architects need accurate information on environmental forces for sustainable design of reef pontoons. Managers, as well as designers, need information on the severity of environmental forcing that is appropriate for design.

- A risk-based design is advocated, defined and recommendations for design encounter probabilities are given.
- Guidance for the appropriate calculation of the environmental design inputs is given
 - wind speed and direction
 - wave height, period and direction
 - current speed and direction
 - water level

Loads to be considered in the design of a floating pontoon and its mooring system comprise: loads imposed by the environmental conditions; loads exerted by the structure itself and its contents; and loads applied by any adjoining/attached facilities. These load components are used to assess and design the pontoon facility to ensure adequacy of the mooring system, structural integrity of pontoon elements, stability, buoyancy and safe operations. Components of the loads can be grouped as follows:

Environmental Loads (this chapter)

Wave forces are typically larger than wind forces for moored tourist pontoons. The relative magnitude depends on the site, with the importance of waves increasing at more exposed locations. Both wave and wind forces are typically much larger than current forces, but again this is location specific.

Component	Characteristics
Winds Waves Currents	Loads will be determined according to the likely intensity and direction of maximum winds, waves and currents experienced during normal operating conditions at the site and the intensity of cyclonic conditions that may occur in extreme events.
Water levels	While not constituting an applied load as such, the design water level has a strong influence on the nature of wave loading and the response characteristics of the mooring system, and hence is crucial in design. It also critically affects design clearances and vessel draught requirements.

Dead and Live Loads (Chapter 9)

Fixed loads	Self-weight of the pontoon members and elements, including any attached facilities.
Hydrostatic forces	Water pressure exerted on the hull of the pontoon.
Varying loads	Relating to storage of materials, equipment, visitors & staff and contents of storage vessels. Also includes growth of biological organisms on the pontoon hull.
Berthing loads	Impact forces generated by visiting & tender craft.
Water on the deck	Additional weight contribution.
Flooding in damaged condition	Additional weight contribution.

Methods and procedures to be used to estimate the magnitude of each environmental load component are defined in this chapter. Dead and live loads are discussed in Chapter 9. In some instances separate design load intensities will be derived, to be applied for different design states and at different scales (e.g. for individual member design or for entire force exerted on the pontoon for mooring design). Consequently, more than one design load may be defined for each of the load components listed above.

Design states for Environmental Loads

In the following sections, three principal design states, *operational*, *non-cyclonic*, and *cyclonic*, are defined. Using mooring systems as an example, the pontoon may have a single or multiple systems. A single system must cope with all three design states, whereas, each configuration of a multiple system may be designed for a single design state. These states are defined as follows.

Maximum Operating Conditions	The maximum environmental forcing under which the facility would be expected to <i>remain fully operational</i>.
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This design state is intended not only as a means of ensuring the safety and comfort, but also ensuring the quality of the overall experience of users of the facility. For example, a pontoon may have above water structures (e.g. awnings) that are deployed only during operation, or mooring components that are designed for use only during normal operation. Maximum operating design criteria are used to prevent failure of the structures or mooring system while visitors are using the facility. Ecological damage from pontoon or anchor line movement should be negligible. Safety of visitors must be ensured.

Maximum Non-Cyclonic Conditions	The maximum non-cyclonic environmental forcing.
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This design state is established to prevent failure of the facility during severe non-cyclonic conditions. During this condition, it is unlikely that the facility would be either in full operation or secured for a cyclone. As this condition is likely to be commonly occurring (say, two year return period), anchor movement, structural damage, and ecological damage from pontoon or anchor line movement should be minimal. This design state may not apply to all facilities or to all components of one facility. For design of components that will remain unchanged during a tropical cyclone, cyclonic design inputs will prevail, and this design state may be inoperative.

Cyclonic Conditions	A design intensity of environmental forcing during tropical cyclones.
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Greater movements of the pontoon and its mooring lines can usually be tolerated in an extreme event, since these events are rare. However, the components and the system must still be designed to withstand the applied loads at a particular level of severity without excessive damage to the structure or the surrounding environment. As discussed in Section 5.2, this criterion is based on a risk analysis. The severity of the event is defined in terms of a nominated design encounter probability, which corresponds to an adopted level of risk. Structural and ecological damage will increase as this design level is exceeded. As the loading decreases below the criterion, structural damage will diminish and ecological damage will be restricted to defined zones/corridors.

Design inputs and design objectives

Environmental loads affect both the quality of experience of the visitor and the performance of the facility. Box 5.1 lists these experiences and performance attributes under various design objectives and relates each to the design state and the relevant environmental loading. The designer must meet the design objectives for site selection, coral viewing, snorkelling, SCUBA diving and boating areas, and in the design of the pontoon, auxiliary structures and the mooring system(s). Design criteria and constraints for the relevant design attributes are defined in Chapters 6 to 9.

Box 5.1 Design objectives and attributes, design states, and primary design forces								
Design objective	Design attribute	Design State			Primary Design Forces			
		Operating	Non-cyclonic	Cyclonic	Wind speed & direction	Wave height, period & direction	Current speed & direction	Water level
Serviceability, function and safety								
Visitor comfort in transit to pontoon site	Pitch and roll of boat	0				0		
Visitor safety in transfer between boats and structures	Relative movement of boats and structures	0			0	0		0
Visitor comfort on pontoon	Pitch and roll of pontoon	0			0	0		0
Safety and comfort of swimmers, snorkellers and divers	Forces on swimmers, snorkellers and divers	0			0	0	0	0
Structural integrity								
Integrity of mooring system(s)	Forces on pontoon	0	0	0	0	0	0	0
Integrity of above water structures	Forces on structures	0	0	0	0	0		
Environmental protection								
Movement of mooring lines	Movement of pontoon Dynamic action of lines	0	0	0	0	0	0	0
Shading of coral by pontoon	Positions of the pontoon during commonly occurring conditions	0			0	0	0	0

Box 5.1 is a template from which environmental design loading will be discussed. The primary environmental forces (wind, waves, currents, and water levels) are addressed in sections 5.5, 5.6, 5.7 and 5.8, respectively. In each section, the environmental forces will be discussed in terms of the three design states – *Operating*, *Non-Cyclonic* and *Cyclonic*.

5.1 Design approach: Acceptable risk

The operating and non-cyclonic design states discussed in the following sections are described in terms of *maximum* conditions during these states. The *Operating* state will often be determined by operator experience – when the winds are greater than a specified amount from specified directions, conditions are uncomfortable and the operator either goes to an alternative site or does not offer a trip that day. For the *Non-Cyclonic* state, a probability distribution is more applicable for design than it is for the operating state. However, the upper end of the magnitudes of the non-cyclonic forcing can be conservatively predicted without an unacceptable economic penalty, so it is not necessary to have a rigorous probabilistic assessment of design loads. The *Cyclonic* state is different. Tropical cyclones are infrequent and a design based on the most severe forces would make many pontoon installations uneconomic, as well as much less environmental friendly. A probabilistic assessment of design loads for cyclonic conditions is essential.

Historically, the determination of the severity of the environmental forcing to be used for engineering design has been handled in several ways. One method has been to specify predetermined values in a design code. Examples of this type of specification are the following: *The design wind speed shall be 45 m/s. The setback from the shoreline shall be 50 m. The minimum floor level shall be 1.0 m above highest astronomical tide.* It is a temptation for public planning and management agencies to set a standard design level for all projects. For example, state or local authorities might establish minimum setback distances or minimum ground floor elevations for coastal developments. They might expect *all* developments to adhere to this one standard. However, the consequences of flooding for a hospital, a house, a storage shed and a parking lot are vastly different. It is not sensible to require the same level of severity for the design criteria of these structures that vary greatly in importance.

Another technique often used for complex, multi-dimensional events is called the *design storm*. For example, the *probable maximum hurricane* and the *standard project hurricane* have been used in the USA for storm surge studies. A *category 4* tropical cyclone has been used for the design specification for pontoons in the GBR. Unfortunately, this criterion often does not adequately define the severity of the cyclone. The Safir-Simpson scale (categories 1 to 5) of severity of tropical cyclones is based on maximum wind speed (formerly central pressure) of the cyclone. Although central pressure of the storm is important, other parameters, such as radius to maximum winds and forward speed are also very important. Storm path relative to the project location is the most important parameter of all. The severity of the category 4 cyclone varies greatly with changes in the values of these unspecified parameters. Furthermore, if the criterion is applied as the most severe conditions (path, speed and radius) for a category 4 cyclone, then the criteria are most likely far too severe for pontoon design in the GBR. In short, the use of the design storm technique can lead to design levels with an unknown variability.

Risk – probability and consequence

The concept of risk is important for engineering design. Common usage of the term risk - to mean the chance or probability of an event - is *not* the definition that will be used here. We will define risk by multiplying the *probability* of the event by its *consequence*, and expressing the product in dollars. Consider the following example. Although the probability of a meteorite striking a hectare-sized area of a farmer's field is the same as the probability of it striking a hectare-sized nuclear power plant, the difference in consequences of these two events is enormous. Thus, these two events may have equal *probability* but unequal *risk*, because they have unequal *consequences*. For the reef situation, these guidelines recommend that the design criteria should vary with the consequence of failure. Thus different loading criteria (different *encounter probabilities*, see below) may be assigned for a large floating hotel, a multi-story tourist pontoon, a small day use pontoon and a helicopter landing pontoon, because the consequences of failure of these structures may vary widely.

It is not possible to be risk-free in any endeavour. Some level of risk must be tolerated. The users of these guidelines (management agencies, proponents and designers) may have different perceptions of risk. Although the design levels will often be specified by codes of practice or by the decree of a management agency, it is possible that the owner may desire more severe design criteria because of a greater perception of risk. For example, identical pontoons with identical environmental conditions but operated by different companies may have different risks associated with structural failure, since one pontoon may be the only facility for that operator, whereas the other operator may have several alternative destinations.

A risk analysis can be very expensive; therefore, a full risk assessment is usually limited to projects for which the consequences of failure are catastrophic (e.g. large dams and nuclear facilities). These *guidelines* advocate the consideration of risk, but not a full risk assessment, in the determination of design criteria. A more heuristic, qualitative assessment of risk is adopted. Box 5.2 presents some basic definitions and derivations of probability terminology.

Box 5.2 Background - Probability

Definitions of probability terminology

In what follows wave height will be used as the example parameter for which we desire magnitude versus frequency information. The reader could substitute wind speed, current speed, or water level for wave height in the following.

Probability of exceedance

Exceedance is defined as the occurrence of a magnitude that is *equal to or greater than* a specified value. Exceedances of a given wave height are assumed to generate a Poisson process. The Poisson process is commonly used to model the random occurrence of events, for example, the arrival of ships at a port, the failure of machinery, or storm surge levels at a point of the coastline. The number of exceedances of a wave height in a unit time (usually specified as a year) is assumed to follow the Poisson probability distribution given as

$$f(x, l_H) = \frac{e^{-l_H} l_H^x}{x!}, \quad 5.1$$

where x is the number of occurrences and l_H is the average annual frequency of exceedance of wave height, H , expressed as occurrences per year. But, the designer is not usually interested in the probability that a given level, H , is exceeded a fixed number of times, say 5. Instead, the probability that the level is equalled or exceeded at least once is calculated. This requires the calculation of the combined probability of all possibilities other than zero exceedances. The probability of zero exceedances *or* one or more exceedances is equal to 1.0, since this covers all the possibilities. Thus, the probability of at least one occurrence, the *annual exceedance probability*, P_e , (often named *AEP*) can be expressed as 1.0 minus the probability of zero exceedances or

$$\begin{aligned} P_e(h) &= 1 - f(0, l_h) \\ &= 1 - e^{-l_h} \end{aligned} \quad 5.2$$

If l_H is small, Equation 5.2 can be simplified using the first two terms of the power series expansion for the exponential function, resulting in

$$\begin{aligned} P_e(H) &= 1 - e^{-l_H} \\ &= 1 - \left[1 + (-l_H) + \frac{(-l_H)^2}{2!} + \frac{(-l_H)^3}{3!} + \dots \right] \\ &\approx l_H \end{aligned} \quad 5.3$$

Thus, for more severe wave conditions (return periods above about 10 years), the probability of exceedance (P_e) is approximately equal to the average annual frequency of occurrence (l_H).

Return period

The design wave height is often specified in terms of the *average* waiting time between wave heights *equal to or greater than* the specified value. Depending upon the importance of the structure being designed, the 50, 100, or 500 year values are among those commonly specified. These specifications are in terms of *return period*, R_H , (often called *Average Recurrence Interval* or *ARI*), which is defined (Equation 5.4) as the inverse of l_H .

$$R_H = \frac{1}{l_H} \quad 5.4$$

Encounter probability

The *encounter probability* of a given wave height can be defined as the probability that an *equal or greater* wave height occurs *within a given length of time*, often selected to be the *design life* of the facility. Calculating encounter probability gives the planner a more enlightening estimate of the chance that the design level will be exceeded than does the specification of return period alone, because the length of time

for which information is needed is explicitly included.

In the derivation of an expression for encounter probability, it is convenient to consider its complement, *nonencounter probability*. The probability of *not* encountering a wave height equal to or greater than a given level within L years is equal to the product of the probabilities of not exceeding the given level in each of the L years. Since the probability of *not* exceeding H is $1.0 - P_e(H)$, the nonencounter probability is given by

$$\begin{aligned} P_{NE}(H; L) &= [1 - P_e(H)]^L \\ &= \left[1 - 1 - e^{-\frac{1}{R_H}} \right]^L \\ &= e^{-\frac{L}{R_H}} \end{aligned} \quad 5.5$$

Nonencounter probability is easy to calculate because only one combination is possible: the wave height is not encountered in any of the L years. Encounter probability is more difficult because many combinations need to be considered. For example the wave height could be exceeded only in the 10th year, in all the years, or only in the 2nd, 7th, and 15th years, etc. All combinations have to be considered. Fortunately, encounter and nonencounter are the only two possibilities, so once nonencounter probability is calculated using Equation 5.5, encounter probability, P_E , becomes

$$\begin{aligned} P_E(H; L) &= 1 - P_{NE}(H; L) \\ &= 1 - e^{-\frac{L}{R_H}} \end{aligned} \quad 5.6$$

Table 5.1. Encounter probability (%) as a function of four project lives, $L = 10, 20, 50$, and 100 years and two return periods, $R = 100$ and 200 years.

L (years)	Encounter Probability (%)	
	$R = 100$	$R = 200$
10	9.5	4.9
20	18	9.5
50	39	22
100	63	39

For example, Table 5.1 shows that the 100-year wave height has an 18% chance of the being exceeded *at least once* during any 20 year period. Note that the probability of exceeding the 100-year wave height in 100 years is 63%, and not 100%, as might be assumed.

Recommended design probability for cyclonic conditions

A design probability should be appropriate to the risk associated with failure of the proposed structure. In order to estimate this probability, permanently moored tourism structures are ranked in five classes of increasing importance and thus increasing consequence of failure (Box 5.3). The first three classes (small, medium and large) are ranked by size and type of facilities. Examples are (small) helicopter pontoon, (medium) single story pontoon, and (large) multiple story pontoon. These three classes represent the majority of pontoon developments (circa 2000). Tourists will be present on structures of these three classes only during relatively mild conditions; therefore, the threat of severe injury or death during extreme environmental forces (i.e. tropical cyclones) is very unlikely. The main consequences of failure are (i) loss of use of the facility; (ii) damage to the facility; (iii) environmental damage to the site; (iv) cost of re-establishment (design, permitting, construction, installation and advertising); (iv) bad publicity affecting the owner, other operators, GBRMPA and World Heritage values; and (v) a small, but still possible, threat to shipping if components float free.

Classes *D* and *E* differ from the first three in that overnight visitors are expected. This increases the chance that the facility will be occupied during severe weather conditions; and therefore, increases the chance of injury and death. Moreover, class *E* (Floating Hotel) is likely to have extensive and expensive facilities that result in greater consequences of failure.

Recommendations for design encounter probabilities and equivalent return periods for five classes of pontoon facilities are given in Box 5.3. For example, a class *C* structure (typical of top-of-the-line facilities circa 2000) has a recommended encounter probability of 0.10 and a nominal design life of 30 years. This means that environmental forcing that equals or exceeds the design criteria has a 10% chance of occurring *at least once* during a thirty year period.

The nominal design return period incorporated in the draft wind code A1170.2 for terrestrial public buildings is 500 years. Box 5.3 recommends levels below this for the first three classes, since these structures are unlikely to be occupied during times when the design forces are encountered. For classes *D* and *E* the nominal return periods are longer than the land-based code. Occupants of terrestrial structures will have alternative shelter if an individual building fails. However, offshore structures have no such alternatives and rescue may be hours away, thus the necessity for stronger designs.

Box 5.3 Recommended design encounter probabilities and return periods for pontoon structures in the GBR						
Class		Description	P_E	L (yr)	R (yr)	Nominal R (yr)
A	Small (< 15 m)	no facilities no overnight staff or guests e.g. - helicopter pontoon	0.10	10	95	100
B	Medium (< 40 m)	usually single story limited facilities no overnight staff or guests	0.10	20	190	200
C	Large (> 40 m)	often multi-story medium to extensive facilities overnight caretakers no overnight guests	0.10	30	285	300
D	Overnight Visitors	any size less than about 20 overnight visitors	0.05	30	585	600
E	Floating Hotel	multi-story extensive facilities more than about 20 overnight visitors	0.05	50	975	1000
<i>P_E</i> is encounter probability, <i>L</i> is project life, and <i>R</i> is return period.						

5.2 Design winds

A designer of a reef-based pontoon requires wind information for several purposes. As well as creating forces directly on individual above-water structures and on the pontoon as a whole, winds also cause waves and currents.

Wind information is usually given in vector format. Both magnitude and direction are specified. The usual reference system for direction is *direction coming from*, so a southeasterly wind comes from the southeast and goes toward the northwest. Wind speed is given in knots, km/h or m/s. Table 5.2 gives conversion factors for speed. For example, a wind speed of 10 knots equals 18.5 km/h (10×1.852) and 5.14 m/s (10×0.514).

Table 5.2 Conversion factors between wind speed units

	knots	km/h	m/s
1 knot =	1	1.852	0.514
1 km/h =	0.540	1	0.278
1 m/s =	1.945	3.600	1

All wind speed specifications reflect averages over time, and different averaging periods are required for different uses of the wind information. Normally, design wind loads on a marine structure are based on a gust duration ranging from 3 seconds up to about 30 seconds. The selection of the relevant gust duration depends on the size of the unit being considered or its ability to respond to the wind gust. Typically, a 3-second gust duration is appropriate for determining the maximum static wind loads on individual members of a structure (c.f. design of terrestrial structures). A 15-second gust duration is appropriate for determining maximum total static wind loads on larger structures of a scale of 30 to 50 metres (API, 1987). See Chapters 7 and 9 for details of design. The two most common specifications of wind speed durations are ten minute (most field measurements such as automatic meteorological stations throughout the Coral Sea) and 3 second (wind code used for structural design, AS1170.2). The two columns in Table 5.3 allow conversion between these standards, as well as to other common specifications of wind durations. For example, a 10-minute average wind speed of 10 m/s implies a three-second gust speed of 12.6 m/s (10×1.26); a three-second gust of 30 m/s implies a 10-minute average wind speed of 23.7 m/s (30×0.79).

Table 5.3 Conversion factors between averaging periods of wind speed

	Convert from	
Convert to	10 Min.	3 s
10 minute	1	0.79
1 minute	1.11	0.88
15 second	1.19	0.94
3 second	1.26	1

Wind speed and direction also vary both horizontally and vertically. Wind speed varies with elevation in the boundary layer near to the Earth's surface; therefore, the elevation of the gauge and the elevation of the structure to be designed are both important. A standard elevation of 10 metres is usually adopted for measurement. In marine design it is customary to use the 10-m wind speed for all elevations below 10 m. If a more accurate estimate of wind speed at elevations below 10 m is required, adjustments can be derived in accordance with techniques outlined in references such as API (1987).

With respect to variation in the horizontal, the design wind can be the *local* wind (drag on structures and local water surface currents), the average over an up-wind length or *fetch* wind (wave prediction) or the *regional* winds (water current estimation).

The recommended values of duration and elevation of wind data for use in pontoon design are indicated in Box 5.4.

Box 5.4 Recommendations for wind parameter specification	
Duration of averaging period	
Wind drag on individual structural members	3 s
Wind drag on pontoon ¹	10 to 30 s
Wave and current prediction	10 min
Elevation of measurements	
Wind drag on individual structural members at all locations from sea level to 10 m	10 m
Wind drag on pontoon	10 m
Wave and current prediction	10 m
¹ see Chapter 7 for specifics	

Design winds - maximum Operating condition

Designers use design wind inputs under operating conditions (see Box 5.1) in considering serviceability, function and safety aspects of the facility, such as the comfort and safety of visitors on the pontoon, and while swimming, snorkelling or diving. The tabulation also indicates that designers need to know wind speed and direction in providing for the structural integrity of the mooring system and above water structures, and the tolerable movement of the mooring system under these conditions.

Box 5.5 How environmental loads are used in design: Winds – Operating conditions			
Design objective	How design winds are used	Criteria and method of calculation of design winds	Chapter
<i>Serviceability, function and safety</i>			
Visitor comfort in transit to pontoon site	Wind speed and direction for input to wave prediction.	No standard criteria – comparison with known conditions at other sites • Local knowledge • Site visits • Wave modelling	6
Visitor comfort on pontoon Visitor safety in transfer between boats and structures	Wind speed and direction for input to wave and current prediction.	No standard criteria – comparison with known conditions at other sites • Site visits • Wave modelling	6
Safety and comfort of swimmers, snorkellers and divers	Wind speed and direction for input to wave and current prediction.	No standard criteria – comparison with known conditions at other sites • Site visits • Wave and current modelling	6
<i>Structural integrity</i>			
Integrity of mooring system	Design of operational moorings. • Drag force on pontoon. • Input to calculation of wave and current forces	Maximum winds during operation ¹	7
Integrity of above-water structures	Design of structural members only present during operation. • Drag force on members.	Maximum winds during operation ¹	9

Environmental protection			
Movement of mooring lines	Design of operational moorings • Drag force on pontoon. • Input to calculation of wave and current forces	Maximum winds during operation ¹	7
Position of pontoon (shading of coral)	Design of operational moorings • Drag force on pontoon. • Input to calculation of wave and current forces	Common conditions during operation	7
¹ Once the limit of operations is determined based on the <i>serviceability, function and safety</i> criteria, then the maximum wind speed is determined.			

Selection of the design wind speed for the operating condition may be governed by either conditions at the site or conditions in transit from the mainland to the site. Usually it is not the direct wind forces that determine the limits of operation; it is more often the wind-generated wave energy and current speed that are the important items. The pitch and roll of boats and pontoons, and the current and wave effects on snorkellers and SCUBA divers, cause a level of discomfort or danger that determines the limiting criteria. It is not appropriate to stipulate a universal design wind speed in view of the many variables involved. For example, a pontoon that is well protected from waves and currents, and also has a short and sheltered transit route, can provide a quality experience at a higher wind speed than can a more exposed pontoon.

It is possible, given wind speed and direction, to (i) calculate the waves and currents; (ii) calculate the resulting movement of boats and floating structures; and (iii) correlate these movements with human discomfort. However, the second of these calculations is difficult, expensive and is a function of a wide range of forcing parameters and vessel characteristics. Furthermore, quantifying the prediction of seasickness is very subjective. Consequently, a state-of-the-art determination of vessel motion for the one-of-a-kind structures typical of GBR pontoons is not recommended.

A combination of numerical modelling and field visits to determine operational limits is recommended. Field visits to a proposed site and along a transit path during a range of environmental conditions are the best technique to determine the hard-to-define aspects of comfort, safety and quality of experience. Wave and current models, forced with a range of wind speeds and directions, can produce waves and currents at both prospective and existing pontoon sites and transit paths. With knowledge of the comfort, safety and operational limits of the existing sites, the operational limits of prospective pontoon sites can be estimated.

Once limiting operational wind conditions are determined, based on serviceability, function and safety objectives, these maxima can be used to meet the structural integrity and environmental protection design objectives. The criteria and method of calculation of design winds for operational conditions are outlined in Box 5.5.

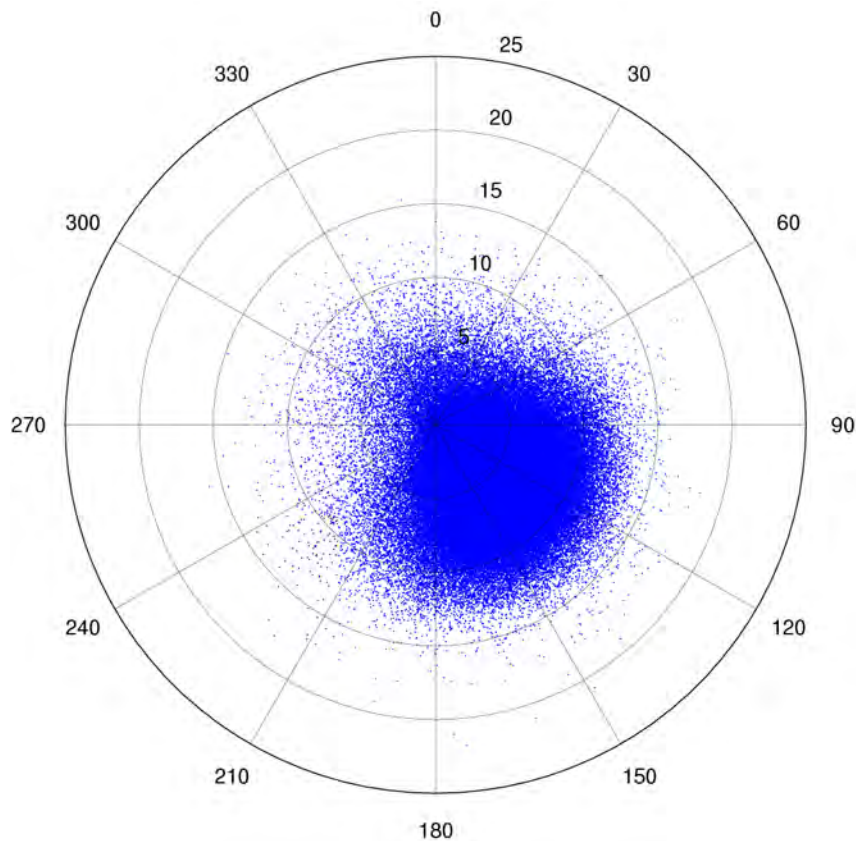


Figure 5.1 Wind data from Willis Island 1940 – 1999 (non-cyclonic conditions). Direction (wind coming from) relative to North. Wind speed in m/s.

Design winds- maximum Non-Cyclonic condition

For non-cyclonic conditions, design wind characteristics must be determined in relation to the structural integrity of the mooring system and above water structures, and tolerable movement of the mooring system (see Box 5.1)

In the GBR, the large-scale (synoptic) wind conditions during non-cyclonic conditions are usually caused by the pressure gradient between a band of low pressure at lower latitudes and movement of high pressure cells from west to east at higher latitudes. Mesoscale deviations from the regional pattern (e.g. sea breeze and storm fronts) may also be important. However, the effect of sea breeze diminishes with distance from the mainland, and storm fronts are fewer and less intense than on the subtropical east coast of Australia. The 60-year wind record (1940 to 1999) from Willis Island was analysed to show the relationship between wind speed and direction during non-cyclonic conditions (Figure 5.1). In general, non-cyclonic winds very rarely exceed 20 m/s and the predominant wind directions are from the S to E directions. Based on data from the Willis Island meteorological station (Figure 5.1), Box 5.6 contains the recommended wind speeds and directions for maximum non-cyclonic conditions. The criteria and method of calculation of design winds for maximum non-cyclonic conditions are outlined in Box 5.7.

Box 5.6 Design wind speed and direction maximum non-cyclonic conditions	
Direction	Design Speed (m/s)
N	15
NE	15
E	20
SE	20
S	20
SW	15
W	15
NW	15

Box 5.7 How environmental loads are used in design: Winds – Non-Cyclonic conditions			
Design objective	How design winds are used	Criteria and method of calculation of design winds	Chapter
<i>Structural integrity</i>			
Integrity of mooring system ¹	Design of moorings, which are not used during tropical cyclones • Drag force on pontoon • Input to calculation of wave and current forces	<i>Maximum</i> non-cyclonic conditions • wind speeds at eight directions - Box 5.6	7
Integrity of above-water structures	Design of structural members, which will be stowed during a cyclone watch. • Drag force on members.	<i>Maximum</i> non-cyclonic conditions • wind speeds at eight directions - Box 5.6	7
<i>Environmental protection</i>			
Movement of mooring lines ²	Design of moorings • Drag force on pontoon. • Input to calculation of wave and current forces	<i>Maximum</i> non-cyclonic conditions • wind speeds at eight directions - Box 5.6	7
¹ If pontoon does not have cyclone moorings then cyclonic conditions will determine mooring design. ² Even if cyclonic conditions prevail for the structural design of the moorings, movement must be restrained during maximum non-cyclonic conditions.			

Design winds – Cyclonic conditions

For cyclonic conditions, design wind characteristics must be determined in relation to the structural integrity of the mooring system and above water structures, and tolerable movement of the mooring system (see Box 5.1). Background information on tropical cyclone wind fields is presented in Box 5.8.

Box 5.8 Background - Cyclone Wind Field

The structure of tropical cyclone wind fields has undergone extensive study (e.g. Holland, 1980). The main features are: (i) a core region or “eye” of low pressure and weaker winds, which has a radius of usually between 10 and 50 km; (ii) a very rapid increase in wind speed from the outer eye to a band of very high winds just outside the eye and then a more gradual decrease in speed with increasing radial direction; (iii) a clockwise (southern hemisphere) spiral of wind directions about the eye; (iv) an inflow angle of approximately 25° towards the centre of the storm; (v) higher wind speeds to the left of the storm and lower speeds to the right (southern hemisphere) for a moving storm with the observer looking in the direction of storm movement.

A secondary eyewall can be found in Coral Sea tropical cyclones such as *Justin*, (Callaghan, personal communication) and *Althea* (Callaghan, 1996). The secondary vortex is as a second band of severe winds at a radius significantly greater than the radius of the primary vortex.

Synoptic winds, created by the pressure gradients between the cyclone and high pressure cells at mid latitude, are common during cyclones in the Coral Sea. The winds created by this pressure gradient are particularly important for locations more than about 5 cyclone radii south of the storm track.

McConochie *et al.* (1999) included the second eyewall and synoptic winds with the Holland vortex to model six thousand synthetic tropical cyclones in the Coral Sea. A current project in the *CRC GBRWHA* has as its first task the presentation of return period and encounter probability curves for winds during tropical cyclones.

Tropical cyclone wind statistics at a resolution of 1500 m throughout the GBRMP will be simulated from the population of cyclones that affect the GBR in a *CRC GBRWHA* task due for completion in 2001. Until this data is available, the Australian Wind Code, *AS 1170.2* is recommended for determination of design winds under cyclonic conditions.

AS 1170.2 specifies 3-second gust speeds for *ultimate* state design. However, marine design traditionally uses *permissible* state design. Ultimate state wind speed, W_u (m/s), can be calculated as a function of return period (see Box 5.3 for recommendation of return periods for cyclonic design) with Eqn (5.14) (Greg Reardon, personal communication).

$$W_u = 24 + 6.6 \ln R \quad 5.14$$

To convert from ultimate state to permissible state use

$$W_p = \frac{W_u}{1.225}, \quad 5.15$$

where W_p is permissible state wind speed in m/s.

Due the possibility that the tropical cyclone could approach the site from any direction, the magnitude determined from Eqn. 5.15 should be applied at each of eight directions (N, NE, E, SE, S, SW, W, and NW). The criteria and method of calculation of design winds for maximum cyclonic conditions are outlined in Box 5.9.

Box 5.9 How environmental loads are used in design: Winds – cyclonic conditions			
Design objective	How design winds are used	Criteria and method of calculation of design winds	Chapter
<i>Structural integrity</i>			
Integrity of mooring system	Design of cyclone moorings • Drag force on pontoon	Risk based - return period ¹ • wind speed from Eqn. 5.15 • apply at eight directions	7
Integrity of above-water structures	Design of structural members • Drag force on members	Risk based - return period ¹ • wind speed from Eqn. 5.15 • apply at eight directions	7
<i>Environmental protection</i>			
Movement of mooring lines	Design of moorings • Drag force on pontoon.	Risk based - return period ¹ • wind speed from Eqn. 5.15 • apply at eight directions	7
¹ See §5.1, 5.3 for recommended design return period to be used in Eqn. 5.15.			

5.3 Design waves

Designers of reef infrastructure require accurate wave information. This information must include magnitude (e.g. wave height and wave period), direction and frequency of occurrence (e.g. return period or encounter probability).

For the GBR, the most severe wave conditions occur during tropical cyclones. Seaward of the GBR, during non-cyclonic conditions, significant waves heights can reach approximately 4 m (Wolanski, 1986). However, during tropical cyclones significant wave heights are commonly greater than 10 m and could be as large as 20 m during a very severe storm (Young, 1989). Inside the GBR the wave energy is greatly reduced (Hardy and Young, 1996). Unfortunately field data inside the reef matrix is very sparse. To overcome the lack of data it is necessary to use computer models to numerically predict wave energy (see *Wave Modelling*, below).

Wind generated waves have an important influence on both operational and cyclonic design conditions. A pontoon location must be sheltered from the commonly occurring wind (wave) directions because wave energy in unsheltered locations will often create uncomfortable conditions for pontoon visitors. In general, most existing pontoons are located immediately to the northwest of a coral reef or inside the lagoons of a single reef to provide shelter from the commonly occurring southeasterly to easterly winds.

Designers of reef tourism infrastructure will need the following wave information: (See Box 5.10 for explanation of these terms.)

- Significant wave height, H_s
- Peak wave period, T_p
- Mean wave direction, q_m

This information is the minimum that is required. It may be necessary to obtain this information for multiple wave directions and for more than one severity level. More sophisticated design techniques will require additional information, such as

- Wave frequency spectrum
- Wave frequency-directional spectrum

These may also be required for multiple design cases of direction and intensity.

Box 5.10 Background - Waves

The most commonly used conceptual model of the sea surface assumes it is composed of a large number of sinusoidal waves that can have a wide range in both frequency and direction. A two dimensional *frequency-direction spectrum*, $E(f, \theta)$ represents this sea surface as the density of wave energy as a function of both frequency and direction. This can be used as the forcing input to numerical and physical models of pontoon motion. Unfortunately, frequency-direction spectra are difficult and expensive to obtain since the time series of at least three independent measurements is required (more are required for an accurate representation). Instruments (e.g pitch-roll buoys) or instrument arrays (e.g multiple pressure gauges) capable of measuring such spectra are very expensive; therefore, field measurements of frequency-direction spectra are very rare.

A much more common form of wave spectrum is the one dimensional *frequency spectrum*, $E(f)$, which describes the distribution of wave energy as a function of frequency and ignores direction. It is much easier to obtain since only one time series is required. Unfortunately, field measurements in the GBR region are very rare, so frequency spectra based on field measurements will not be available for engineering design.

The wave energy information contained in a wave spectrum is often reduced to wave height and wave period parameters. The *significant wave height*, H_s , is a measure of the total energy of a wave field. The *peak period*, T_p , indicates the wave period with the highest energy level. Both the significant wave height and the peak period will usually correspond closely to a *visual* estimate of the dominant waves. In fact, the concept of significant wave height arose in World War II as a visual wave estimation technique for the planning of amphibious landings. The significant wave height is calculated as

$$H_s = 4.0 \sqrt{\int E(f) df} \quad 5.7$$

where the square root of the total wave energy has dimensions of length and the coefficient (4.0) gives the result that, in deep water, the significant wave height of a narrow banded spectrum is approximately equal to the average height of the largest 1/3 of the waves.

The peak period is often calculated as the inverse of the frequency that contains the highest energy density. Unfortunately, small changes in the spectrum can cause large fluctuations in the value of the peak period. A more stable result can be obtained by using a weighting system (Young, 1998), as given by

$$T_p = \frac{\int E^4(f) df}{\int f E^4(f) df} \quad 5.8$$

Empirical wave formulae

Table 5.4 Empirical wave growth formulae for deepwater, fetch limited waves as a function of wind speed, U (m/s) and fetch length, F (km) (SPM, 1984)

	Fetch limited	Fully developed
H_s (m)	$1.62 \times 10^{-2} U \sqrt{F}$	$2.48 \times 10^{-2} U^2$
T_p (s)	$6.24 \times 10^{-1} (U F)^{1/3}$	$8.30 \times 10^{-1} U$
t (h)	$8.93 \times 10^{-1} \left(\frac{F^2}{U} \right)^{1/3}$	$2.03 U$

For simple geometry and deep water, empirical formulae based on field measurements can be used to estimate the significant wave height and peak period of waves. So-called *fetch limited* waves are limited by the distance upwind over which the waves can grow. For example, at a given site, a reef, island or the mainland may limit the fetch in certain directions. A *fully developed* condition occurs if the fetch is long and the waves reach maximum development. Formula for the calculation of significant wave height, H_s (m) and peak wave period, T_p (s) for deepwater waves, as a function of wind speed, U (m/s) and fetch length, F (km) are given in

Table 5.4. The table also includes equations for *minimum duration*, *t*, or the time during which the wind must remain constant in speed and direction for the equations to be valid.

Table 5.5 gives examples using these formulae for two wind speeds (25 and 15 knots). These winds are representative of stronger operational winds (say, 25 knot SE and 15 knots N) for a hypothetical pontoon location.

Table 5.5 Selected results using fetch limited empirical wave growth formulae

25 knots (» 12.5 m/s)				15 knots (» 7.5 m/s)		
H _s (m)	T _p (s)	t (h)	Fetch Length (km)	H _s (m)	T _p (s)	t (h)
0.20	1.4	0.4	1	0.12	1.2	0.5
0.29	1.8	0.6	2	0.17	1.5	0.7
0.45	2.5	1.1	5	0.27	2.1	1.3
0.64	3.1	1.8	10	0.38	2.6	2.1
3.88	10.4	25.4	Fully developed	1.40	6.2	15.2

For example, in Table 5.5, fully developed waves for a 25 knot wind have $H_s = 3.88$ m, but this would require 365 km of fetch (calculation not shown) and a constant wind over the whole of the fetch for over 25 hours. Although the wind duration is not extreme, the fully developed fetch length is far longer than that for almost all locations inside the GBR matrix. These wave conditions can occur seaward of the GBR in the open waters of the Coral Sea. However, even with the shorter fetches more representative of inside the GBR matrix, 25 knot winds can cause uncomfortable conditions for swimmers.

These formulae should only be used for *estimates* of waves caused by local winds over fetches that are free from obstructions and in water that is not shallower than $\frac{1}{2}$ the wave length. Thus the use of these formula are severely restricted (to short fetches) in the geometrically complex GBR. However, for *preliminary* site selection, these estimates are reasonable for locally generated waves over fetches between reefs.

Wavelength is a function of wave period and water depth (*h*) as given by Eqn. 5.9 and for representative examples in table 5.6.

$$L = \frac{gT}{2\pi} \tanh\left(\frac{2\pi}{L}h\right) \quad 5.9$$

Table 5.6 Wavelength, *L* (m) for selected wave periods, *T* (s) and water depths, *h* (m).

	<i>T</i> (s)				
<i>h</i> (m)	6	8	10	12	14
10	48	71	92	113	134
15	53	82	109	135	161
20	55	89	121	152	183
deep	56	100	156	225	306

Even with wind that is constant in direction over a wide and unfettered fetch, wave energy arrives at a point from many directions. Obstructions are common as a function of direction in the geometrically complex GBR matrix; therefore the assumptions inherent in the fetch-limited equations of Table 5.5 are violated. Another empirical method that allows calculation of *directional* wave energy in *irregular* fetches is that of Krylov. This method has been published only in the Russian literature, but an explanation is available in Massel (1996). Although it still assumes deepwater, the Krylov method can account for a fetch length that is a function of direction, as is often the case in the GBR matrix.

For this method, rays are drawn in a radial direction from the point at which wave information is required. These rays divide the region “up-wave” of the point into discrete segments each of which sweeps an angle equal to $\Delta\theta$. The recommended value of $\Delta\theta$ is 22.5° and seven sectors are created with centres at $\theta = 0^\circ, \pm 22.5^\circ, \pm 45^\circ$, and $\pm 67.5^\circ$, where $\theta = 0^\circ$ faces from the point of interest directly into the wind. The significant wave height is calculated by the following sequence.

$$H_s = \left(\frac{16}{p} \sum_{i=1}^7 \bar{H}_{n_i} \Delta E_i \right)^{1/2}, \quad 5.10$$

where

$$\bar{H}_{n_i} = 0.16 \frac{U^2}{g} \left[1 - \left(1 + 6 \times 10^{-3} \left(\frac{g X_i}{U^2} \right)^{0.5} \right)^{-2} \right], \quad 5.11$$

and

$$X_i = r_i \cos q_i, \quad 5.12$$

where r_i is the radial distance from the point to the end of the fetch in the sector with a central angle of q_i . Values of ΔE for $\Delta\theta = 22.5^\circ$ are given as

q_i	-67.5	-45	-22.5	0	22.5	45	67.5
ΔE_i	0.0405	0.120	0.2111	0.2468	0.2111	0.1250	0.0405

The peak period is calculated as

$$T_p = 24.35 \frac{U}{g} \left(\frac{g H_s}{1.6 U^2} \right)^{0.625}. \quad 5.13$$

Wave modelling

Simple empirical equations as in Table 5.5 or in the Krylov method are usually appropriate only for preliminary estimates of design wave conditions in the GBR. This is especially true for conditions during tropical cyclones, where the wind field is rapidly changing in both space and time. As part of the *Engineering Program* of the *CRC Reef* the wave conditions for the population of cyclones that threaten the GBR have been simulated (Hardy *et al.*, 2001). Over 6000 synthetic tropical cyclones have been modelled to provide wave information at a resolution of approximately 1500 m for almost all of the GBR. This information includes probability and duration curves for significant wave height, peak wave period, and mean wave direction. Thus, a designer will be able to choose the wave characteristics associated with the acceptable amount of risk for individual portions of a project. This data is available in the *Atlas of Cyclone Waves in the Great Barrier Reef* (<http://tsunami.jcu.edu.au>). Background information of wave modelling in the GBR is presented in Box 5.11.

Box 5.11 Background – Wave Modelling

Hardy et al. (2000) developed a wave generation model, *WAMGBR*, especially for the GBR, by adapting the state-of-the-art wave generation model, *WAM*, (Komen *et al.*, 1994). The most important improvement is a technique to include the dissipative effects of features, in this case coral reefs, that are too small to be adequately resolved in the numerical grid. Thus, model outputs can contain effects of features much smaller than grid resolution. The goal of this reef parameterisation dissipation scheme is to provide a simple and economical way to account for energy losses at a computational point due to sheltering of “up-wave” reefs. The technique provides better estimates of wave energy if the output of that grid is used as a final product, and it also improves boundary conditions for nested grids. Full details of the technique and other model improvements are given in Hardy et al. (2000).

The numerical wave model used to produce cyclone wave information for the GBR is in a class called wave generation models. (See Young, 1999 and Komen *et al.*, 1994 for detailed discussions of numerical wave modelling.) The primary purpose of such models is to predict the creation, growth and propagation of surface waves.

During a model simulation, wave information is calculated at each point in a numerical grid that represents discrete locations in space. The inputs to the modelling are depth wind speed and direction at each grid point. Depths, of course, vary in space but are usually held constant in time (i.e. tidal fluctuations are ignored). Wind speed and direction are allowed to vary in both space and time. The model calculates wave growth from wind input wave-wave interaction, as well as wave transformations caused by shoaling and refraction, and energy losses from bottom friction and wave breaking. At a given time step, the model calculates wave information at each grid point and then repeats calculations over the spatial grid at each of a series of time steps. Thus the model can predict the creation and transformation of waves in both space and time.

The primary output of the model is a directional wave spectrum (the density of wave energy as a function of both frequency and direction) at each grid point for each time step. The spectral information is usually condensed into several more commonly used quantities, such as significant wave height (H_s), peak period (T_p) and mean direction (q_m).

The process of modelling waves suffers from a conflict of physical scales. On one hand, waves develop over hundreds, even thousands of kilometres. On the other hand, shallow water with horizontal dimensions on the order of 10 m can significantly affect the local wave spectrum. If a resolution of 10 m were chosen for modelling output, then a numerical grid at that resolution, which extended over a region large enough to include all wave generation processes, would require computer resources that are impossible to obtain.

This conflict of resolution versus extent has traditionally been handled by using a series of “nested” numerical grids. An outer grid extending over the total wave generation region provides the results at a coarse resolution (say 20 nautical mile). This parent grid is assumed to cover the region over which waves develop. Thus, no wave energy comes into the grid from across its outer boundaries. A series of finer grids focus on the area of interest by nesting inside this parent grid at successively finer resolutions. Because each nesting reduces the spatial coverage of the grid, significant amounts of wave energy may enter the boundaries of the nested grids. Therefore, each grid must provide boundary conditions for the next smaller grid until the desired resolution is reached. The standard rule of thumb is that the resolution of successive grids should be reduced no more than 5:1 so that the interpolation of boundary values from coarser grid to the more resolved grid will be reasonably accurate. The nested grid system used for generation of the *Atlas of Cyclone Waves in the GBR* (<http://tsunami.jcu.edu.au>) was three grids with resolutions of 20, 4, and 0.8 minutes of arc, the finest of which is approximately 1500 m.

The 1500 m resolution used in the *Atlas* is far coarser than that necessary to accurately define the wave climate in areas of rapid changes in bathymetry (i.e. within metres of a reef edge). Unfortunately, it is not possible to increase the resolution to an arbitrarily small value using existing wave generation models. There are three main barriers to a goal of providing wave information at a very fine scale for the whole of the GBR. Firstly, extensive computer resources would be required to model the whole GBR region (say 2000 by 200 km) at a resolution much less than 1500 m. Secondly, bathymetric data are not available at very fine resolutions, and manual digitisation of existing data or newly commissioned data collection would be required for resolution much finer than that presented in these *Guidelines*. Finally, physical processes not usually included in wave generation models, such as wave diffraction and shallow water nonlinear wave interactions become increasingly important at finer resolutions. Thus, very fine scale modelling is only viable for a few selected local areas, and must depend on the gathering of additional depth information and the use of other wave modelling systems. To do this for the entire GBR is prohibitively expensive.

Accuracy of the tropical cyclone meteorological database for the Coral Sea region is limited to the time period after the advent of weather satellites in the Australian region (1969). A recent summary of the tropical cyclone database is given in Puotinen et al. (1997). Data on cyclone track, central pressure, and radius to maximum winds are necessary to generate the spatially and temporally varying wind field that forces the wave generation model.

Waves and coral reefs

Waves are reflected, refracted, diffracted, as well as lose significant amounts of energy to wave breaking and bottom friction as they cross windward reef edges and travel across shallow reef flats. Hardy and Young (1996) found that significant wave height reduced to $\frac{1}{2}$ the water depth within several wavelengths after the waves cross a windward reef flat. The shallow water over reef flats is the great equaliser. Furthermore, some transmitted energy is shifted to harmonics of the peak of the incident spectrum. For example, there is a transfer of energy from 10-second waves to 5-second waves. Thus wave spectra in the reef matrix are broader than those outside in the Coral Sea. Although breaking waves increase water depths on reef flats through generation of wave setup (Gourlay, 1996), and thus increase the amount of transmitted energy, the effect of wave-induced water levels is minor in the GBR if compared with the effect of tidal changes.

Design waves - maximum Operating condition

The principal considerations for design wave inputs under operating conditions relate to serviceability, function and safety aspects, such as the comfort and safety of visitors in transit, on the pontoon, and while swimming, snorkelling or diving (Box 5.1). Designers need to know wave characteristics (height, period and direction) in providing for the structural integrity, tolerable movement of the mooring system, and position of the pontoon during a range of operating conditions.

During transit from the mainland to the pontoon site, trip segments that are exposed to long fetches (say, >50 km) will cause uncomfortable conditions during strong winds, especially if the travel time of the segment is greater than about 15 minutes. Data of wave height, period and direction during commonly occurring conditions *could* be provided by numerical modelling. However, there is a very complex relationship between the values of these parameters, boat movement, and instance of seasickness and these calculations are rarely done. Instead, experience is most often used, and operators often use a criterion based on wind speed rather than wave height when making a decision to cancel an operation. For a new site in an unfamiliar area, wave modelling could be used to provide comparisons between the proposed new site and existing sites for which the conditions are well known. This could provide the operator with a good estimate of level of comfort for a range of wind conditions at the new site. By mid 2002 a wave atlas for trade wind conditions should be available through the *CRC GBRWHA*. This database will allow comparisons between sites.

No guidelines on snorkeller comfort in waves are available. Obviously, discomfort increases with wave height. However *wave steepness* is also important. Large wave steepness will cause discomfort to swimmers on the surface. For example, a wave with a height of 0.25 m and a wave period of 10 seconds (longer wavelength) might be barely noticeable, but for a wave period of 2 seconds (very short wave length) it might be uncomfortable to a snorkeller. For underwater activities (scuba diving), the longer the wave period (longer wavelength) the deeper the penetration of wave energy into the water column.

Pitch and roll of the pontoon will increase with wave height and as wavelength approaches twice the dimension of the pontoon. Floating structures of different sizes, masses and restraints will respond with different frequencies and amplitudes to wave forcing. The maximum differential movement between boats and pontoons will be the sum of amplitudes of the movement of the two structures.

The wave conditions in the GBR dictate that a pontoon must be sheltered from commonly occurring wind/wave directions. However, many installations will have one or more directions from which the protection is inadequate. A common technique among operators with multiple sites is to use the site that has the best sheltering characteristics for the conditions on the day. Throughout most of the GBR, the most common wind/wave directions will be from south to east and most pontoons are located with protection from nearby reef flats in these directions.

The criteria and method of calculation of design waves for operational conditions are outlined in Box 5.12.

Box 5.12 How environmental loads are used in design: Waves – Operating conditions			
Design objective	How design waves are used	Criteria and method of calculation of design waves	Chapter
<i>Serviceability, function and safety</i>			
Visitor comfort in transit to pontoon site	Upper limit on operating conditions between mainland and pontoon site. Compare wave conditions along new route with those along known route.	No known criteria – comparison with known conditions at other sites Criterion usually specified in terms of wind speed (eg strong wind warning) • Local knowledge • Wave modelling	6
Visitor comfort on pontoon Visitor safety in transfer between boats and structures	Compare waves at new and known sites.	No known criteria – comparison with known conditions at other sites • Wave modelling • Empirical wave calculations (Table 5.5 or Krylov)	6
Safety and comfort of swimmers, snorkellers and divers	Wave height and length – wave steepness Compare steepness between new and known sites	No known criteria – comparison with known conditions at other sites • Field visits • Wave modelling • Empirical wave calculations (Table 5.5 or Krylov)	6
<i>Structural integrity</i>			
Integrity of mooring system	Design of operational moorings	Maximum conditions during operation ¹ • Wave modelling² • Empirical wave calculations (Krylov)	7
<i>Environmental protection</i>			
Movement of mooring lines	Design of operational moorings	Maximum conditions during operation ¹ • Wave modelling² • Empirical wave calculations (Krylov)	7
Position of pontoon (shading of coral)	Design of operational moorings	Most <i>common</i> conditions during operation • Wave modelling² • Empirical wave calculations (Krylov)	7
¹ Once the limit of operations is determined based on the <i>serviceability, function and safety</i> criteria, then the maximum waves during these conditions are determined. ² If the location is not well sheltered from all directions, fine scale modelling is strongly recommended in order to determine wave design inputs			

Design waves – Non-Cyclonic condition

This design state is fully active only if separate mooring systems or components are used for non-cyclonic and cyclonic conditions. If the same system is used for both, then the greater loads during cyclonic conditions will dictate structural integrity. Even without separate mooring systems, it will still be necessary to restrict movement of anchor lines during the more common non-cyclonic conditions.

For maximum non-cyclonic conditions, design wave characteristics must be determined in relation to structural integrity and tolerable movement of the mooring system (Box 5.1). The criteria and method of calculation of design waves for operational conditions are outlined in Box 5.13.

Box 5.13 How environmental loads are used in design: Waves – Non-Cyclonic conditions			
Design objective	How design waves are used	Criteria and method of calculation of design waves	Chapter
Structural integrity			
Integrity of mooring system ¹	Design of moorings	Maximum non-cyclonic conditions ² - Wave modelling³ - Empirical wave calculations (Krylov)	7
Environmental protection			
Movement of mooring lines	Design of moorings	Maximum non-cyclonic conditions ² - Wave modelling³ - Empirical wave calculations (Krylov)	7
¹ Determined by cyclonic forcing if facility does not use cyclone moorings. ² For wind speeds at eight directions (see §5.2, Box 5.6) ³ If the location is not well sheltered from all directions, fine scale modelling is strongly recommended in order to determine wave design inputs			

Design waves – Cyclonic condition

For cyclonic conditions, design wave characteristics must be determined in relation to structural integrity and tolerable movement of the mooring system (Box 5.1). Wave data during tropical cyclones is available at a resolution of 1500 m throughout the GBR in the *Atlas of Cyclone Waves in the GBR* (Hardy *et al.*, 2001). These data need to be interpreted by an expert, in order to provide the best design estimates for a specific pontoon location. The criteria and method of calculation of design waves for maximum cyclonic conditions are outlined in Box 5.14.

Box 5.14 How environmental loads are used in design: Waves – Cyclonic conditions			
Design objective	How design waves are used	Criteria and method of calculation of design waves	Design Chapter
Structural integrity			
Integrity of mooring system	Design of cyclone moorings	Risk-based encounter probability ¹ Wave Atlas ²	7
Integrity of above water structures	Design of cyclone moorings, buoyancy of pontoon, and above-water structures.	Risk-based encounter probability ¹ Wave Atlas²	7
Environmental protection			
Movement of mooring lines	Design of cyclone moorings	Risk-based encounter probability ¹ Wave Atlas²	7
¹ See §5.1, Box 5.3 for recommended design criteria ² Fine scale wave modelling may be necessary to optimise inputs for some locations.			

5.4 Design currents

A designer of a reef-based pontoon requires current information for several purposes.

For the GBR, the most severe current conditions occur during tropical cyclones. Unfortunately, field data inside the reef matrix are very sparse. To overcome the lack of data it is often necessary to use computer models to numerically predict currents (see *Hydrodynamic Modelling*, below).

A pontoon location must be sheltered from the commonly occurring wind directions because waves generated by local winds will often create uncomfortable conditions in unsheltered locations. In general, most existing pontoons are located immediately to the northwest of a coral reef or inside the lagoons of a single reef in order to obtain shelter from the commonly occurring southeasterly to easterly winds. Unfortunately, this does not mean that shelter is provided for currents.

Water currents in the GBR are primarily caused by a variety of sources, such as astronomical tides, regional and local meteorological forcing (wind and pressure), the East Australian Current (EAC), continental shelf waves, and breaking waves. The first two are usually the most significant for pontoon mooring design. The EAC is generally weaker than wind and tidal currents but can be important for operational conditions. Currents induced by breaking waves can be very strong in surf zones and on reef flats, but pontoons should not be placed there. Current speed and direction may vary over a variety of time scales ranging from seconds to seasons, as well as spatially in both vertical and horizontal directions.

All currents vary in the vertical direction because of boundary layers at both the seabed and the sea surface. Background information of currents in the GBR is given in Box 5.15. Tidal currents can often be adequately represented by a depth-averaged value. Wind-generated currents also have a significant depth-averaged component, but can have a sharply varying vertical profile at the surface. Currents are strongly affected by the bathymetry and geometry of the local area; therefore, horizontal variations in space can be significant, particularly close to coral reefs. The EAC and depth-averaged wind-generated currents tend to follow the isobaths (depth contours), but tidal currents may travel normal to the isobaths as tides cause an exchange of water across reef flats into lagoons of individual reefs. Depth-averaged currents of all types will sweep around reef outlines rather than across reef flats. In the lee of reefs, eddies may cause complicated patterns of speed and direction in both space and time.

Box 5.15 Background: Currents

East Australian Current

Especially for pontoon locations nearer the outer edge of the continental shelf, the EAC could be important. The EAC approaches the Australian continent from the Coral Sea at a latitude of approximately 14° and then bifurcates into southeasterly and northwesterly flowing components that parallel the continental shelf break. In the deepwater off the continental shelf, current speeds can be as much as 1 m/s. Speeds are much lower on the continental shelf. A speed of 20 cm/s (sometimes as great as 30 cm/s) for outer reefs, reducing to zero at the coastline, with a direction parallel to the coastline is a rough estimate of the EAC in more open waters of the GBR lagoon. For locations south of the bifurcation point, the EAC will flow southward in more open waters, but tends to follow the bottom contours in the near vicinity of reefs. Unfortunately, the bifurcation position and the strength of the EAC are highly variable and difficult to predict. The EAC can meander and create eddies, both of which can cause strong and highly variable currents on the outer portion of the continental shelf.

Throughout the region of the southerly flowing EAC, wind driven currents created by the commonly occurring southeasterly winds often oppose the EAC; therefore, the EAC is often more noticeable during calm periods or during northerly or northeasterly winds.

Tidal currents

Tidal currents are a function of tidal range and bathymetry. Obviously, regions with larger tidal ranges have larger tidal currents. Less obvious is the effect of the local bathymetry and geometry on tidal currents. The direction and strength of tidal currents inside more complex regions in the GBR matrix must be determined by measurement or modelling.

Since the tides are deterministic, accurate estimates can be obtained relatively easily from measurements and/or numerical modelling. Although spot measurements with a hand held instrument could give useable estimates, a fixed current meter deployment of longer than a month or a numerical modelling exercise will be necessary to provide adequate design values.

Wind currents

Winds can cause both local and regional current patterns. Current speeds will be affected by wind speed, direction and duration as well as by the local and regional bathymetry. Regional winds of sufficient duration will cause regional currents that can be reasonably represented by a depth-averaged current that follows the bottom contours. Near reefs these currents will sweep around the reef outline and will cause eddies in the wake. These regional currents can be measured if the measurement campaign is sufficient to cover seasonal variations and includes a range of wind speeds and directions. Because a six-month measurement program will be needed, numerical modelling offers an attractive alternative.

Local winds cause surface currents that move in the direction of the wind. The commonly stated “3% of the wind speed” that is often used for *surface* currents accounts for both the free surface boundary layer and the depth-averaged components of the current in areas unaffected by the bathymetry. A location in the lee of the reef will have a depth-averaged component of the wind-generated current that has been greatly modified in both speed and direction by the upwind reef. The surface current will move in the wind direction and the depth-averaged component will sweep around the reef following the bathymetric contours. A rough estimate of the surface current speed in the lee of a reef would be less than 3%, say 2%, of the wind speed.

Hydrodynamic modelling

Numerical hydrodynamic models have been used for over 25 years to predict current and water levels in coastal areas at numerous locations around the world. Techniques for the computer modelling of tidal and wind driven currents and water are well advanced. Models are routinely used to predict water levels during storms (storm surge) and currents during both tidal and wind forcing for a wide variety of purposes, including sediment and pollutant transport and for determining forces on structures.

A brief outline of a hydrodynamic model and modelling techniques follows. Hydrodynamic models solve the equations of conservation mass and momentum in order to calculate water velocities, and water surface elevations are functions of both position and time. Unfortunately, there are no analytical solutions to these equations. In other words, one cannot merely “plug in” values of position and time into a mathematical equation and get velocities and water levels for that point. Instead, results have to be obtained by numerical techniques.

In a numerical solution, the physical characteristics of the area are represented on a spatial grid. Among the characteristics specified at each grid point are (i) whether the point is land or water, (ii) depth at water points, and (iii) friction factors for the seabed. Forcing is applied to the model through wind stress at the water surface or water elevations on the model boundary. Solutions to conservation of mass and momentum require the calculation of differences in quantities in both space and time. At a fixed time, spatial differences can be calculated using values at adjacent grid locations. At a fixed point in space, time differences are calculated using values at successive time-steps. In this manner velocities and water elevations can be determined at a moment in time by “sweeping” through the grid. Values of velocities and water elevations are obtained for the next time step by repeating the sweep of the grid and updating values to the new period.

Just as in wave modelling (see Section 5.4 on wave modelling), hydrodynamic modelling often uses nested grid systems in order to provide adequate resolution for the area of interest, and economically model processes that occur over very large areas. Common nested grid resolutions might be as follows: 5, 1, 1/5, 1/25 minutes of arc. The last two are approximately 370 and 74 m.

Currents in coastal areas are often well represented by two-dimensional flow, since vertical velocities are usually very much smaller than horizontal velocities. As computer capabilities have improved, three-dimensional (3-D) models are becoming more common. Most commonly used 3-D models are called sigma, σ models, which are not fully three dimensional, but model in a fixed number of vertical layers. Three-dimensional capability can be important to pontoon projects because *surface* rather than *depth averaged* currents are needed for forces on structures and snorkellers.

Despite the advances over recent years, use of hydrodynamic models is still limited to experts. Fortunately, expertise is becoming more widespread and most of the major Australian engineering consulting firms have in-house modelling capability. One area of difficulty for which experience is not widespread is the modelling of currents in the complexity of the GBR matrix. Economical modelling requires the use of sub-grid scale model capabilities so that the smaller reefs can be represented without the need for a very small spatial grid size.

Not all of the forcing mechanisms are easy to model. Tidal and wind-driven current modelling has been well established and is, fortunately, representative of the most important currents. Tide and wind-driven currents can be modelled in hindcast (real events) if adequate wind data is available. More commonly, synthetic events are modelled, for which wind forcing (e.g. uniform and steady 15 knot southeasterly winds) can be specified. A proper choice of synthetic events can cover the range of currents necessary for design purposes. Modelling the EAC is difficult because of the lack of adequate boundary conditions for forcing. However, modelling should be able to give indicative values or relative values of magnitude between locations.

Hydrodynamic modelling during tropical cyclones is a specialised application that requires specification of the cyclone wind field that varies rapidly in both space and time.

Design currents – Operating conditions

As they do for waves and winds, designers use design current under operating conditions in considering serviceability, function and safety aspects of the facility, such as the comfort and safety of visitors while swimming, snorkelling or diving (see Box 5.1). The tabulation below also indicates that designers need to know current characteristics (speed and direction) in providing for the structural integrity of the mooring system and above-water structures, for the tolerable movement of the mooring lines, and for offset position of the pontoon. The recommended approach is a combination of measurement and modelling. Measurements can provide calibration and verification for modelling. Ideally the measurement program should include a full range of tidal conditions and some instances of near maximum operational wind speed (say 25 knot winds). As the currents may vary rapidly with horizontal position close to the reef, some care is needed to place the current meter in a representative location. Unfortunately measurements can only be economically obtained at a small number of positions; therefore, modelling is important to define the pattern over the whole of the project area.

Current speeds are needed for both commonly occurring conditions and for maximum operating conditions. The maximum operating conditions will most likely be determined by other criteria (either wind or wave effects, e.g. strong wind warning).

The recommended modelling procedure is to model a combined tide and wind forcing, i.e. a spring-neap tidal cycle for *each* wind speed and directions common during operational conditions, as well as for the maximum operating wind conditions. For example, a two week simulation (spring to neap tide) would be repeated for each combination of two wind speeds (say, 10 knots for common and 25 knots for maximum) and three wind directions (say southeast, east, and north), for a total of six simulations.

Once the maximum conditions are identified, currents should be modelled for these conditions. The criteria and method of calculation of design currents for maximum operating conditions are outlined in Box 5.16.

Box 5.16 How environmental loads are used in design: <i>Currents – operating conditions</i>			
Design objective	How design currents are used	Criteria and method of calculation of design currents	Chapter
<i>Serviceability, function and safety</i>			
Safety and comfort of swimmers, snorkellers and divers	Current speeds and directions during operational conditions Compare magnitudes between new and known sites	No known criteria – comparison with known conditions at other sites • Field visits • Current measurement and modelling ¹	6
<i>Structural integrity</i>			
Integrity of mooring system	Design forces on operational moorings	Maximum conditions during operation ² • Current measurement and modelling ³	7
<i>Environmental protection</i>			
Movement of mooring lines	Design forces on operational moorings	Maximum conditions during operation ² • Current measurement and modelling ³	7
Position of pontoon (shading of coral)	Design forces on operational moorings	Most <i>common</i> conditions during operation • Current measurement and modelling ³	7
¹ Modelling for a complete spring-neap tidal cycle coupled with a series of direction and speed combinations to represent common and maximum operating conditions (e.g. southeast, east and north with 10 and 25 knots). ² Once the limit of operations based on the <i>serviceability, function and safety</i> criteria (wind, wave or current may be the critical factor) is determined, then the maximum current speeds and directions during these conditions are determined. ³ Both measurement and fine scale current modelling is strongly recommended.			

Design currents - Non-Cyclonic conditions

For non-cyclonic conditions, design current characteristics must be determined in relation to structural integrity and tolerable movement of the mooring system (see Box 5.1). This design state may not apply to all facilities or to all components of one facility. For design of components that will remain unchanged during a tropical cyclone, cyclonic design inputs will prevail, and this design state will be inoperative.

Measurements cannot be expected to capture data during maximum non-cyclonic conditions because of their infrequent occurrence. Although 3% of wind speed (in open waters) and 2% behind reef flats can be used for *preliminary* design estimates, numerical modelling is recommended for detailed design.

The criteria and method of calculation of design currents for maximum non-cyclonic conditions are outlined in Box 5.17.

Box 5.17 How environmental loads are used in design: Currents – Non-Cyclonic conditions			
Design objective	How design currents are used	Criteria and method of calculation of design currents	Chapter
<i>Structural integrity</i>			
Integrity of mooring system ¹	Design of moorings	Maximum non-cyclonic conditions ² • Current measurement and modelling ³	7
<i>Environmental protection</i>			
Movement of mooring lines ⁴	Design of moorings	Maximum non-cyclonic conditions ² • Current measurement and modelling ³	7
¹ Determined by cyclonic forcing if facility does not use cyclone moorings. ² For wind speeds at eight directions (see §5.2, Box 5.6). ³ Fine scale current modelling is strongly recommended. ⁴ Less movement may be required during this design state even if the mooring system structure is designed to cyclonic standards.			

Design currents - Cyclonic conditions

For cyclonic conditions, design current characteristics must be determined in relation to structural integrity and tolerable movement of the mooring system (see Box 5.1).

For cyclonic conditions, design winds and waves have pre-determined references to help define recommended design inputs. For the winds it is the AS1170.2 wind code, and for waves it is the *Atlas of Cyclone Waves in the GBR*. Unlike waves, design currents have no set standard, since an ensemble of tropical cyclones has not been numerically simulated for the GBR region. Fortunately, loads created by currents are expected to be much smaller than those created by waves and wind. It may be possible to obtain an estimate of current speeds by applying the approximations 3% of the wind speed (for open directions) and 2% (for directions with wind across nearby reef flats) as a design current. These magnitudes would be calculated for eight directions for a wind speed calculated by Eqn. 5.15. The difficulty with this crude technique is that it is untested in areas with complex geometry such as pontoon sites in the GBR. It may under- or overestimate the magnitude of current by an unacceptable amount. If underestimated, the chance of failure increases, and, if overestimated, the cost of construction, installation and environmental impact is higher than is necessary. Hydrodynamic modelling can provide information for design currents for not only the cyclonic design state, but also for operational and non-cyclonic conditions. Much of the cost of a modelling exercise is in the set-up and testing of a model for a particular site; therefore, multiple uses of model output for all three design states creates an economical tool. Hydrodynamic modelling is highly recommended for the determination of design current during cyclonic conditions.

A risk-based assessment, similar to that for waves, would be prohibitably expensive, so a more simple design storm approach is recommended. Hydrodynamic model simulations of tropical cyclone with a central pressure of 955 hPa, a radius to maximum winds of 30 km, and a forward speed of 20 km/h are recommended. Four simulations with the path of the cyclone, chosen to pass along a line with closest approach equal to the radius of maximum winds (to the north, south east and west of the site), is recommended. For the 4th and 5th categories of structure (overnight visitors) a greater number of simulations and some at a lower central pressure (935 hPa) may be warranted.

The criteria and method of calculation of design currents for cyclonic conditions are outlined in Box 5.18.

Box 5.18 How environmental loads are used in design: <i>Currents – Cyclonic conditions</i>			
Design objective	How design currents are used	Criteria and method of calculation of design currents	Chapter
<i>Structural integrity</i>			
Integrity of mooring system	Design of cyclone moorings	Design storm ¹ • Current modelling ²	7
<i>Environmental protection</i>			
Movement of mooring lines	Design of cyclone moorings	Design storm ¹ • Current modelling ²	7
¹ See text for recommendations.			
² Fine scale current modelling is highly recommended.			

5.5 Design water levels

The primary components of water level for engineering design are astronomical tide, storm surge, and wave effects. Background information on water levels in the GBR is given in Box 5.19. For many coastal and ocean engineering projects the design water level will be a combination of all three components. In pontoon installations, design water levels will be important for determining (i) minimum bottom clearance under floating structures; (ii) movement of mooring chains during the tidal cycle; (iii) maximum elevation of moored structures for calculation of mooring stiffness and offset of the pontoon; and (iv) elevation of non-floating structures.

Box 5.19 Background – Water Levels

Astronomical tide

The astronomical tide is deterministic. Given a suitable water level time history, a harmonic analysis can produce amplitudes of a suitable number of sinusoidal constituents, and the water level as a function of time can be predicted. However, deployment of a tide gauge is expensive and data collection must extend for at least ½ year for the analysis to be more accurate than simpler procedures. For most pontoon installations, design will not be highly sensitive to small differences in water level, so highly accurate tidal predictions are not needed. The highest astronomical tide (*HAT*), Mean low Water Springs (*MLWS*), and Lowest Astronomical Tide (*LAT*) are among the values useful for design and they can be estimated at most reef locations by use of the *Queensland Official Tide Tables* or the *Australian National Tide Tables* published annually by Queensland Transport and Hydrographic Service Royal Australian Navy, respectively. These sources provide detailed information for “Standard Ports” and for numerous “Secondary Places”.

In general, the amplitude of the tidal signal reduces with distance offshore, so the closest offshore stations will provide the best estimates for most pontoon locations. Nearby coastal stations will usually provide a conservative estimate of the tidal parameters.

Storm Surge

Storm surge has two main components, wind set-up and pressure set-up. Another component, the effect of the rotating Earth or the Coriolis force, has a reduced influence on water levels in offshore areas away from the mainland coast.

Wind set-up is the most important component. The shear stress on the water surface during strong winds causes a slope of the water surface in continental shelf waters. The magnitude of the slope is proportional to the square of the wind speed and is inversely proportional to the water depth. Therefore, the slope is greater in shallower water. Also, since the sloping water surface will increase in elevation with distance from the edge of the continental shelf, the wind set-up will be much larger in coastal locations compared with offshore locations.

At the mainland Queensland coast, for more severe conditions during the close passage of a tropical cyclone, the magnitude of the wind set-up can approach the value of the maximum tidal range. In general, the wind set-up at a mid-shelf location will depend on the wind speed and direction, depth of water, and distance from that location to the outer edge of the shelf.

An increase in water level by pressure set-up is caused by the so-called “inverse barometer effect”. Lower atmospheric pressures under a tropical cyclone, draws up the water surface much like a straw draws up a milkshake. For each 1 hPa drop in atmospheric pressure, the sea surface will rise approximately 1 cm. So, for example, under the eye of a 950 hPa cyclone the water surface would rise (1010-950 = 60 cm) 60 cm. Of course pressures at greater radial distances from the eye are higher than 950 hPa and therefore the rise would be less at those locations.

Storm surge is the combination of the wind set-up and pressure set-up. Storm surges of more than seven metres have been recorded at the coast during cyclones in the Gulf of Mexico. Along the Queensland coast measurements have not reached these levels, although surges of approximately three metres (eg. Althea, 1971) have been recorded. The increase in water level during a storm results from a complicated mix of storm (position, strength, etc) and site specific (bathymetry and geometry) parameters, especially in coastal locations. Fortunately for the offshore location of most GBR pontoons, the effects are less site-specific and much smaller in magnitude.

The relative timing of the storm surge and astronomical tide are important for the calculation of the total water level. As the value of the storm surge will be much less than the maximum tidal range for most pontoon locations (mid shelf), a low tide can completely negate the effect of a severe storm surge. As a rule of thumb, it is expected that pressure set-up and wind set-up will be roughly equal for mid-shelf pontoon locations. Therefore increases in water level could be approximately 1 metre during the close passage of a tropical cyclone.

Wave effects on water level

The presence of waves alters not only the instantaneous position of the water surface as the wave form passes, but also the elevation of the underlying mean water surface at frequencies lower than that of the wind waves. *Wave set-up* and *set-down* occur if wave heights decrease or increase, respectively.

Increases in wave heights due to shoaling of waves in shallow water result in wave set-down. Set-down in the near vicinity to pontoons is unlikely to have a significant effect on water levels as the relatively deep water close to the pontoon limits the increase in wave height due to shoaling. Thus the changes to the minimum clearance under a pontoon due to wave set-down is less than the magnitude of the uncertainty in the calculation of the water level.

Significant wave set-up and accompanying wave-induced current occurs in the surf zone. Since pontoons will not be located in the surf zone of a reef, wave set-up will have little effect on water levels at the pontoon.

For fixed, bottom-mounted structures, *wave runoff*, *wave overtopping*, and *wave crest elevation* will be important quantities. However, since these structures are rare in the GBR, calculation techniques are beyond the scope of these guidelines.

Recommendation for design water levels

Although the highest astronomical and lowest astronomical tides are, theoretically, the most extreme levels over an 18.6 year tidal epoch, the predicted tidal level approaches close to these extremes every year. Given that minor meteorological effects (pressure changes and winds) and other continental shelf and oceanic waves can often cause variations of ± 0.2 m in the predicted water elevation, elevations very close to HAT and LAT tend to occur on at least an annual basis. During tropical cyclones, the water level at *offshore* reef locations will always be elevated above predicted tidal levels. However, storm surge will be far less than at the coast. Also, the duration of the maximum surge is on the order of two to three hours, so it is unlikely that it will occur during high water of a large spring tide.

The recommended design water levels are given in Box 5.20.

For inshore locations or pontoons placed on fringing reefs of large continental islands, numerical modelling will be necessary for the cyclonic conditions. In these locations it is possible that storm surge could be significant and that that design water levels will be higher than HAT.

Box 5.20 Recommended design water levels		
Design state	Maximum level	Minimum level
Operational	HAT	LAT
Non-Cyclonic	HAT	LAT
Cyclonic	HAT	MLWS
Assumptions: • Pontoon is well outside of the reef surf zone. • Location is in the GBR matrix (i.e. mid shelf) and not close to the coast or in the immediate vicinity of a large continental island. • The off-reef depth of the nearby continental shelf is more than about 15 m. • Mooring system is designed so that it is not sensitive to small uncertainties (< 0.25 m) in maximum or minimum water level.		

5.6 Recommended Reading

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6 PONTON SITING, LAYOUT AND CONFIGURATION

	Summary
6.1	Site selection
6.2	Pontoon layout and configuration

Summary

- **Proponents, designers** and **managers** should use this chapter to determine the site, layout and configuration of the pontoon facility.
- The basis for planning and design to meet multipurpose requirements related to function and safety, structural integrity, environmental protection and amenity, is presented.
- The scope and method of the tasks, the objectives and criteria to be met, and the relevant personnel, planning and design tools, input and output data and other information are described.

Some of the earliest steps taken by a tourism operator in establishing a pontoon facility on the Reef are those of selecting the site and determining the layout and configuration of the facility. In spite of the vast extent of the GBR, a limited number of suitable sites are available that meet the strict criteria relating to policy and management of the Reef, and the function, viability and amenity of the operation. Although the pontoon facilities are normally floating structures that can be relocated to other sites, it is not a simple task to find suitable alternative sites, to gain approval to use other sites, and to reconfigure the pontoon and ancillary facilities to suit a new site. Hence, site selection is a crucial task that the pontoon operator must undertake in a thorough and systematic manner for new pontoon installations.

The layout and configuration of the pontoon facility is closely inter-related with site selection. Not only do the size and type of the pontoon and ancillary facilities installed at a site depend on the characteristics of the site, but they also determine the suitability of the site for the proposed facility. Layout and configuration is therefore established in an interactive manner with site selection for new pontoon facilities. Where existing installations are to be modified or retrofitted with a new mooring system, the layout and configuration is constrained by the existing site and by the characteristics of the facility components (eg. pontoon body) retained at the site.

Multiple objectives relating to serviceability, function and safety; structural integrity; environmental protection; and amenity and cultural values, play a significant part in pontoon site selection, and in determination of facility layout and configuration. It is crucial in these early steps that the pontoon proponent and designer select a site which, among other things, meets Marine Park zoning and management planning requirements, is located within a viable transit distance to port, is protected from prevailing and severe sea conditions, and has good quality coral and suitable conditions for recreational activities and craft access. Furthermore, the facility layout and configuration must provide adequate space and facilities, withstand severe environmental loads, ensure safety, stability and comfort for visitors under operating conditions, and protect the coral substrate from environmental damage.

This chapter outlines these crucial early project planning and design tasks and sets them within the context of the *10-Step Planning, Design and Implementation Procedure*. Site selection is undertaken as part of Steps 1 and 2 in *Phase 1: Concept*. The layout and configuration tasks form part of Steps 1 and 2 in the *Concept* phase, and Step 4 in *Phase 2: Feasibility*. Planning and design tasks are described in this chapter in terms of the following planning and design elements, and are linked to the hierarchical structure and ordered sequence of activities that lead

from **project phases**, through **project steps** to **planning and design tasks** (Chapter 3):

- **scope** and **purpose** of each task
- list and brief description of suggested **planning, design and implementation task steps**
- specific tasks relating to **site investigation and characterisation**
- **design objectives, criteria and constraints** relating to the task
- **planning and design tools** that may be used
- **input data** that will be required, and **outputs** from the task
- list of **personnel** who are likely to undertake the task

6.1 Site selection

The tourism operator will investigate and select a site for a new pontoon facility early in the project sequence once initial concepts relating to the type, size, configuration and method of operation of the facility are established. Information on the expected number of visitors, the type and size of pontoon facilities to be provided, the operating range for craft, Marine Park zoning, shelter provisions, coral conditions, and options for innovative mooring arrangements will guide the search for suitable sites. Several alternative sites may be identified and their suitability investigated against a range of criteria. This will usually be undertaken in two stages in Steps 1 and 2 of the *10-Step Planning, Design and Implementation Procedure*, as outlined in Box 6.1. The site selection task is usually undertaken in conjunction with determination of the pontoon layout and configuration (Section 6.2), and is a preliminary to mooring and anchor design (Chapters 7 and 8).

Box 6.1 Indication of project phasing for Site selection task <i>refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3, Box 3.2), Project Planning and Design Task Schedule (Chapter 3, Box 3.3) and Site Investigation and Characterisation Tasks (Chapter 4; Boxes 4.3, 4.5, 4.7 and 4.9)</i>	
Purpose	Task Description
Phase 1 Concept	
Step 1 Initial Concepts Identify alternative sites suitable for locating the pontoon.	Collect information on available sites, access routes, coral conditions and shelter for new projects. Evaluate alternative pontoon sites against established criteria and identify potentially suitable sites. Discuss proposals with GBRMPA.
Step 2 Concept Design Select the preferred pontoon site.	Determine the size and type of the pontoon operation and the means of access to the site. Evaluate alternative pontoon sites against established criteria and choose the preferred site. Discuss proposals with GBRMPA, and document and submit information for assessment.
Step 3 GBRMPA Preliminary Assessment	Preliminary consideration of the suitability of the site, and identification of non-conforming issues relating to zoning, environmental impacts etc.
Phase 2 Feasibility	
Step 4 Feasibility Design Confirm the site on the basis of detailed studies.	Confirmation of the site following detailed studies on layout and configuration, mooring and anchor design.
Step 5 GBRMPA Detailed Assessment	Confirm or reject site selection.

Design objectives, criteria and constraints

Various design **objectives**, and quantitative and qualitative design **criteria** provide the basis for evaluation of alternative sites, and selection of the preferred site (Box 6.2). These objectives and

criteria reflect proponent and stakeholder requirements, and policy, legislative and management provisions relating to human use and natural ecosystem function for the pontoon development. Semi-quantitative criteria relating to *serviceability, function and safety*, and quantitative criteria relating to *structural integrity*, are generally defined in terms of the design states and loadings (eg. operating conditions; cyclonic loads) identified in Chapter 5. Criteria for *environmental protection*, and *amenity and cultural values* are mainly qualitative in nature and are derived principally from the policy and management provisions (Chapter 2). The proponent and designer should account for relevant legal, physical, environmental, social, political and economic **constraints**, relating to legislation, regulations and zoning; the presence of adjacent tourist developments and infrastructure; timing for development of the project; and/or available funding.

The principal features of the site itself that may affect its suitability for a pontoon installation, are the level of protection offered by the adjoining islands, reefs and coastline; the site bathymetry; and the quality and distribution of corals at the site.

Box 6.2 Design objectives and criteria for site selection	
Design objective	Criteria
<i>Serviceability, function and safety</i>	
Ensure visitor comfort and safety in transit to pontoon site.	Choose site and vessel access route from shore to minimise travel distance and extent of open water conditions and, thereby, avoid visitor distress.
Ensure visitor safety in transfer between boats and structures.	Ensure adequate protection from prevailing winds and waves to minimise the relative movement of boats and structures.
Ensure visitor comfort and safety on pontoon.	Ensure adequate protection from prevailing winds and waves to minimise pitch and roll of the pontoon.
Provide adequate space and facilities for operation.	Satisfy minimum requirements for recreational and operational facilities (eg. swimming, snorkelling and diving areas; ancillary craft access routes).
<i>Structural integrity</i>	
Ensure integrity of mooring system(s).	Ensure adequate protection from severe winds, waves and currents to minimise environmental loads on the structure. Ensure suitable water depth, substrate condition and adequate space on the ocean floor to install a mooring system capable of withstanding the environmental loads on the structure.
<i>Environmental protection</i>	
Control movement of pontoon and mooring lines.	Ensure adequate protection from prevailing and severe weather conditions to minimise pontoon and mooring line movement. Choose site with suitable ocean floor and substrate conditions, which cause minimum obstruction to pontoon and mooring line movement.
Minimise the effects of shading of coral by the pontoon.	Choose site with maximum sand substrate coverage or ability to relocate significant corals to minimise the effect of pontoon shading on the corals.
<i>Amenity, conservation and cultural heritage</i>	
Maintain conservation values.	Ensure conservation values (eg. coral reef or protected fauna) of the region are not compromised by pontoon installation at the site.
Provide for aesthetic values.	Ensure scenic amenity of the site is not adversely affected by installation of the facility.
Protect cultural heritage.	Consider the possible effects of the pontoon facility on cultural and heritage values of indigenous people and others. Consider the effect of the development on hunting and gathering activities on reefs and surrounding areas. Consider specific cultural or heritage values for the individual reef (eg. shipwrecks or other wrecks at the site).

Design task steps

Site selection will usually be done in several steps. Firstly, a site on a particular reef will be selected, and then the actual location for the pontoon on that site will be chosen. The first level choice may be a stretch of several hundred metres along a reef, which meets the requirements for zoning, proximity, protection, amenity etc. This will usually be achieved by identifying potential sites from resource mapping information and undertaking a reconnaissance survey by boat or by plane. Various locations for the pontoon may be available on the section of reef chosen in the initial assessment. The second level assessment will examine the site options in more detail and determine the preferred location to meet the requirements for the proposed facility. This will involve on-site, underwater investigations in which the initial concepts for the pontoon size, facilities, method of operation, and mooring configuration will be considered for the site.

The proponent and designer will evaluate the suitability of alternative pontoon sites and, in conjunction with GBRMPA, choose the preferred site according to how well the above site selection criteria are met (Box 6.2). Detailed calculations, such as the environmental loading forces on the structure, will not be necessary at this stage. Instead, a semi-quantitative evaluation of wind and wave conditions will be used to compare the relative exposure of alternative sites (eg. the likely effects at the site of open sea waves of, say, 3 metre and 6 metre height from various directions).

An outline of the various design provisions to be made in site selection is given in Box 6.3.

Box 6.3 Design provisions in site selection	
Issue to address	Design provisions and mitigation measures
Marine Park zoning and management planning (Chapter 2)	Pontoons can only be sited where Marine Park zones and management plans allow tourist structures. Site acceptability may be affected by a regional tourism strategy, or other strategies governing Marine Park permits. Marine Park management plans, governing intensive tourism operations such as pontoons or other structures, may apply for individual reefs and islands in high usage area. In assessing a proposal, GBRMPA may consider the effect on future options for the Marine Park, including the effect on other users of the site, long-term changes that may occur to values of the reef, or alterations to the legal status of the area.
Operator considerations	The company mission or marketing identity may dictate the general location of the pontoon installation (eg. retain the company association with a particular reef location or type of operation). Other constraints on the proponent's operation may govern the site (eg. desire to centralise activities in a particular region).
Customer considerations	To meet customer expectations and demands, pontoon sites on the GBR will normally be outer reef locations. The site should provide for a facility that incorporates diving and snorkelling operations, and semi submersible and glass bottomed boat operations. The site must be valued for diving compared with other outer/mid shelf reefs. Reasonable water clarity and visibility must be available to permit coral viewing. Reasonable quality and variety of corals, coral cover and richness of coral communities is required. The potential for interpretation of reef ecology in association with tourist programs may be considered.

Location on GBR, shelter and protection (Chapter 5)	Site selection is based on the characteristics of the reef, travel distance, shelter, and the capacity to operate multiple facilities. An outer reef location with viable transit distance from the mainland base is desirable. Consider protection from deepwater cyclone waves and smaller waves during operating conditions (desirable pontoon sites are normally sheltered from prevailing southeasterly winds). Ensure protection from the prevailing sea conditions and reasonable protection in cyclonic conditions from any direction. It may not be possible to economically design pontoons for exposed locations. Provide for visitor comfort and safety in transit to the pontoon site, for visitor safety in transfer between boats and structures, and for visitor comfort and safety on the pontoon. Local operator knowledge is essential to define the best locations on the reef.
Proximity to other facilities or vessels	Preferably locate in close proximity to other facilities or vessels in case of emergency. In assessing a proposal, GBRMPA may consider the value of the adjacent reef area for commercial fishing or other operations.
Facility area	Ensure adequate area is available for installation, operation and salvage of the facility. Ensure the pontoon and ancillary activities can be housed without significant damage to the environment. Consider provision for future development of the site such as expanded facilities.
Water depth and substrate condition	Shallow water (typically less than 20 metres deep) is normally desirable for coral viewing and other recreation activities. Ensure suitable water depth for vessel draft and anchorage. Ensure suitable water depth to permit the installation of moorings with adequate scope. The configuration of coral and areas of clear sand substrate affect the placement of mooring lines and anchors.
Ancillary vessel access	Ensure adequate and safe vessel access to the pontoon structure for vessels in addition to the catamaran used for visitor transit. Ensure adequate vessel manoeuvring area and sufficient area for safe and protected moorings for ancillary vessels.
Amenity and use of site	The visual impact of fixed or floating structures breaking the horizon in the Marine Park may be greater than onshore, where structures are set against hills, forests, buildings. Choose materials, colours and profiles to blend with the reefs and marine waters. In assessing a proposal, GBRMPA will consider if the tourist program and facility will alter the existing amenity for the area.

How to do Site Selection

refer Steps 1 and 2 of 10-Step Planning, Design and Implementation Procedure (Chapter 3)

Inputs

- configuration and layout of existing pontoon installations
- alternative layouts and configuration of the pontoon, including mooring arrangements
- Marine Park zoning plans, marine charts, aerial photographs and bathymetric charts
- tropical cyclone, wind and wave characteristics for the region

Planning and design tools

- *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Chapter 5)

Personnel

- coordination and preparation of required information by the proponent's project manager
- close involvement from the proponent's management group and delegated representative
- involvement from the operations manager / resort planner
- specialist support from an economist, environmental engineer / scientist, marine engineer / naval architect, hydrodynamics engineer, geotechnical engineer, marine biologist or others as required
- input from the marine technician, particularly in site investigations
- management agency's interests represented by the GBRMPA delegate and project manager

Outputs

- initial concepts for a prospective new facility, identifying the port location, prospective reef and access routes, and the preferred pontoon site - Step 1
- conceptual design of the preferred scheme defining the site and access arrangements for new projects - Step 2

Associated tasks (including site investigation and characterisation)

- Consider the need for, and the economic viability of, tourist pontoon operations in the vicinity - Step 1.
- Estimate project costs and examine the economic viability of the tourist pontoon operation - Step 2.
- Undertake preliminary hydrodynamic studies for the site (Chapters 4 and 5).
- Undertake a reconnaissance survey of prospective sites for new projects and identify alternative sites for the facility - Step 1 (Chapter 4).
- Obtain basic site bathymetric information and place a location marker, eg. buoy, at the likely site(s) - Step 1 (Chapter 4).
- Undertake preliminary bathymetric surveys, geotechnical and ecological assessments of the site - Step 2 (Chapter 4).
- Establish survey control markers and buoys at the preferred site to identify the location and orientation of the pontoon, mooring, anchors and other facilities - Step 2 (Chapter 4).
- Consider the size and configuration of the facility and prepare initial sketches - Step 1 (Section 6.2).
- Prepare conceptual layouts and configurations of the pontoon facility - Step 2 (Section 6.2).
- Consider specialised features such as innovative mooring arrangements (Chapter 7).

6.2 Pontoon layout and configuration

The layout and configuration of new or existing pontoon facilities will depend on the chosen site, and the type, size, configuration and method of operation of the facility. Information on recreational features to be provided, site hydrodynamic conditions, site bathymetry and coral, and options for innovative mooring arrangements will be used to determine and evaluate facility layout and configuration against a range of criteria. This will usually be undertaken in three stages in Steps 1, 2 and 4 of the *10-Step Planning, Design and Implementation Procedure*, as outlined in Box 6.4.

Box 6.4 Indication of project phasing for Pontoon layout and configuration task <i>refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3, Box 3.2), and Project Planning and Design Task Schedule (Chapter 3, Box 3.3) and Site Investigation and Characterisation Tasks (Chapter 4; Boxes 4.3, 4.5, 4.7 and 4.9)</i>	
Purpose	Task Description
Phase 1 Concept	
Step 1 Initial Concepts Identify potential layouts for the pontoon and ancillary facilities.	Collect information on bathymetric and coral conditions for alternative sites. Consider the size and configuration of the facility and prepare initial sketches, including modifications for existing facilities. Discuss proposals with GBRMPA.
Step 2 Concept Design Determine preliminary layouts and configuration for the facility.	Determine the size of the pontoon operation, the level of use, the facilities to be provided, and the type of activities to be conducted. Evaluate alternative layouts against established criteria and prepare conceptual layouts and configurations of the pontoon facility and mooring system, showing upgraded components for existing facilities. Examine measures to mitigate the effects of the facility on ecological, social and cultural values. Consider methods for installation and salvage, and operation and maintenance of the facility. Discuss proposals with GBRMPA, and document and submit information for assessment.
Step 3 GBRMPA Preliminary Assessment	Preliminary consideration of the suitability of the site layout and configuration, and identification of non-conforming issues relating to mooring type, disturbance to coral etc.
Phase 2 Feasibility	
Step 4 Feasibility Design Determine detailed mooring layout, configuration and movement tolerances.	Confirm the facilities to be provided, and the type of activities to be conducted. Identify zones and corridors for movement of the pontoon and mooring system, and iterate through mooring design alternatives until the desired zone and movement tolerances are established. Evaluate alternative layouts against established criteria and prepare detailed layouts and configurations of the preferred pontoon system, showing upgraded components for existing facilities, and including moorings and anchors. Define configuration and layout of pontoon ancillary facilities, including platforms, walkways, water storage, waste storage and disposal as required (principally for new projects). Assess the environmental effects of the facility, including installation, operation and salvage, and mitigate ecological, social and cultural impacts (Chapters 9 and 10). Discuss feasibility designs with GBRMPA, and document and submit information for assessment.
Step 5 GBRMPA Detailed Assessment	Confirm, reject or suggest modifications to site layout and configuration.

Design objectives, criteria and constraints

As with site selection, various design **objectives**, and quantitative and qualitative design **criteria** provide the basis for evaluation of site layout and configuration (Box 6.5). Semi-quantitative criteria relating to *serviceability, function and safety*, and quantitative criteria relating to *structural integrity*, are generally defined in terms of the design states, loadings and movement limits (eg. operating conditions; cyclonic loads; mooring movement) identified in Chapters 5 and 7. Criteria for *environmental protection*, and *amenity and cultural values* are mainly qualitative in nature and are derived principally from policy and management provisions (Chapter 2). The proponent and designer should account for relevant legal, physical, environmental, social, political and economic **constraints** that apply to site layout and configuration.

The principal features of the site itself that may affect the suitability of the pontoon layout and configuration, are the level of protection against winds, waves and currents offered by the adjoining islands, reefs and coastline; the site bathymetry; and the quality and distribution of corals at the site.

Box 6.5 Design objectives and criteria for pontoon layout and configuration	
Design objective	Criteria
<i>Serviceability, function and safety</i>	
Provide space and facilities for operation.	Satisfy minimum requirements for recreational facilities and visitor amenities (eg. swimming, snorkelling and diving platforms; ancillary craft berths; ablution areas; food preparation).
Ensure visitor comfort and safety on pontoon.	Provide adequate recreation and safety facilities (eg. seating; access ramps; emergency provisions).
Provide for safety and comfort of swimmers, snorkellers and divers.	Choose suitable snorkel and dive routes, and provide adequate recreation and safety facilities (eg. diver lines safety ropes).
Ensure ease of installation and salvage.	Configure structure and facilities to allow ready installation and salvage for the adopted site.
Ensure ease of maintenance.	Incorporate facilities and components that can be readily cleaned, serviced and replaced.
<i>Structural integrity</i>	
Ensure integrity of mooring system(s).	Choose mooring type, size and layout for the adopted site to withstand environmental loads on the structure. Ensure sufficient length and space is available on site for placement and movement of mooring lines.
Ensure pontoon stability and buoyancy.	Ensure the layout of pontoon structure and facilities do not compromise on stability or buoyancy by risking capsize, flooding or interference with flotation.
Provide resistance to berthing loads.	Provide sufficient berthing restraint to secure visiting craft.
Ensure integrity of above-water structures.	Ensure adequate strength of superstructure elements to resist environmental loads due to severe winds, as well as dead and live loads on the structure.
<i>Environmental protection</i>	
Control movement of pontoon and mooring lines.	Protect the coral substrate from pontoon or mooring movement or failure by locating the pontoon and mooring lines clear of the substrate, and restricting movement to defined acceptable zones or corridors.

Minimise the effects of shading of coral by the pontoon.	Configure the pontoon and mooring system and relocate selected corals to minimise the effect of pontoon shading on the coral substrate.
Ensure protection from pollution.	Provide appropriate storage, waste handling and disposal facilities. Provide appropriate materials and coatings to avoid environmental damage and pollution.
<i>Amenity, conservation and cultural heritage</i>	
Maintain conservation values.	Ensure conservation values (eg. coral reef or protected fauna) at the site are not compromised by pontoon and mooring configuration and layout.
Provide for aesthetic values.	Ensure the layout and configuration of the facility does not degrade scenic amenity of the site.

Design task steps

Pontoon layout and configuration will usually be done in several steps. Initially the designers will prepare a preliminary layout and configuration of the pontoon facilities and moorings to suit the site and planned operations, and to address multiple project objectives. Facility components such as viewing chambers, snorkelling platforms and vessel berths are arranged to suit site characteristics such as coral cover, water depth and bottom clearance for the facilities and tender craft. The preferred orientation of the pontoon on the site is chosen to suit the facility components, the site physiography, and the prevailing and severe wind and wave directions. Alternative types, layouts and configuration options for the mooring system are considered, and potential mooring line corridors and anchor locations are identified.

The preliminary studies and layouts will be based on preliminary data for the site. The underwater conditions relating to access, swimming, snorkelling etc. will be studied, and preliminary layouts incorporating all site features and facility components will be prepared. Satisfactory pontoon and mooring layout and configuration will require:

- strategic positioning of the pontoon, mooring lines and anchors
- a secure mooring system to withstand severe topical cyclone loadings
- restricted movement of the pontoon and mooring lines in normal operation and in extreme loading conditions
- protection of coral substrate
- pontoon stability and adequate structural capacity
- provision of safe access and berthing facilities for service craft

In the second stage studies, the designers prepare a detailed layout and configuration of the mooring system, based on the preliminary layouts and detailed site investigations. The acceptable movement limits for the pontoon and mooring lines and components are determined for use in the design of system components in the mooring and anchor design task. Several iterations of mooring system layouts and mooring designs may be undertaken prior to finalisation.

The mooring layout and configuration takes account of pontoon facility requirements, such as viewing chambers, snorkelling platforms and vessel berths; site characteristics such as suitable mooring line corridors and anchor locations; and the prevailing and severe wind and wave loadings. The layout should account for specific environmental constraints such as exclusion zones for the pontoon and moorings. This may involve relocation or sacrifice of specific corals to provide acceptable shading effects from the pontoon footprint or acceptable corridor provisions for the mooring lines and for vessel access and berthing.

The permissible movement zones for the pontoon and mooring lines shall be developed by the proponent and the designer in consultation with, and to the approval of, GBRMPA. The designer shall prepare a plan of the site showing the bathymetry and coral substrate, and the defined zones that represent the movement limits for the mooring lines. The permissible zones for pontoon movement may be different for the operating condition (frequent movement affecting shading of coral), and extreme conditions (infrequent excursions that may cause collision with the reef). The boundaries of the zones must include a safety margin, determined in consultation with GBRMPA (eg. 1 metre for mooring lines; 3 metres for pontoon shading; and 5 metres or 20 % of clear space from reef for pontoon collision).

Where conventional catenary mooring systems are used, permissible pontoon excursions and mooring line movements must be determined to ensure that damage associated with pontoon shading or impact, and that dragging or lifting of mooring lines and anchor blocks is restricted to acceptable levels. Pontoon movement from the stationary position during maximum operating conditions should be controlled in order to minimise the zone of influence of coral shading. Under extreme conditions associated with tropical cyclones, the objective is to prevent physical impact on the corals from the pontoon or sweeping mooring lines. These constraints are site-specific, depending on the site physiography and relative coral value and its sensitivity.

Objectives for mooring and anchors facilities can be achieved by, for example: 1) providing additional or lengthened mooring lines; 2) adopting alternative anchor arrangements, such as grouted screw anchors in lieu of concrete gravity anchors; and 3) transplantation of coral from critical areas. Depending on the available scope for placement of mooring lines, the conventional catenary type mooring system may not be suitable, and an alternative taut mooring system attached to fixed piles may be considered.

The proponent and designer will evaluate the suitability of alternative pontoon and mooring layouts, and choose the preferred layout according to how well the above layout and configuration criteria are met (Box 6.5). Whereas detailed calculations of the environmental loading forces on the structure and mooring lines will be undertaken as part of the associated mooring design task, this will not form part of the layout and configuration task. Semi-quantitative evaluations of wind and wave conditions will be undertaken, however, to compare their effects on the structure (eg. the likely effects of open sea waves of, say, 3 metre and 6 metre height from various directions).

Designers will define the configuration of the mooring system in sufficient detail to allow detailed studies of the mooring loadings, capacities and movements to be undertaken as part of the mooring and anchor design task (Chapters 7 and 8). Detailed site layouts incorporating all site features and facility components will be prepared in conjunction with the naval architect or marine engineer drawings of the mooring and anchor system, prepared as part of the mooring and anchor design.

An outline of the various design provisions to be made in determining the pontoon layout and configuration is given in Box 6.6.

Box 6.6 Design provisions in pontoon layout and configuration	
Issue to address	Design provisions and mitigation measures
Pontoon shape and orientation	Sometimes a rectangular structure is not always suitable for the pontoon, and an irregular structure shape may be adopted to suit the viewing chamber and other facilities. The pontoon orientation should suit the prevailing wind and wave directions, the layout of the viewing chamber and other recreation facilities, and the desired mooring arrangement. Pontoon orientation will be governed by the suitability of approach paths for craft to access the pontoon, the physical constraints posed by the surrounding reef structures, and the location and proximity of sensitive coral communities.
Recreational facilities	A diversity of passenger needs can be catered for by providing an underwater observatory, semi-submersible craft berthing etc. In a fully integrated design, pontoon levels, facilities, berth area etc. are chosen to provide a total day plan for passenger comfort, crew satisfaction, cleaning and efficiency. The configuration of underwater observatory, resort diving, snorkelling etc. should be chosen according to the site and the visual amenity of the corals. The underwater hardware (eg. mooring lines and anchors) should be located to minimise impact on visual amenity. Protected swimming and snorkelling areas should be provided, with reasonable swimming access and water clarity for coral viewing, and safe operating conditions with respect to currents etc. Provision should be made for suitable dive and semi-submersible routes.
Pontoon ancillary facilities	Provide activities/facilities for the daily visitation capacity, including on-board essential services (eg water storage; wastewater storage and treatment).
Mooring type and suitability (Chapter 7)	Structural integrity of the mooring system is required to ensure the pontoon does not drift and interfere with the reef or other structures. Various mooring systems (eg. cyclone or dual system) and various types of mooring (eg. conventional catenary or taut mooring) can be considered. Mooring leg symmetry and long mooring leg lengths are desirable characteristics for a satisfactory mooring. Conventional catenary mooring systems often require long catenaries or mooring scope. Mooring design is influenced by hydrodynamic design conditions and degree of exposure to severe weather. The sea floor physiography, the location and proximity of surrounding reef structures and sensitive coral communities, and the configuration of coral and areas of clear sand substrate determine the mooring lines and anchor layout. The approach access path for visiting craft affects the layout of mooring lines and anchors. Prepare a map of the site to show the layout of coral and other features as a base for defining the layout and configuration of the pontoon facilities.
Anchor provisions (Chapter 8)	The nature of the seabed substrate and its distribution affects the suitability of anchor types and their load capacity. Ensure access is available for installation of mooring lines and anchors without environmental damage.
Provisions for installation, salvage, operating and maintenance (Chapter 10)	Consider the procedures and plant to be used for pontoon and mooring installation, and eventual salvage of the facility and restoration of the site. Provide for operation, maintenance and on-going monitoring.

How to do Layout and Configuration

refer Steps 1, 2 and 4 of 10-Step Planning, Design and Implementation Procedure (Chapter 3)

Inputs

- information on the preferred site and alternative sites
- configuration and layout of existing pontoon installations
- marine charts, aerial photographs and bathymetric charts
- details of existing facilities, in the case of projects that are to be upgraded
- tropical cyclone, wind and wave characteristics for the region
- bathymetric plans and ecological and geotechnical information for the site

Planning and design tools

- *Atlas of Tropical Cyclone Waves in the Great Barrier Reef* (Chapter 5)
- ecological model of disturbance effects on coral

Personnel

- coordination and preparation of required information by the proponent's project manager
- close involvement from the proponent's management group and delegated representative
- involvement from the operations manager / resort planner
- specialist support from an economist, environmental engineer / scientist, marine engineer / naval architect, hydrodynamics engineer, geotechnical engineer, marine biologist or others as required
- input from the marine technician, particularly in site investigations
- management agency's interests represented by the GBRMPA delegate and project manager

Outputs

- initial concepts for a prospective new facility, identifying preferred pontoon size and configuration options – Step 1
- initial concepts for an upgraded facility identifying the prospective means of upgrade for moorings or other components – Step 1
- other special considerations such as innovative mooring systems
- configuration and layout of the facility, indicative sizes of key components, and preliminary assessment of impacts on coral and marine biology for new and upgraded projects – Step 2
- feasibility designs for the scheme, defining the configuration and layout of the facility, sizes and characteristics of major components, environmental assessment and measures for impact mitigation – Step 4
- plan showing site bathymetry and coral substrate with defined zones and corridors representing the permissible locations for the pontoon and mooring lines, and the permissible movement limits – Step 4

Associated tasks (including site investigation and characterisation)

- Identify alternative sites for the facility and choose the preferred site (Section 6.1).
- Consider specialised features such as innovative mooring arrangements (Chapter 7).
- Undertake preliminary hydrodynamic studies for the site (Chapters 4 and 5).
- Undertake preliminary bathymetric surveys, geotechnical and ecological assessments of the site (Chapter 4).
- Establish survey control markers and buoys at the preferred site to identify the location and orientation of the pontoon, mooring, anchors and other facilities (Chapter 4).
- Prepare conceptual mooring and anchor designs (Chapters 7 and 8).
- Undertake detailed hydrodynamic studies of wind, wave and current conditions for the site (Chapters 4 and 5).
- Undertake detailed bathymetric surveys, geotechnical and ecological assessments of the site (Chapter 4).
- Analyse the structure to determine forces and movements in the pontoon and mooring system, and design mooring components to accommodate wind, wave, current, dead and live loads (Chapter 7).
- Select and design suitable anchor type, configuration and size to suit substrate conditions and to accommodate design loads (Chapter 8).
- Assess the stability of the pontoon body, check flotation requirements and undertake preliminary design of pontoon structural members (Chapter 9).
- Define the installation and salvage arrangements for the facility (Chapter 10).
- Define the operation and maintenance program for the facility (Chapter 10).
- Define the environmental monitoring program for the facility (Chapter 10).
- Estimate project costs and examine the economic viability of the tourist pontoon operation.
- Prepare and document EIS or PER where these are ordered.

7 MOORING DESIGN

	Summary
7.1	Mooring line arrangements, behaviour and good design practice
7.2	Design methodology
7.3	Simplified Mooring Design Procedure
	Step A Identify criteria, constraints and design inputs
	Step B Define load cases
	Step C Determine steady state environmental forces
	Step D Undertake preliminary design of mooring line properties
	Step E Develop mooring force-offset relationships
	Step F Determine mean pontoon offsets and oscillating motions
	Step G Determine maximum line and anchor forces, and line movements
	Step H Evaluate performance against design criteria
	Step I Check pontoon stability during operational conditions
	Step J Address miscellaneous design requirements
	Step K Confirm and review design
7.4	Detailed design of individual components and connections
7.5	How to do Mooring Design
7.6	Recommended reading

Summary

- **Designers** should use this chapter to select and design the pontoon mooring systems, using environmental forcing inputs from Chapter 5 and details of the layout and configuration of the pontoon facility from Chapter 6.
- Various mooring system arrangements are introduced, several mooring system design approaches are reviewed and a design methodology proposed, and key issues and good design practice are described to emphasise the difficulties in mooring system design for pontoons on the GBR.
- A *Simplified Mooring Design Procedure* is presented, outlining design requirements and objectives, design tasks and methods of analysis for determining forces and movements in the mooring system and for designing mooring components.
- In the *Simplified Mooring Design Procedure*, the designer matches environmental forcing from wind, waves and currents with the strength of the mooring line elements and components, and the permissible limits placed on movement of the pontoon and mooring lines.
- Given the complexity and uncertainties involved in pontoon mooring design, supplementary design criteria are specified to ensure a degree of flexibility is maintained in the mooring system during extreme environmental loading, and to ensure stability during operational conditions.
- Relevant personnel, planning and design tools, input and output data are described, and an outline of design documentation to be submitted for assessment by GBRMPA is presented.

Mooring design for tourist pontoons is a specialist marine engineering task, which must be carefully integrated with site selection, pontoon layout and configuration, anchor and pontoon body design. In addition to providing for structural integrity of the pontoon and mooring system, the designer must recognise the multipurpose requirements of tourist pontoon facilities, relating to function and safety, amenity and environmental protection. The technology for developing and designing pontoon mooring systems on the GBR to meet these requirements, is far from complete. Many difficulties must yet be addressed and overcome before comprehensive guidance for mooring design can be provided to practitioners and managers.

The type and configuration of pontoon moorings are governed by site characteristics and the need to withstand tropical cyclonic loadings and to satisfy operating conditions. Pontoons are normally located over and adjacent to corals in shallow water, typically less than 20 metres deep. Whereas prevailing weather conditions are predominantly calm, the severe conditions that occur

during tropical cyclones require provision of substantial mooring systems, which are not readily accommodated in, or compatible with, the shallow water and fragile environment in which the pontoon is situated. Alternatives to the conventional chain and block catenary mooring system involving components such as elastic element inserts are being considered, and research and development of enterprising and innovative solutions must occur to adequately address mooring requirements.

This guide to mooring design reflects “work-in-progress” on the development and design of appropriate mooring systems for the GBR, and provides a base for on-going development of a more comprehensive approach. Pontoon operators and designers are encouraged to collaborate with researchers and managers to this end. Techniques may change over time as a result of new research, proven methods and modern technology, and improved mooring and anchor systems may be developed as alternatives to those described.

The design procedures presented in this Chapter follow a simplified and conservative mooring design approach. Alternative approaches and techniques, such as sophisticated dynamic mooring design packages may be considered, but this may require an investment of resources in research, development and analysis to demonstrate their suitability. The procedures are not intended to be prescriptive. This would be inappropriate due to the variety of conditions and circumstances encountered, and the complexities of designing moorings for these conditions. The characteristics of some complex projects may require more comprehensive investigation and design approaches than those outlined here.

This guide should be applied to both new tourist pontoon installations and to existing facilities that are to be upgraded or retrofitted to meet updated requirements for installations on the GBR. It may also be used to guide the design of other, smaller pontoon-type structures, such as swim platforms, helicopter pontoons, and floating decks for reef and jetty access, which are often used in the Reef environment in conjunction with the tourist pontoons. Many of the principles and details presented here will apply to such auxiliary structures, even though their function, configuration and detail differ from tourist pontoons.

Mooring design will usually be undertaken in three stages of a pontoon project: Step 2 (*Concept Phase*), Step 4 (*Feasibility Phase*) and Step 6 (*Implementation Phase*) of the *10-Step Planning, Design and Implementation Procedure* (Chapter 3), as outlined in Box 7.1. The mooring design task is usually undertaken in conjunction with the pontoon layout and configuration (Chapter 6) and anchor design (Chapter 8).

Project concepts must be well developed, and an extensive array of input information must be compiled prior to undertaking mooring design. The decisions and outcomes of these early studies are intimately related to the mooring system that will be adopted, and consideration must be given at this stage to the needs and constraints that will be placed on the mooring arrangement. Due to the complex and iterative processes involved in mooring design, several trials and evaluations may be needed prior to development of a final arrangement that satisfies all criteria. The following assessments and studies would typically be well advanced before formal mooring design commences:

- site selection for the pontoon
- conceptual design of the size, geometry and profile of the pontoon
- selection of the preferred orientation of the pontoon
- development of a sensible and practical pattern and layout of mooring lines
- determination of wind, wave and current design loads at the site.

Box 7.1 Indication of project phasing for <i>Mooring Design</i> task refer 10-Step Project planning, design and implementation procedure (Chapter 3, Box 3.2) and Project planning and design task schedule (Chapter 3, Box 3.3)	
Purpose	Task description
Phase 1 <i>Concept</i>	
Step 1 Initial Concepts	No significant activities.
Step 2 Concept Design Develop alternatives for mooring configuration and components	Consider alternative mooring line corridors and anchor locations to suit the preliminary layout and configuration of the pontoon facilities and mooring system for new or upgraded facilities. Prepare concepts of the mooring system, considering alternative mooring types and likely sizes to suit the alternative mooring layouts. Consider methods for installation and salvage of the mooring system. Discuss proposals with GBRMPA, and document and submit information for assessment.
Step 3 GBRMPA Preliminary Assessment	Preliminary consideration of the suitability of the alternative mooring systems proposed and identification of non-conforming issues relating to mooring type and size etc.
Phase 2 <i>Feasibility</i>	
Step 4 Feasibility Design Prepare detailed mooring designs to suit the layout and configuration of the mooring system.	Prepare detailed mooring layout and configuration to take account of the pontoon facility requirements; site characteristics such as suitable mooring line corridors and anchor locations; acceptable movement limits for the pontoon, mooring lines and components; and the environmental loads from winds, waves etc. Consider conventional catenary type mooring systems or alternative taut mooring system attached to fixed piles. Analyse the structure to determine mooring system forces and movements on the basis of the design loads and the geometry and configuration of the mooring system. Compare mooring capacities and movement limits with mooring design forces, and choose mooring types, configuration and sizes. Prepare engineering drawings for the mooring system, showing detailed layouts and configurations of the moorings, and upgraded components for existing facilities. Consider methods for installation and salvage, and operation and maintenance of the mooring system. Discuss feasibility designs with GBRMPA, and document and submit information for assessment.
Step 5 GBRMPA Detailed Assessment	Confirm, reject or suggest modifications to mooring design, engaging specialist assistance, as required.
Phase 3 <i>Implementation</i>	
Step 6 Detailed Design Prepare detailed designs and specifications for the mooring system components.	Undertake detailed design analyses to finalise sizes, material requirements and construction methods for mooring components. Prepare workshop fabrication drawings, specifications and tender documents for the mooring system components.

7.1 Mooring line arrangements, behaviour and good design practice

Moorings represent the critical structural element in a tourist pontoon facility, often controlling the performance and acceptability of the entire project. The following factors increase the cost and difficulty of mooring design for pontoons in the GBR compared with other offshore structures:

- Pontoons are usually positioned very close to coral that is sensitive to physical disturbance. Thus the movement of the pontoon must be severely restricted, requiring a “stiff” mooring system.
- Location of anchors and mooring lines are often restricted by the presence of coral formations. This often makes the mooring system asymmetrical and reduces the possible length of lines, both of which affect mooring integrity and complicate analysis and design.
- Pontoons are often moored in relatively shallow water, reducing the effective load capacity of the mooring system. Once a line is completely mobilized (off the ground), it is perilously close to the taut (“snatch”) condition, which must be avoided. Thus shallow water moorings demand much smaller tolerances in pontoon position.
- The mooring system must also handle extreme forcing during tropical cyclones, as well as hold the pontoon in a relatively rigid position during milder operational conditions. Thus a single mooring system requires innovative techniques, or a dual system could be used.
- The shape and size of pontoons are very different from the ships, floating (oil) platforms or barges, upon which almost all of the previous knowledge of mooring systems is based.

Mooring arrangements and line characteristics

A multi-point mooring system, comprising a mooring line and anchor connected to each of, at least, four points on the pontoon, has conventionally been used. These mooring lines comprise heavy mooring chain attached to one or more anchors on the seabed for each mooring leg. Conventionally, dumper blocks, clump weight sinkers and line buoys have been used in an attempt to dampen the dynamic effects of the mooring forces on the anchors and to reduce the likelihood of the mooring lines coming in contact with and damaging the corals. Various supplementary *cyclone mooring* arrangements, such as a single-point, cyclone swing mooring, have been employed for extreme conditions in some installations.

Alternative pontoon mooring systems and their performance characteristics are described in Box 7.2, and simplified illustrations are presented in Box 7.3. Typical mooring line components and their characteristics are presented in Box 7.4.

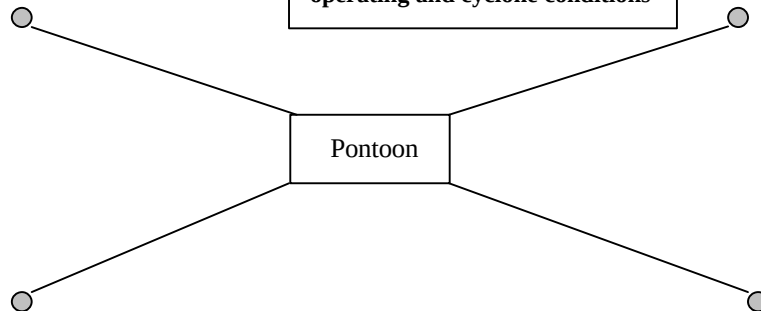
Box 7.2 Alternative pontoon mooring systems	
Mooring system type	Description and performance characteristics
1 Combined mooring	This mooring type uses a single system of restraint for both normal operating conditions and cyclone conditions.
2 Sacrificial cyclone mooring	This system uses sacrificial mooring lines, which secure the pontoon close to the reef during pontoon operation, but which are designed to fail during cyclone conditions, allowing the pontoon to weathervane around an admiralty mooring.
3 Permanent cyclone mooring	This system is similar to System 2, although the admiralty mooring, which allows the pontoon to weathervane, provides the permanent mooring system. During daily pontoon operation, extra lines are used to winch the pontoon closer to the reef.
4 Dual mooring	This type employs two completely independent mooring systems. A permanent mooring is provided for operating conditions close in to the reef, whereas under impending severe conditions, the pontoon is relocated to a temporary cyclone mooring, allowing the pontoon to weathervane around an admiralty system.

Box 7.3 Pontoon mooring system configurations

System 1

Combined Mooring

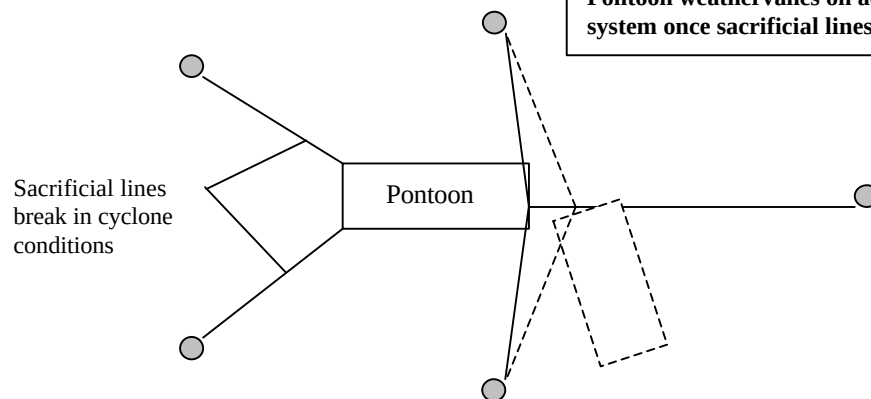
Single mooring system for operating and cyclone conditions



System 2

Sacrificial Cyclone Mooring

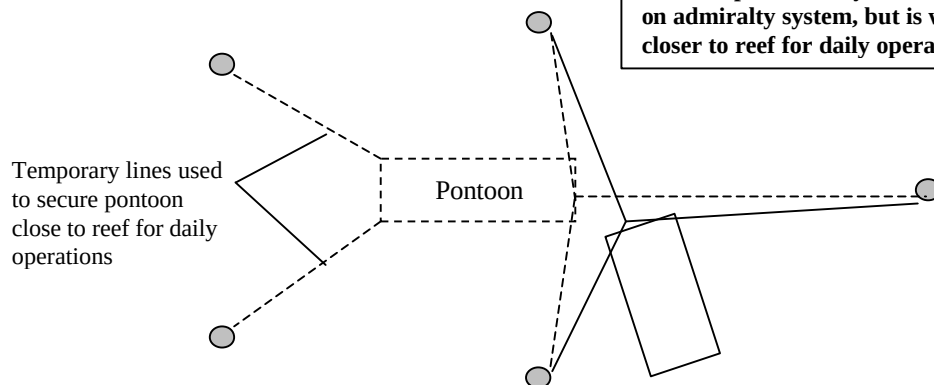
Pontoon weathervanes on admiralty system once sacrificial lines break



System 3

Permanent Cyclone

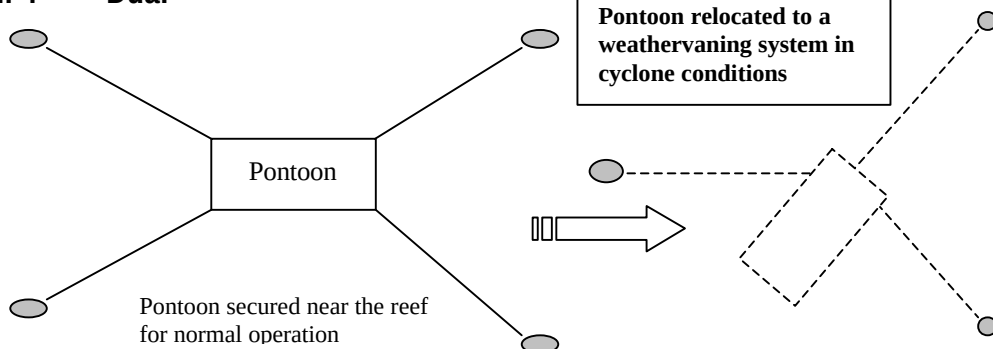
Pontoon permanently weathervanes on admiralty system, but is winched closer to reef for daily operation



System 4

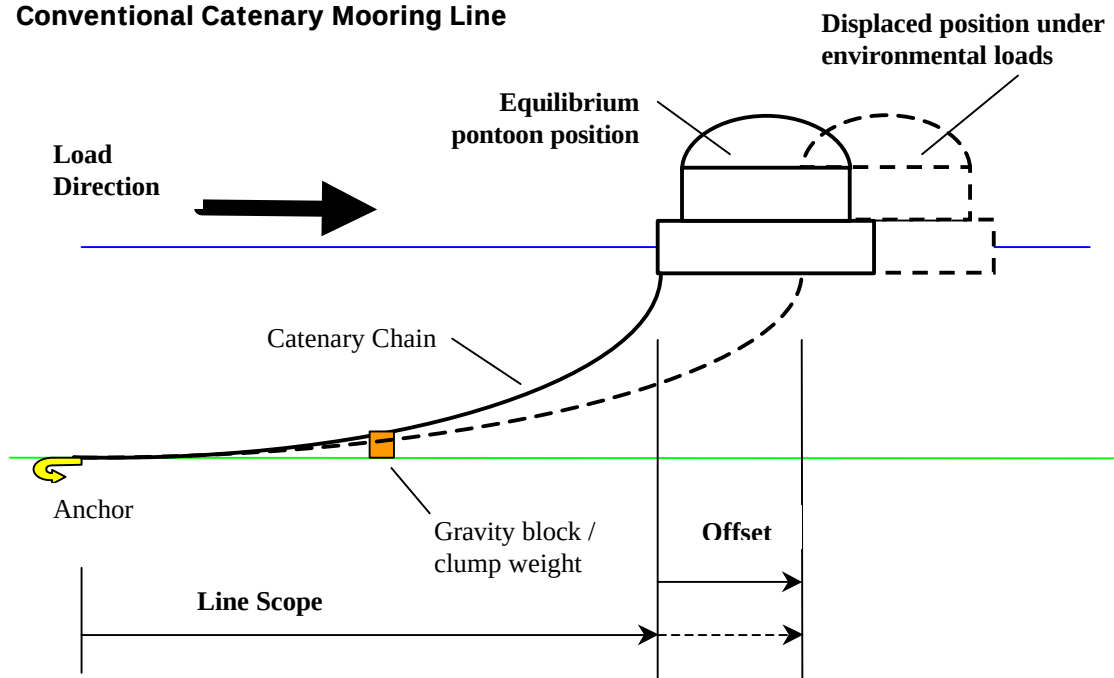
Dual

Pontoon relocated to a weathervaning system in cyclone conditions

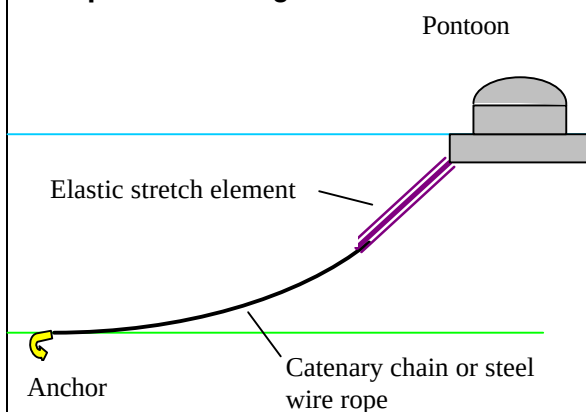


Box 7.4 Mooring line components and characteristics

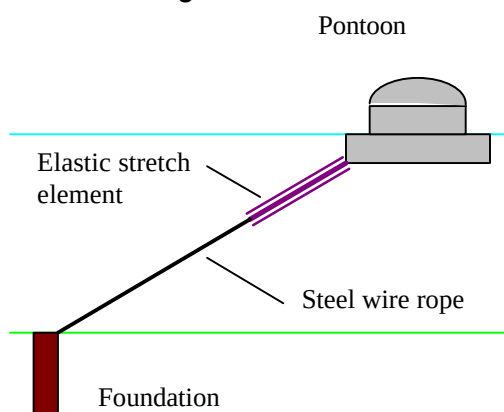
Conventional Catenary Mooring Line



Composite Mooring Line



Taut Mooring Line



Performance characteristics of a *catenary*

A catenary shape is formed by a chain or rope that is suspended between two points, supporting its own weight. This type of mooring line absorbs forces through the spring-like action of the straightening of the catenary shape of the line as it hangs under the action of the load applied and its own self-weight. While the catenary retains this spring prior to straightening, it is considered to behave *flexibly* to applied load. As the catenary straightens out, it becomes progressively *stiffer*, ie. the force required to extend the line any further, increases manifold. When the catenary line is stretched to the point of straightening, it is said to have *snatched* (because this stretching occurs dynamically and the line jerks and snatches as the load then attempts to stretch the material of the mooring line).

Mooring line behaviour and key design issues

Mooring lines are used to hold and restrict the movement of pontoons that are subject to environmental loads associated with wind, wave, current and the effects of water level changes, as well as berthing loads from the access vessels. For simplification, applied environmental loads are normally separated into those that apply relatively steady forces (ie. wind, current and a component of wave loading), and those that induce oscillatory motions (ie. wave frequency motions and slow wave drift effects). Further explanation of the steady and oscillatory contributions to wave loading on floating vessels is provided in Tsinker (1995) and API (1995). General comments on the relative contribution of wind, wave and current to the total force are noted in Box 7.5.

Box 7.5 Relative contributions of wind, wave and current to total force applied to pontoons

The relative contribution of wind, wave and current to the total force acting on a pontoon facility can vary sharply, depending on several factors:

1. Pontoon shape and profile above and below the water line.
2. Intensity of the environmental loading.
3. Direction of wind, wave and current loading relative to pontoon orientation.
4. Degree of protection offered to approaching waves.
5. Site bathymetric profile as it effects waves and development of currents.

Either wind, wave or current forces could dominate the combined force in any specific situation, depending on the site, pontoon and event characteristics. It is also possible that for a particular pontoon at a specific site, wave loading could dominate in one direction in operating conditions, for example, whilst wind loading in another direction could dominate in cyclonic conditions.

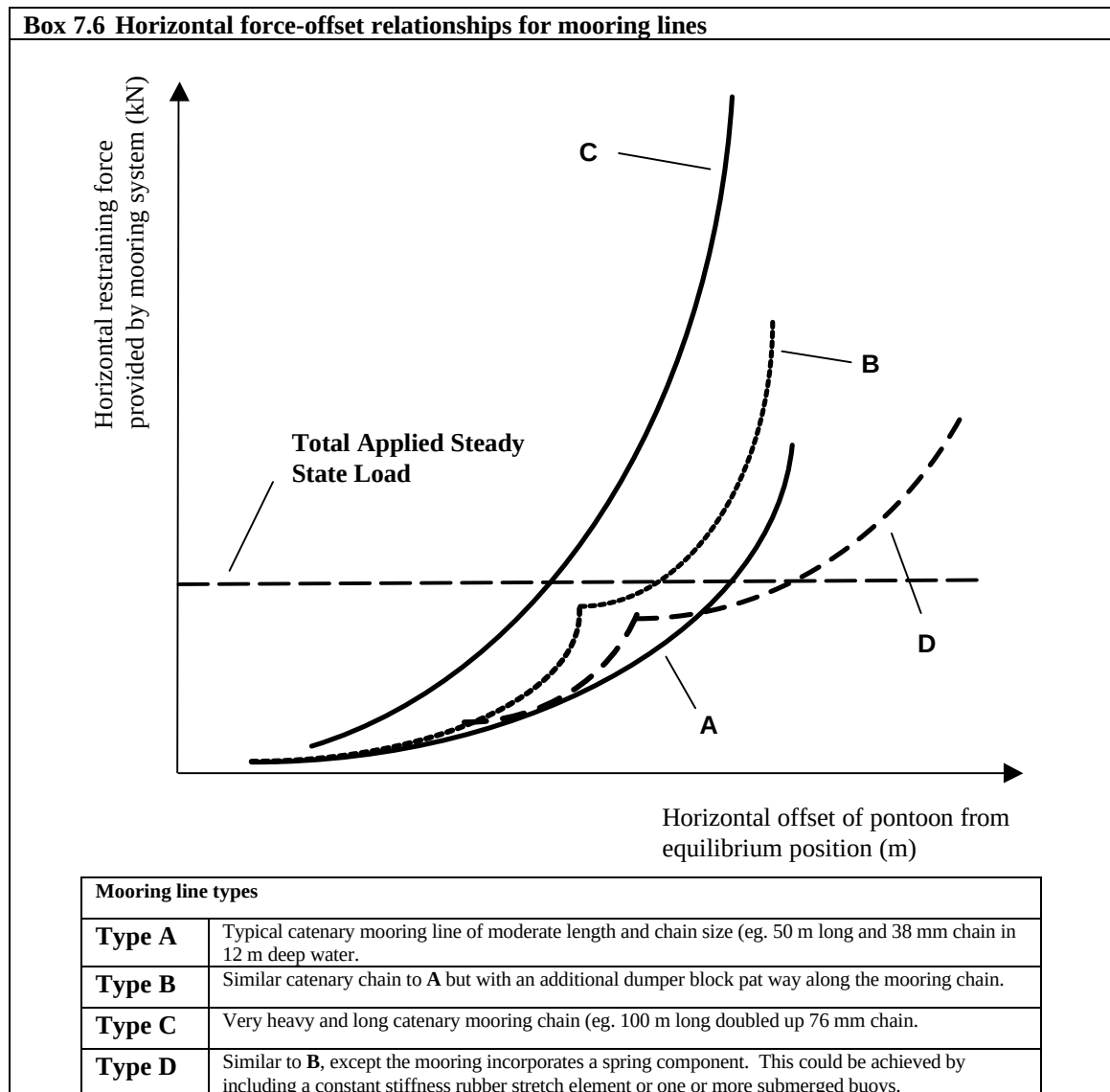
In most instances, current loading is not expected to dominate in extreme events, because, for other functional reasons, sites will normally be chosen so that currents are minor. The maximum wind load is directly proportional to the amount of windage area exposed, and, depending on the five factors listed above, may be more or less than forcing from wave effects.

As forces from wind, waves or currents are applied to the moored structure, the structure moves and the forces in the mooring line(s) change. Force-offset curves are used to illustrate this behaviour. The force-offset characteristics of several hypothetical mooring lines (Box 7.6), illustrate the principal issues complicating the practical and economical design of mooring lines for tourist pontoons in the GBR. The water at pontoon sites is relatively shallow, and extreme loading may occur as a result of tropical cyclones.

For the entire mooring system (which usually comprises several individual lines), to safely restrain the pontoon under the applied environmental loading, the system must be capable of accommodating a finite degree of oscillation around the steady state load condition. The magnitude of this oscillation is comparable to the wave height. It is very difficult and expensive to develop mooring lines for these pontoons (positioned close to reefs) such that reasonable scope for oscillation around the steady state load offset is available in extreme environmental loading.

For **Mooring Lines A and B** in the diagram, the pontoon has very limited ability to oscillate about the point of steady state load offset. In this case, the mooring lines snatch at very small offset distances beyond the point where the line of steady state force crosses the mooring line force-offset curve. These snatch conditions cannot be permitted as this not only threatens failure of the mooring lines, but also induces unstable dynamic motions.

Mooring Line C offers an improvement to that of **A and B**, although the scope for oscillation before snatching is still quite limited. Furthermore, this arrangement would be excessively expensive, the length may not be able to be installed, and the weight on the pontoon in extreme environmental loading may compromise buoyancy. **Mooring Line D** theoretically provides reasonable flexibility even beyond the point of steady state load offset, thereby offering a most desirable force-offset performance relationship for the pontoon in extreme loading. Because it is also important to hold the pontoon in a relatively rigid position during milder operational conditions, arrangement **D** can be even more effective if the maximum offset in operating conditions is maintained just prior to the lifting of the clump weight (ie. just before the kink in the force-offset curve in Box 7.6). Unfortunately, no proven existing **Type D** arrangement is readily available. A **Type D** characteristic force-offset curve can however be created in theory, and two examples of devices that can be used in conjunction with conventional catenary lines are described in Box 7.7, together with comments on their present limitations:



Box 7.7 Components used to achieve the flexibility of a <i>Type D</i> mooring line	
Mooring line component	Performance characteristics
Elastic (rubber bungy) element on the end of a catenary chain.	This system is very effective in theory, but suitable products for the capacity required are as yet unproven. Issues of end connection, long term durability and life of elasticity are unresolved.
Submerged buoys , in conjunction with dumper blocks in a conventional catenary.	The use of multiple large units, as would be required to provide sufficient capacity, is as yet untried. Buoys introduce their own dynamic response, which can adversely affect the behaviour of the entire mooring system. Multiple submerged buoys may be undesirable for aesthetic and access reasons.

Good design practice

Until innovative systems such as those described above are readily available and proven, it will be difficult to develop and design a feasible pontoon mooring system that will be adequate for both operating and cyclonic conditions. Given the difficulties presently experienced in developing the necessary ***Type D*** characteristic force-offset curve, operators and designers must also focus their attention on methods to reduce the magnitude of loads imposed on pontoons. Some practices that can contribute to significant reductions in the forces induced in mooring lines and the associated movements are described in Box 7.8. Chapter 6 – *Pontoon siting, layout and configuration* deals with these issues.

In addition to the general principles for siting and configuration that aim to reduce mooring systems requirements, several other *good design practices* that promote stability and reliability should be adopted (Box 7.9). This list is not intended to be exhaustive, and designers should also conform to conventional best marine engineering practices, applicable to moorings restraining floating vessels in relatively shallow water conditions.

Box 7.8 Design considerations to reduce loading and other demands on pontoon mooring systems	
Design aspect	Design provisions
Site selection	Choose a site that offers protection against waves in most directions (particularly the more common wind directions), and where currents are small. Avoid conditions that could produce breaking waves. Select a location that offers an adequate number and length of clear corridors around the pontoon for laying out mooring lines and anchors.
Pontoon orientation	Orientate the long side of the pontoon parallel to the direction of maximum wave loading. Notwithstanding this, consideration should also be given to the predominant direction and intensity of wind and current.
Pontoon body	Reduce the drag of the pontoon profile above the water line. Pay particular attention to canopy structures, and the means of minimising drag coefficients and the wind load area on the structure. Whereas collapsible canopy systems offer potential advantages, reliable mechanisms for these are not adequately developed. Canopies that are removed or manually collapsed in an impending cyclonic event may provide a more reliable system. Minimise the under water profile and the drag coefficient of the pontoon structure. Consider reducing the aspect ratio (ie. length to breadth ratio of the pontoon), as a means of enhancing stability (particularly roll). Consider using catamaran shaped hulls instead of the conventional circular tube floatation units. Orient these hulls parallel to the primary wave direction (with no closure hulls normal to the primary wave), and adopt a stiff structural deck. This will significantly reduce wave and current forces in directions parallel to the long side of the pontoon.
Mooring arrangement	Ensure reasonable symmetry in the mooring system configuration and symmetry in the effective stiffness (particularly in the direction of maximum wave loading), to share induced load evenly and minimise pontoon rotation. Provide sufficient scope and mass in mooring lines, and sufficient stretch in elastic elements (if used), to achieve an acceptable range of movement while maintaining moderate stiffness, thereby avoiding <i>snatch loading</i>.

Box 7.9 Design practices to promote mooring system stability and reliability
Avoid passing mooring lines over the top of coral outcrops. Avoid splitting lines in two, as a means of accommodating coral obstructions. If this is unavoidable or if lines are split to permit load to be shared between two anchors, minimise the angle between the split lines. Avoid use of synthetic rope in mooring lines where possible, because some doubts exist relative to long-term durability, effects of fish bites, and difficulty with end effects. Use pre-tension of lines intelligently as a means of restricting pontoon movements during operating conditions. Pre-tension can offer benefits to pontoon stability and comfort, in addition to improved restraint and better performance under dynamic loading during operational conditions. Tension should be set so that pontoon excursion is limited during operation, but without rendering the system too stiff during extreme conditions.

7.2 Design methodology

Conventional design approaches for mooring systems can be grouped into four generic procedures. Box 7.10 lists and explains the basis behind each of these four methods, and summarises the positive and negative attributes of each with respect to floating pontoon structures moored in a shallow water environment. Each of these methods is discussed below, and a recommended design approach is identified.

Recommended design approach

Due to the shortcomings of the *Simplified Equivalent Static* approach (Box 7.10), this procedure is not suitable for assessment of floating pontoons in the GBR environment and should not to be used. In these *Guidelines*, attention is focused on a simplified form of the *Quasi-Static* approach because it offers a systematic method that can be applied in a consistent and clear manner. It can also provide solutions with an acceptable degree of confidence. Simplifications are necessary, since certain parameters needed for the conventional *Quasi-Static* approach have not been developed for tourist pontoons moored in GBR type conditions. The suggested method is referred to as the *Simplified Mooring Design Procedure (SMDP)*.

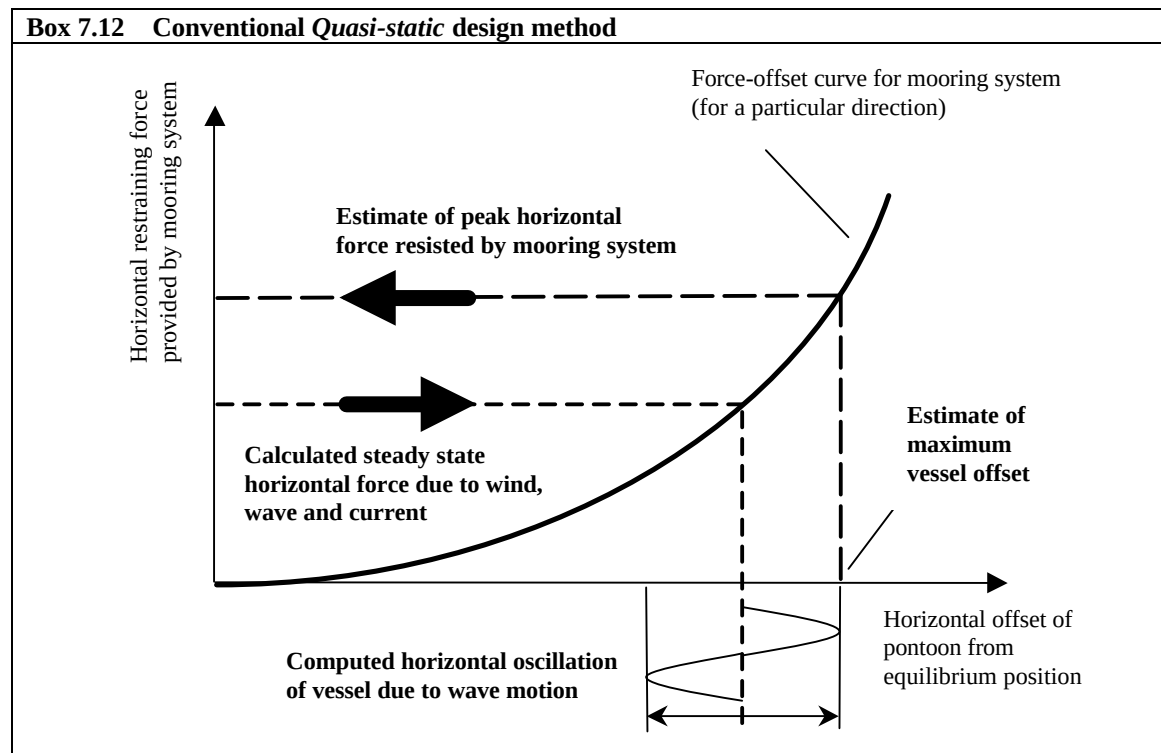
More sophisticated *Dynamic Numerical Model* or *Physical Model Response* approaches can be adopted, provided professionals qualified and experienced in this specialist field of marine engineering coordinate and undertake these studies. These approaches are specifically recommended where a non-conventional mooring system is proposed, and where the pontoon mooring arrangement does not meet the prerequisites set down in Section 7.3 (Box 7.16 - *Prerequisites for application of the SMDP*). Box 7.11 summarises the required capabilities for numerical and physical models, if they are to be applied to pontoon mooring design in the GBR. This is followed by a description of how the *Quasi-static* approach is modified to produce the *SMDP*, which is supported in these *Guidelines*.

Box 7.10 Design approaches for pontoon mooring systems		
Characteristics	Advantages	Disadvantages
Design Method 1 - Simplified equivalent static load procedure <i>Not recommended for design of mooring systems for tourist pontoons.</i>		
This method assumes applied environmental forces can be represented as a single static horizontal force, which produces a corresponding static vessel displacement. The technique disregards the dynamic component of applied forces, mooring response and pontoon movement. Conventional engineering equations are used to compute a steady state force for wind, wave and current loading.	This method is simple and can be easily standardised.	It ignores dynamic effects. The static procedure can grossly misjudge peak mooring line loads (it will underestimate forces for the typical shallow water and stiff mooring systems used in the GBR). It provides a very poor estimate of likely peak pontoon offset under applied loads.
Design Method 2 – Quasi static approach <i>Refer to API (1987a) for a full description of the method. Force equations and coefficients for determination of steady state forces from wind, wave and current appear in publications such as DNV (1991) and BS6349 (1989).</i>		
This method separates environmental loads into steady state and dynamic components. Conventionally, wind and current are considered as steady state forces, as is a component of wave loading, referred to as the steady drift force. Normally, the steady drift force is estimated from design curves, which have been developed from computer models for specific vessel types. <i>Mean vessel offset</i> is determined by balancing the combined steady state force applied to the pontoon with the offset that produces a matching static resistance by the mooring system. Vessel motions are assumed to result from a combination of wave frequency motions and a low frequency (wave drift) effect. The <i>amplitudes</i> of these motions are estimated either by direct modelling or, where available, by reference to published charts developed for similar vessel types. <i>Maximum vessel offset</i> is estimated by adding the <i>mean offset</i> to the combined <i>amplitudes</i> of the vessel motions. Peak mooring forces are determined by computing the static restraint developed in the mooring lines when the vessel is positioned at the peak offset.	Method is applied in a series of clearly defined steps. Provides some account of the dynamic response factors. In combination with appropriate safety factors, can produce safe designs. Often incorporates performance data from real monitoring.	Account for dynamic effects is only approximate. Embodies numerous approximations and simplifications. The conservativeness of the method has only been verified for a particular range of vessels and for medium depth water.
Design Method 3 - Dynamic numerical model		
Uses advanced computer programs to simulate the dynamic vessel response and associated mooring forces. Commercial software programs are available, for example AQWA, 1995 and programs based on Van Oortmerssen, 1976.	Permits full appreciation of the dynamic influence factors in loading and response. Accommodates the complex interaction and interdependence between the pontoon and the mooring system. Allows sensitivity analysis to examine the relative importance of various parameters and load types.	Requires detailed and complex input data to be compiled. Difficult to standardise the method. Difficult to test the accuracy of the solutions produced by a particular model. Difficult to assess whether a particular program is suitable for the specifics of pontoons in the GBR environment. Expensive and time-consuming to complete analyses.
Design Method 4 – Physical model response		
Determines the performance and response of the prototype vessel, using a scaled physical model of the vessel and mooring system, and subjects the system to the design wind and hydrodynamic forces.	Studies the performance of the actual pontoon configuration. Permits direct determination of pontoon offset and mooring line tensions.	Expensive to construct and operate. It is a complex task to ensure all properties are appropriately scaled. Difficult to re-produce the actual range of environmental loads applied.

Box 7.11 Minimum requirements for numerical and physical modelling based design approaches	
Design Method 3 – Dynamic numerical model	
Wave forces on the pontoon should be evaluated with due consideration of the relative importance of drag, inertia and diffraction effects. Provide justification of the choice of solution method for wave forces.	
The following contributions should be included and justified in the representation of the hydrodynamic damping of the motions of the pontoon, unless it can be demonstrated that a particular contribution has limited significance, or that the case being modelled is not a governing design case:	
Wave frequency motions	• frequency dependent damping • radiation damping • viscous drag contributions
Low frequency motions	• wave damping • viscous drag contributions • chain line damping
Wind and current drag force coefficients on the pontoon are to be evaluated from published data, if available. Otherwise, wind tunnel and current flume testing is to be used to determine the required drag force coefficients. Wind and current forces may be modelled as steady loads.	
Wave frequency and low frequency (drift) wave forces on the pontoon are to be determined by a three-dimensional potential flow solution.	
Time domain simulations are to be carried out for three-hour realizations of each sea state under consideration. Each three-hour sea state realization must be continuous, non-repetitive, but repeatable.	
The non-linear restoring stiffness characteristics of the pontoon catenary spread mooring are to be incorporated in the numerical model of the pontoon dynamic behaviour.	
The modelling must take into account any relevant operating practices for the facility.	
Analyses must consider credible worst combinations of circumstances.	
Design Method 4 – Physical model response	
An experienced physical modeler should design and coordinate the study and interpret model results.	
A detailed model test specification should be produced in advance of any model building and model testing activities. The model test should be carried out in accordance with best practice and in particular the following requirements should be observed.	
All physical testing of the pontoon model should be undertaken at a scale that is both suitable for the working area of the wave basin or flume, and does not reduce the confidence in the results of the physical modelling study. Model scale ratios of less than 1:60 may be too small to provide reliable sea-state representations. The full scope of the pontoon mooring lines should be modeled. The working area of the wave basin or flume is to be of sufficient size to accommodate the full scope of the mooring lines with respect to the axis of wave loading.	
The scale model of the pontoon should take into consideration both the structure below sea level and all the elements above the water level. In particular, where deck structures are significant and may attract significant wind loads, these should be modeled in keeping with the model scale.	
The immersed mass per unit length of the mooring lines is to be scaled in keeping with the chosen model scale. Appropriate steps shall be taken (for example, in regard to surface roughening, cross-section area distortion), to ensure that scaling of hydrodynamic drag forces on the mooring lines is in keeping with the chosen model scale.	

Development of the SMDP from Design Method 2 – Quasi-static design approach

The *Quasi-Static* method refers to a simplified design approach, where the effects of dynamic response are accommodated in an equivalent static manner. The maximum anticipated oscillatory response of the vessel to a particular level of environmental (wave) load is superimposed on top of the vessel offset resulting from the steady component of the environmental loads. These effects are combined to provide an estimate of the maximum vessel offset and the associated peak line forces. Moderately high factors of safety are normally applied to the peak line forces estimated with this technique, in view of the many approximations that are introduced. Box 7.12 illustrates the fundamentals of the conventional *Quasi-Static* approach and explains how the response is determined. The fundamental differences between the conventional *Quasi-Static* method and the suggested *Simplified Mooring Design Procedure* for tourist pontoons are explained in Box 7.13.



Box 7.13 Modifications to the conventional <i>Quasi-static</i> design method	
Design aspect	Modifications
Steady state loads	The simplified method effectively adopts the same approach as the conventional method, computing the steady load contributed by mean wind, wave and current. In respect to mean wave loading, however, the conventional approach uses published relationships for mean wave drift force, produced for ship-shaped and semi-submersible facilities. Tourist pontoons have significant dissimilarities to these other floating structures and no data are available. An alternative method is used, based on the assumption of full wave reflection.
Oscillating motions	
Peak offset and line forces	
	In the conventional method, the magnitude of oscillations (comprised of slow drift oscillations and wave frequency oscillations), is approximated by using <i>Response Amplitude Operators (RAOs)</i> , which present results of model and field measurements of ship and semi-submersible facilities for different wave periods and facility classes. Unless <i>RAOs</i> have been specifically developed for tourist pontoon structures of the type to be used, a conservative approach is adopted. It is assumed the oscillating motion of the pontoon matches that of a water particle in the prevailing dominant wave frequency. Only the horizontal component of oscillation is used, whereas the vertical component is neglected.
	No adjustment is made to the conventional <i>Quasi-Static</i> technique when calculating the peak offset position of the pontoon and the maximum force generated in the mooring lines once the steady state force and oscillating motion have been defined.

Summary: Mooring design policy adopted in these <i>Guidelines</i>
• The <i>Simplified Equivalent Static</i> procedure is not suitable for assessment of floating pontoons in the GBR environment and should not to be used. • These <i>Guidelines</i> focus on the <i>Simplified Mooring Design Procedure (SMDP)</i>, which is a simplified form of the conventional <i>Quasi-Static</i> approach. • More sophisticated analysis using a Dynamic Numerical Model or a Physical Model Response, may be considered by experienced professionals.

7.3 Simplified Mooring Design Procedure

In formulating the *Simplified Mooring Design Procedure (SMDP)* for use in the design of practical mooring systems for pontoons in the GBR, the following key principles have been adopted (Box 7.14).

Box 7.14 Guiding principles for <i>Simplified Mooring Design Procedure (SMDP)</i>
The method must be relatively simple and hence conservative, providing a rational solution to this extremely complex inter-active problem. The design process must produce a solution that ensures the system behaves in a predictable and flexible manner while providing the necessary restraint to satisfy comfort and safety criteria The design approach must be non-prescriptive, recognising the individuality of projects and the experience offered by mooring design practitioners. (Consequently, onus is placed on practitioners to be skilled in the design of mooring systems in the GBR environment, because the solution procedures are not exhaustive). While the design procedure would focus on a conventional system of catenary mooring lines, it would not stifle alternative approaches if they were adequately validated. Innovative solutions would be encouraged where these systems are credible and performance has been proven. (The procedure presented is applicable to composite mooring systems containing catenary lines with elastic insert segments, however it should not be applied directly to a <i>taut mooring</i> system because of the uncertain dynamic response characteristics with this type of system).

The SMDP can be applied to the design of conventional chain and wire rope catenary mooring line restraint systems. It can also be used for the design of catenary mooring lines that incorporate an elastic (stretch) element. It cannot be applied to the design of a *taut* mooring line system because the behaviour, dynamic response and forces generated within this system are vastly different to that of a catenary mooring line arrangement. A full dynamic numerical model or physical model must be employed to determine response and facilitate design of a *taut* mooring line system. Pre-requisites for adopting the simplified design procedure in the analysis and design of a conventional mooring system for tourist pontoon project are identified in Box 7.15.

Box 7.16 lists the sequence of design tasks for the *Simplified Mooring Design Procedure*. Details of each of these design steps, and how they are applied to mooring systems for pontoons in the GBR environment, are described in the subsequent sections. Many of the design principles and specific criteria that are defined and explained apply equally to the *Dynamic Numerical Model* or *Physical Model Response* design approaches.

Box 7.15 Pre-requisites for application of the <i>Simplified Mooring Design Procedure</i>	
Design aspect	Comment and Limitations
The pontoon must be designed to behave in a stable manner, particularly with limited roll motion	Roll response will be a function of the pontoon length, breadth and aspect ratio; the wave characteristics; the mooring pattern; and the restraint provided in cyclone loading. If roll is severe, then pontoon displacements will have an excessive vertical component, compromising the basis behind the simplified approach. Although not a compulsory requirement, it is strongly recommended that mooring arrangements do not incorporate lines that cross over underneath the pontoon. This system contributes to increased roll response and threatens the integrity of the SMDP solutions.
The pontoon must not be positioned in exposed sea conditions, ie. fetch must be limited in all directions.	Pontoon vertical motions would be considerable in exposed seas and in these conditions the <i>Simplified Mooring Design Procedure</i> can not provide reliable solutions. As with excessive roll behavior, the scale of motions will induce additional stretching and dynamic behaviour of mooring lines and subsequent increases in line forces. These are not adequately accounted for by the procedure.
The mooring system must comprise several lines configured in a balanced radial pattern with compatibility in <i>effective stiffness</i> .	Although an entirely symmetrical layout is usually not possible because of physical obstructions and other constraints, designers should aim for balance. The key lines that combine to resist the applied load in a particular direction should have similar <i>effective stiffness</i> , to avoid excessive rotation (yaw), and to help achieve an even distribution of mooring loads.
Where conventional catenary lines are proposed, generous scopes must be provided.	Mooring line scopes typically greater than four to six times water depth will be necessary for the system to display sufficient flexibility over a realistic range of movement. Greater mooring line scope also assists in limiting the vertical component of load applied to seabed anchors by attached mooring lines.
Sufficient extension must be provided in elastic element inserts if they are used in catenary mooring lines.	Extension of the elastic element during the peak pontoon offset must not exceed the manufacturer's limit on elastic stretch.
Buoys shall not be used in the mooring system.	Historically, (submerged) buoys have been used in some projects with the intention of elevating mooring lines above the seabed to reduce abrasion damage to the coral. Buoys, however, introduce complex dynamic line response characteristics, which cannot be accommodated by the SMDP.

Box 7.16 Design task sequence for <i>Simplified Mooring Design Procedure</i>	
Steps	Task description
A	Identify criteria, constraints and design inputs 1. Verify the applicability of the <i>Simplified Mooring Design Procedure</i> for the project. 2. Obtain data on site physiography, pontoon size and preferred pontoon position (Chapters 4 and 6). 3. Define pontoon geometry, profiles and displacement (Chapter 6). 4. Define exclusion zones around the pontoon site where mooring lines are not permitted, and define the constraints on permissible pontoon and mooring line movements (Chapter 6). 5. Input conceptual plan for number, type and geometrical arrangement of mooring lines (Chapter 6). 6. Input design wind speeds, wave heights, currents and water levels (Chapter 5).
B	Define load cases Based on the conceptual arrangement for the pontoon position and mooring system layout: 1. Define the different load cases that must be considered. 2. Set design environmental conditions for each load case.
C	Determine steady state environmental forces For each load case: 1. Determine projected areas to be used for steady state force calculations. 2. Assign appropriate drag/drift factors to each body area for wind, wave and current loads. 3. Compute steady state forces for wind, wave drift, current and the combined load.
D	Undertake preliminary design of mooring line properties For <i>beam sea</i> and <i>head sea</i> load directions: 1. Determine the critical load case. 2. Determine the critical mooring line and estimate the proportion of load carried and the maximum design offset due to oscillating motions. 3. Develop a preliminary design of individual mooring line properties.
E	Develop mooring force-offset relationships For each load direction: 1. Develop a force-offset relationship for each mooring line. 2. If Design Method 1 for pontoon offset (Step F) is used, construct a horizontal force-offset relationship for the mooring system for each load direction.
F	Determine mean pontoon offsets and oscillating motions For each load case: 1. Design Method 1: Use the mooring system force-offset relationship to predict mean offset. 2. Design Method 2: Compute the mean pontoon offset for the applied steady state load. 3. Estimate the maximum design offset position of the pontoon due to oscillating motions.
G	Determine maximum line and anchor forces, and line movements For each load case: 1. Estimate maximum pontoon offset. 2. Derive peak force in each mooring line and peak vector force applied to anchors. 3. Define maximum pontoon movement and maximum mooring line movements/sweep.
H	Evaluate performance against design criteria Check conformance of forces and movements with the set design criteria for each load case.
I	Check pontoon stability during operational conditions 1. For each load direction, evaluate the natural resonant frequency of the mooring system and compare with the lowest wave frequency, to ensure a satisfactory margin exists between the two. Ensure that if clump weights are used, they do not lift off the seabed during normal operation. 2. Check that heave and roll motions of the ferry, when berthed, are within tolerable limits for passenger disembarking.
J	Address miscellaneous design requirements 1. Ensure that the pontoon, mooring system and anchors can be readily installed, whilst satisfying environmental requirements. 2. Ensure that the mooring system and anchors can be readily accessed for inspection and maintenance. 3. Ensure that the mooring system and anchors can be salvaged, if necessary, without causing significant damage to the surrounding environment.
K	Confirm and review design 1. Adopt mooring design solution if all criteria and constraints are met. 2. Revise the design if the system is unacceptable (return to Step A or D).

Step A Identify criteria, constraints and design inputs											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step A checks to determine if the pontoon mooring system meets the pre-requisites for using the SMDP approach. The criteria used to evaluate suitability of a mooring arrangement are defined, focusing on whether the configuration: (i) suits the spatial limitations imposed by the site; (ii) confines movements to tolerable levels; and (iii) constrains peak line forces to permissible values. Inputs from other chapters are identified, in particular details of the chosen layout and limits set on mooring movements (Chapter 6), and the design intensity of environmental forces and design water levels (Chapter 5).											

Design criteria used to evaluate the acceptability of a mooring arrangement

On the basis that the pre-requisites listed in Box 7.15 are met, design criteria used to evaluate the acceptability of a particular mooring arrangement are:

- A configuration must be chosen so that individual mooring lines and anchors are positioned within acceptably-located corridors
- Pontoon and mooring line movements are limited to defined maximum values
- Maximum induced force in individual mooring lines is limited to acceptable levels
- The geometry of mooring lines in the extreme loading condition are controlled, as a means of ensuring *flexible* behaviour is maintained
- The natural frequency of the mooring system must be less than the operating wave frequency to protect against resonant response.

With respect to items b) and c), separate limits are specified for different load cases (refer to *Step B* of the *Design task sequence for the SMDP* for definition of load cases). Controls and limits for items a) and b) are set in Chapter 6, while for c), maximum permissible load factors (to be applied to the rated breaking load of a mooring line), are presented in *Step H* of the *Design task sequence for the SMDP*. For item d), controls on line geometry in extreme loading are also specified in *Step H*, whilst for item e), criteria to prevent resonance are outlined in *Step I*. The acceptability of a particular mooring system also relies on ensuring that anchor capacities exceed applied loads. In this respect, the onus is on the designer to adopt anchor capacities (Chapter 8), to match the applied loads predicted by the mooring design analysis.

Design inputs

It is not appropriate for the mooring analysis and design to commence until a preferred and acceptable pontoon siting and orientation has been selected. Furthermore, a conceptual plan of the number and pattern of mooring lines, which satisfies the criteria mentioned in a) above, should be well developed. This geometrical information would be generated as outcomes of the studies in Chapter 6, and is required as input into the analysis and design of the mooring system.

Diagrams and layouts showing the dimensions, geometry and profiles of the pontoon facility, as described in Chapter 6, are required as inputs. These are used to compute the magnitude of environmental forces induced on the pontoon, and consequently must include reasonably advanced models of both the above waterline profile and the below waterline profile, together with an estimate of total displacement. To facilitate force calculations, shape, size and configuration of the pontoon hull must be reasonably well detailed for input.

From Chapter 5, the intensity of environmental loading will be specified in terms of design water levels, wind speeds, current, wave heights and periods. These will be used as inputs, together with the geometrical data described above, to compute the environmental forces applied to the structure.

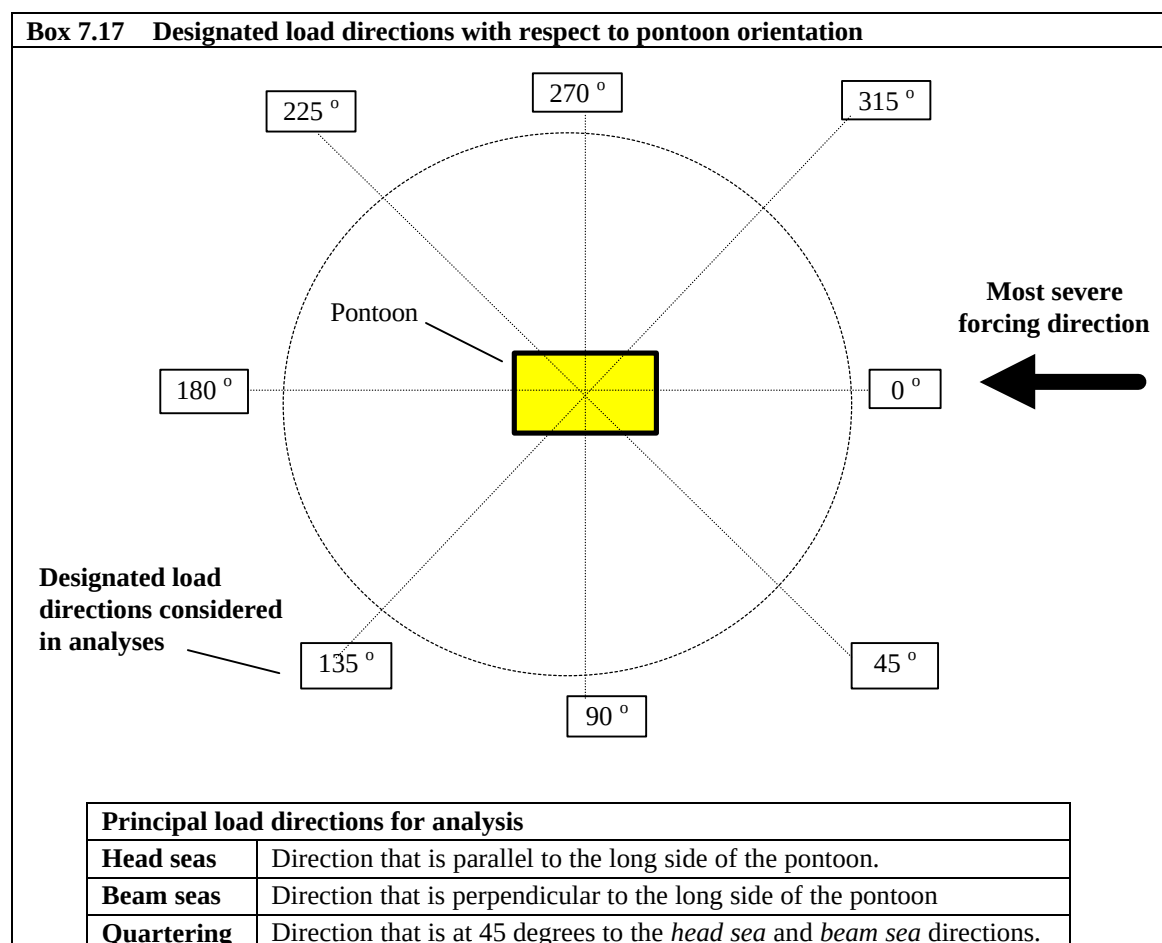
Step B						Define load cases					
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step B defines the various combinations of load cases that must be evaluated for a mooring system. The minimum number of load directions is established, and the various load intensities and design water levels are defined (Chapter 5). The applicability of the conventional <i>damaged mooring condition</i> requirement for design of the pontoon moorings is established.											

To establish the range of load cases to be examined for mooring design, certain project information must first be supplied. Descriptions and illustrations of physical characteristics of the site, pontoon geometry and the conceptual layout of the mooring configuration (refer Chapter 6) will be required. Using this information together with consideration of the following factors, the total number of load cases can be determined:

1. Different load directions
2. Varying intensity of environmental loads
3. Condition of mooring system
4. Changes in water levels.

Load directions

For simplicity, load directions to be adopted in design are defined in Box 7.17, with nominated directions defined relative to the orientation of the long side of the pontoon, which usually will coincide with the direction of maximum exposure to loading. Load directions are defined at 45 degree intervals around the pontoon, ie. a total of eight potential design load directions. If the direction of one of these 45 degree intervals does not align closely with the direction of maximum loading, then additional load directions may need to be examined.



Intensity of environmental loads

The three design states for environmental loading that have been defined in Chapter 5 are summarised in Box 7.18. The intermediate environmental load condition, *Maximum Non-Cyclonic Condition*, is introduced where the **System 4 – Dual Mooring** system is used to secure the pontoon in normal operations and in cyclonic conditions, or when particular lines are designed to break under certain conditions using the **System 2 – Sacrificial Cyclone Mooring** system (Section 7.1). The intermediate condition for **System 4** corresponds to the maximum intensity environmental event occurring at the site, before action would be automatically taken to relocate the pontoon to the alternate cyclone mooring system. The intermediate condition for **System 2** corresponds to the maximum intensity environmental event anticipated before failure of the sacrificial lines occurs.

Design values for wind, current and wave height and period at the pontoon site for each of these load states are specified in Chapter 5.

Box 7.18 Design states for environmental loads (Chapter 5)	
<i>Maximum Operating Condition</i>	The maximum environmental forcing under which the facility would be expected to remain fully operational.
<i>Maximum Non-Cyclonic Condition</i>	The maximum non-cyclonic environmental forcing imposed on the facility.
<i>Cyclonic Condition</i>	A design intensity of environmental forcing during a tropical cyclone event, which has a nominated probability of occurrence.

Condition of Mooring System

It is customary in conventional marine and naval engineering to impose an additional test on the mooring system before it can be accepted. This additional test requires survival of the mooring arrangement in the instance where one mooring line, usually the most heavily loaded, fails (ie. breaks), during an extreme loading event. This additional design case is often referred to as the *damaged system condition*.

This case ensures that if, for unforeseen circumstances, one line experiences premature failure, then the remaining lines have sufficient capacity to restrain the pontoon and prevent progressive failure. Premature failure could be related to a variety of causes, eg. fatigue failure of the line, undetected damage to the line and/or connections, sub-standard strength, and a freak loading condition. For the reasons outlined in Box 7.19, it is not proposed that the pontoons moorings be required to satisfy the *damaged system condition* criterion.

Box 7.19 Damaged system condition for pontoon moorings
The <i>damaged system condition</i> criterion for pontoons in the GBR is unlikely to be able to be satisfied. It can, however, be considered an unreasonable load case in most instances. Firstly, it is normally impractical and undesirable from an environmental and amenity view point to install the extensive mooring line system that would be required to cope with a failure to the heaviest loaded line. Secondly, due to the shallow water characteristic of pontoon sites, catenary mooring lines designed in accordance with these guidelines, are normally sized on the basis of the minimum required weight (gauge) of the line (to provide the required spring effect), rather than on strength. As a consequence, the lines are usually stronger than required and provide very high safety factors on the strength/peak line tension ratio. Hence it is unreasonable to impose this mooring criterion, unless factors of safety on strength failure are close to the allowable limits (Step H). This is unlikely. Therefore, unless mooring lines have safety factors in the peak load condition that are close to the values set out in Step H, it is not necessary to satisfy the Damaged System Condition criterion.

Water levels

The water level adopted in design has a significant influence on the response behavior of the mooring system. For example, when the pontoon is subjected to a particular intensity of environmental loading at the minimum operating water level, the resulting pontoon offset will usually be maximum. Peak mooring line forces can, however, be expected at a maximum operating water level. In addition to these influences, changes in water level may produce a significant variation in the intensity of wave loading at the pontoon site. Consequently, it is necessary to examine the mooring system under conditions of both maximum and minimum expected water levels.

Design values for the maximum and minimum operating water levels at the pontoon site (specified in Chapter 5) are functions of the severity of environmental loading. Recommended design water levels are summarised in Box 7.20

Box 7.20 Recommended design water levels (Chapter 5)		
Environmental load condition	Design water level	
	Maximum	Minimum
<i>Maximum Operating Condition</i>	HAT	LAT
<i>Maximum Non-cyclonic Condition #</i>	HAT	LAT
<i>Cyclonic Condition</i>	HAT	MLWS
# Note: Applicable where System 2 and System 4 dual mooring systems are used (Section 7.1)		

Range of load cases

The range of load cases to be considered must comprise all necessary combinations of:

- load directions
- intensity of environmental loads
- water levels.

Although the magnitude of forcing may vary greatly with direction (especially with sheltering of waves and channeling of currents), it is not appropriate to only check the directions of maximum loading. The restraint provided by the mooring system may also vary significantly with direction, so the strength must be checked to ensure it is appropriate for the design conditions applying in all directions.

Required load case combinations are summarised in Box 7.21. In view of the multitude of load cases that must be analysed, a systematic approach should be adopted to complete the assessment and present the results. Based on the range of combinations indicated in Box 7.21, a total of 32 or 48 individual load cases (depending on whether or not a separate cyclone mooring system is employed), must be covered.

Under certain conditions, it will be reasonable to reduce the number of load directions that need to be considered to less than the eight directions specified in Box 7.17, however the designer must justify any reduction in load directions below the full eight. Pre-requisites for consideration of a reduction are specified in Box 7.22. If the mooring system satisfies all of these pre-requisites, as an absolute minimum, the *three principal load directions* described in Box 7.21 shall be analysed.

Box 7.21 Required load case combinations		
Load direction	Intensity of load	Water level
1. All 8 directions (ie. 45 degree intervals around the entire pontoon, as defined above)	1. <i>Maximum operating condition</i> 2. <i>Cyclonic Condition</i> 3. <i>Maximum Non-cyclonic Condition</i> – if System 2 and System 4 dual systems are used, this load must be applied to the mooring system used for normal operating conditions	1. Minimum design level 2. Maximum design level
Three principal load directions for analysis (if pre-requisites in Box 7.22 are met)		
Head sea	Direction of the most severe environmental loading that is parallel to the long side of the pontoon.	
Beam sea	Direction of the most severe environmental loading that is perpendicular to the long side of the pontoon.	
Quartering	Direction that bisects (ie. at 45 degrees), the most severe head sea and beam sea directions.	

Box 7.22 Pre-requisite conditions for reducing the number of load directions	
Pre-requisite	Comment on significance
Reasonable symmetry in the pattern of mooring lines around the pontoon	Without reasonable symmetry, the pontoon is likely to undergo significant yaw rotation when subjected to environmental loading. Asymmetrical mooring line layouts may mean that the direction of severest loading does not produce the maximum movement because the system may be significantly weaker (ie. offering less restraint) in another load direction.
Consistency in line lengths, effective stiffness and properties of all mooring lines	Even if a mooring system is symmetrical, unless the scope of lines and their properties are very similar, movements and line forces in the severest loading direction do not necessarily produce the worst design case.
Limits on allowable pontoon and mooring line movements must be similar in all directions	If movement limitations are more restrictive in particular directions, design load cases must include at least the direction of severest loading and the direction of severest movement limitations (including cases where they are coincident).

Individual directions of wind, waves and currents for each load case

When defining each load case, the designer should consider the individual direction of the wind, wave and current load components that together constitute the total environmental force on the pontoon. Whilst the design intensity of wind can occur in any direction, the intensity of waves and current and their incident direction is dependent on several factors. Waves, and to a lesser degree currents, will be influenced more by the direction of wind in the hours immediately prior, rather than the instantaneous direction, and also will be heavily influenced by features of the approach path to the pontoon and the surrounding bathymetry. Current speed and direction will be unique to the particular reef location and may be quite different to other locations.

When considering a particular load direction, the wind can be assumed co-linear with the load direction under consideration. Designers require expertise and judgement to determine the appropriate approach direction of waves and current to adopt (Box 7.23).

Box 7.23 Directions of wind, wave and current force components for particular load cases	
Direction of loading	How to apply components of environmental loading
Maximum Operating Condition and Maximum Non-Cyclonic Condition	
Most exposed direction and also in a South-Easterly direction	Assume wind, waves and current are co-linear.
All other directions	Wind is taken in the direction under consideration. Waves and currents can be assumed to be either: • in the same direction as the wind (simple and generally conservative case), or • hydrodynamic studies can be undertaken to evaluate the most likely direction of waves and currents, based on the sustained wind direction and the individual site features.
Cyclonic Condition	
Most exposed direction	Assume wind, waves and current are co-linear.
All other directions	Wind is taken in the direction under consideration. Waves and currents can be assumed to be either: • in the same direction as the wind (simple and generally conservative case), or • hydrodynamic studies can be undertaken to evaluate the most likely direction of waves and currents, based on the likely range of cyclonic winds (in the preceding few hours) and individual site features.

Pontoon stability during mooring of ferry

One additional consideration is required when defining conditions and particulars for load cases corresponding to the *Maximum Operating Condition*. During this condition, the stability and safety of pontoon operations must be maintained in the situation where the passenger ferry is moored to the pontoon. Consequently, forces due to wind, wave and current for the *Maximum Operating Condition* load cases, should be calculated assuming the visiting ferry is berthed at the pontoon and acts integrally with the pontoon. Hence the mooring system must be designed to be capable of restraining the pontoon under the additional forces contributed by the ferry under this intensity of environmental load.

Furthermore, the designer must give consideration to the scale of differential movements occurring between the pontoon and the ferry, to ensure embarking and disembarking activities have adequate safety in environmental loads up to the *Maximum Operating Condition*. The behaviour will be dependent not only on the mooring system, but also on the properties of the lines used to secure the ferry to the pontoon and properties of the ferry itself. Further assessment of the system in this state is explained in *Step I*.

The effects of direct berthing (collision) loads on the pontoon body (fenders) are dealt with in Chapter 9. Because this single impulse load exerted by the ferry on the pontoon will be short duration, the inertia of the pontoon and the finite response time of the mooring system will effectively absorb the impact. The influence on line forces and pontoon displacement can be neglected for practical purposes.

Step C Determine steady state environmental forces											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step C establishes the magnitude of steady state environmental forces for each designated load case. The steady state components of wind, wave and current force for the selected pontoon configuration are calculated on the basis of the relevant projected areas and drag/drift force factors for the structure. A simplified scheme is used, if required, to estimate steady state forces applied in <i>quartering</i> directions.											

The *Simplified Mooring Design Procedure* requires evaluation of the steady forces exerted on the pontoon structure (and also the berthed ferry in the *Maximum Operating Condition*), by the combination of wind, current and waves, during the nominated design environmental conditions. Each force component is determined individually and summed to provide the total steady state force used in calculating the mean pontoon offset and, subsequently, in the mooring design. With respect to waves, it is a wave drift force effect that contributes what can be considered in the design procedure as a steady force.

Steady state loads required in the SMDP can be estimated from:

1. Conventional engineering estimates,
2. Physical models, or
3. Numerical models of facilities.

Physical or numerical models can be used to determine the intensity of steady state wind, wave and current forces for the chosen pontoon geometry and arrangement. An expert in these respective fields must be engaged to complete these studies, and the specific requirements of such modelling are beyond the scope of these *Guidelines*.

In the absence of physical or numerical models, *conventional engineering estimates* can be made. With this technique, components of the steady state force are calculated as a function of pressure intensity, projected areas and published drag coefficients for various member shapes and forms. The recommended approaches to be taken in estimating these steady force components are described below. Where appropriate, reference is made to relevant extracts in published design guides for detailed explanations of calculation procedures and for presentation of various design parameters and coefficients used in the calculations.

Load Directions

As described in *Step B*, the mooring system is to be analysed for loads approaching from directions at 45 degree intervals around the pontoon facility. In line with standard marine terminology, these directions are referred to as *head sea*, *beam sea* and *quartering* approach paths relative to the pontoon orientation, as defined in Step B (comprising a total of two head, two beam and four quartering directions, unless symmetry permits a reduction in these numbers).

Pontoon facilities are conventionally rectangular in plan shape, with the (shorter-sided) ends corresponding to *head sea* directions and the long sides corresponding to *beam sea* directions. Consequently, *head sea* and *beam sea* approach directions are generally perpendicular to the major exposed members and body surfaces, which simplifies the computation of projected areas used for calculating applied force. However, for *quartering* directions, the approach direction is generally oblique to members and body surfaces and the computations are more complicated.

For the quartering directions, steady state forces can be computed, either according to the dimensions of surfaces projected normal to the quartering direction or, alternatively for wind and current, using the simplified approach outlined below. The simplified approach (API, 1987a), allows the designer to estimate the *quartering* load in terms of the *head sea* and *beam sea* direction forces (Equation 7.1). This approximation (defined in Box 7.24) can be used in these *Guidelines* to calculate steady state wind and current forces imposed in *quartering* directions, when the *Simplified Mooring Design Procedure* is adopted. It is only possible to use this method when wind and current force components are co-linear (when computing F_H and F_B).

Box 7.24 Estimate of wind and current steady state force approaching from an oblique direction (API, 1987a)	
$F_f = F_H \left[\frac{2 \cos^2 f}{1 + \cos^2 f} \right] + F_B \left[\frac{2 \sin^2 f}{1 + \sin^2 f} \right] \quad (7.1a)$	
$F_Q = \frac{2}{3} [F_H + F_B] \quad , \text{ for } f = 45^\circ \quad (7.1b)$	
Where	F_f = Force on the pontoon in an oblique direction F_Q = Force on the pontoon in the <i>quartering</i> direction F_H = Force on the pontoon for environmental loading in the <i>head sea</i> direction F_B = Force on the pontoon for environmental loading in the <i>beam sea</i> direction
Refer to Box 7.17 for definition of <i>head sea</i> , <i>beam sea</i> and <i>quartering</i> directions.	

Outlined below are the recommended techniques for computing the steady state components of wind, current and wave drift force.

Wind drag

The basis of the method used to compute the design wind force is presented in Box 7.25, along with a definition of terms. A simple example of steady state wind force calculation is presented in Box 7.26.

The adopted design wind velocity used in the calculations depends on three main factors:

- the severity of the design environmental event
- the time interval or gust period over which the wind speed is averaged
- the elevation of individual members or body surfaces above mean water level.

The design wind velocities for the design *Cyclonic Condition* and *Maximum Operating Condition* environmental states have been defined in standardised form in Chapter 5 (ie. the wind speed averaged over a ten minute time period and at a height of 10 m). It is necessary to adjust the standardised wind speed according to a time interval compatible with the likely response time of the pontoon to wind forcing. Whilst this is a subjective issue, conventional practice for marine and naval facilities suggests a time interval of about 15 seconds is applicable for pontoon structures (of the scale of 50 m length), moored in the GBR environment. Consequently, the standardised wind velocity averaged over ten minutes should be increased by a factor, in accordance with the method outlined in Chapter 5, in order to calculate the steady wind force on a pontoon facility. For pontoons with a significantly different scale or mooring arrangement from that of the present type of facilities, it may be necessary to modify the 15 seconds gust duration. Expert advice must be sought to examine and select a more appropriate duration.

With respect to elevation, it is customary to make no reduction in the wind speed for vessel heights less than 10 metres above mean water level, unless a relatively sophisticated analysis is being performed. Advice in this respect is given in Chapter 5. Because it is anticipated that in the foreseeable future all pontoon facilities will have a maximum elevation less than 10 m above mean water level, for normal design cases, the same design wind speed can be applied to all members and surfaces irrespective of elevation. If an advanced study is being performed, then elements of the pontoon will need to be divided up into zones of different elevation with the design wind speed and the associated wind force calculated separately for each zone.

The total wind force shall be computed from the sum of forces on all exposed surfaces and members above the mean waterline. It shall be necessary to assign the appropriate mean draft line on the pontoon, according to the particular environmental condition, e.g. in the *Cyclonic Condition* event, the pontoon would not be expected to be occupied, while in the *Maximum Operating Condition* the pontoon may or may not have a full live loading of passengers and baggage. For the *Maximum Operating Condition*, the steady state wind force for both draft levels are to be calculated and combined with the corresponding force calculations for current and wave drift, so that the draft level that produces the maximum combined steady state force can be adopted for mooring analysis.

Tabulations and figures presenting appropriate shape coefficients for a range of surface and member shapes appear in a wide range of publications. Particular reference is made to DNV (1991) for a comprehensive discussion and presentation of coefficients. Where appropriate coefficients cannot be found in the literature, experts should be consulted for advice.

Special consideration is required to account for *shielding* and *solidification* effects. *Shielding* relates to a row of frames, walls or columns in the direction of the wind, which shield each other. *Solidification* offers a simplified means of computing wind force for a structure containing multiple, closely arranged members all in a plane normal to the direction of wind (e.g. truss frames). (Refer to DNV (1991) for details and coefficients to use where these effects must be accommodated.)

Box 7.25 Calculation of steady state wind force exerted on the pontoon	
Wind force on a single surface or member	
$F_{wi} = \frac{1}{2} \rho_a v_{tz}^2 A_i C_{Di} \quad (7.2)$	
F_{wi}	= Wind force on a single member or surface, acting in the direction of the wind (N)
ρ_a	= Mass density of air = 1.225 kg/m ³ (dry air)
v_{tz}	= Design wind speed averaged over time “t” at a height “z” m above mean water level (m/s) (defined in Chapter 5)
A_i	= Projected area of the surface or member normal to the direction of force (m ²)
C_{Di}	= Member or surface drag coefficient
Total wind force on the pontoon	
$F_w = \sum F_{wi} \quad (7.3)$	
* Note	1. For a particular wind direction, F_w is the sum of individual wind forces on all exposed surfaces, members and appendages of the pontoon extending above the mean water line (and including the visiting ferry for the <i>Maximum Operating Condition</i> case). 2. If the designer adopts a collapsible canopy roof structure (in order to reduce wind drag in extreme conditions), the system must be tested and performance verified.

Box 7.26 Simple example of steady state wind force calculation

Wind directed in *beam sea* direction (ie. normal to long side of facility)

The diagram shows a side elevation of a pontoon structure. A thick black arrow points upwards from the 'Water surface' line, labeled 'Wind Force Direction'. The structure consists of several parts: a long rectangular base (A1), a smaller rectangular structure on the left (A2), a large curved canopy roof (A4) supported by three vertical columns (A3), and a small rectangular fixture on the right (A5). Each component is enclosed in a box with a label and dimensions.

Wind Force Direction

Pontoon Elevation (Beam On)

- A1 – Pontoon Deck
54 m long, 0.5 m deep
- A2 – Closed-in Facilities
20 m long, 6 m high
- A3 – Column Supports
Each column 6 m high, 0.3m width
- A4 – Canopy Roof
30 m long, average height 2 m
- A5 - Exposed Solid Fixtures
10 m long, 3 m high

$A1 = 54 \times 0.5 \text{ m} = 27 \text{ m}^2$ $A2 = 20 \times 6.0 \text{ m} = 120 \text{ m}^2$ $A3 = 3 \times 6.0 \times 0.3 \text{ m} = 5.4 \text{ m}^2$ $A4 = 30 \times 2.0 \text{ m} = 60.0 \text{ m}^2$ $A5 = 10 \times 3.0 \text{ m} = 30.0 \text{ m}^2$	$C_{D1} = 1.15$ $C_{D2} = 0.93$ $C_{D3} = 1.40$ $C_{D4} = 1.00$ $C_{D5} = 0.95$	$F_{w1} = 383 \times 27 \times 1.15 = 11.9 \text{ kN}$ $F_{w2} = 383 \times 120 \times 0.93 = 42.7 \text{ kN}$ $F_{w3} = 383 \times 5.4 \times 1.40 = 2.9 \text{ kN}$ $F_{w4} = 383 \times 60.0 \times 1.00 = 23.0 \text{ kN}$ $F_{w5} = 383 \times 30.0 \times 0.95 = 10.9 \text{ kN}$ $F_w = \Sigma F_{wi} = 91.4 \text{ kN}$	Design Wind Speed = 25 m/s $F_{wi} = 1.225 \times 25^2 A_i C_{Di} / 2$ $= 383 A_i C_{Di} \text{ (Pa)}$ $\alpha_i = 90 \text{ degrees (angle of wind direction to plane of member)}$ C_{Di} values extracted from DNV, 1991
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Estimated total steady state wind force in *beam sea* direction on pontoon = 91.4 kN

Current Drag

The basis of the method used to compute the design steady state current drag force is presented in Box 7.27, along with a definition of terms. A simple example of steady state current drag force calculation is presented in Box 7.28.

The adopted design current velocity used in the calculations depends on two factors, as follows:

- the severity of the design environmental event
- the elevation of individual members or surfaces below mean water level.

The design current velocities for the design *Cyclonic Condition*, *Maximum Non-Cyclonic Condition* and *Maximum Operating Condition* environmental states have been defined in Chapter 5. These comprise a wind induced and/or a tide induced component. Unless submerged members or chambers extend more than 3 m below the pontoon draught line, the design current velocity is to be assumed constant. For deeper bodies, allowance can be taken of the reduction in the horizontal velocity profile with depth. Constant values to be applied over the upper 3 m of the water column are presented in Chapter 5.

Loads associated with wind- and tide-induced current are calculated by evaluating and summing the drag force contributed by pontoon member surfaces, which extend below the water line. Forces are calculated according to the areas projected on a vertical plane extending below the design water level and normal to the force. As with wind loading, it will be necessary to assign the appropriate draft line on the pontoon, according to the particular environmental state. This is because it will affect the magnitude of projected areas. For example, the draft line in the

Cyclonic Condition event when the pontoon is unoccupied would be different to the draft line in the *Maximum Operating Condition* when the pontoon may be fully occupied with patrons and baggage.

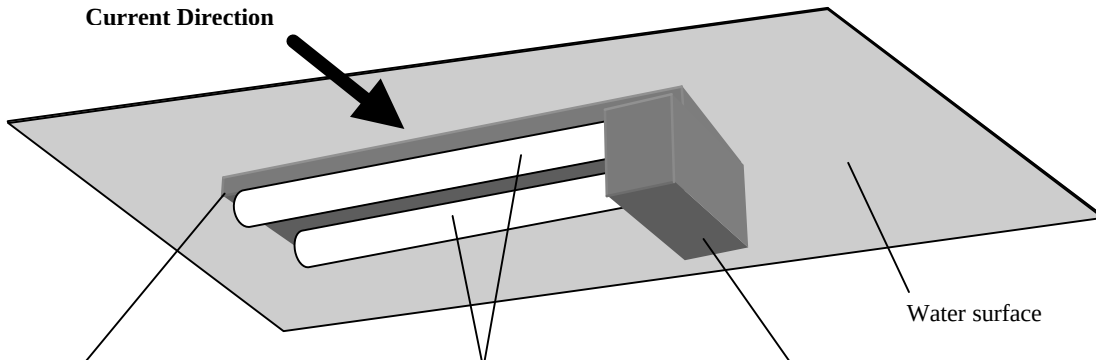
With respect to drag coefficients for a particular member (in constant flow), the coefficient is dependent on several factors, particularly:

- dimensions
- shape and roundedness
- surface roughness (e.g. is marine growth likely)
- group and composite member interference effects
- whether or not there is partial or full submergence of the member.

Tabulations and figures presenting appropriate drag coefficients for a range of surface and member shapes appear in a wide range of publications. Refer DNV, 1991 for a comprehensive discussion and presentation of coefficients. Unless special provisions are made, it should be assumed that surfaces are covered by marine growth when selecting applicable drag coefficients. Where appropriate coefficients cannot be found in the literature, experts should be consulted for advice.

In the simple example calculation (Box 7.28), shielding effects have been neglected and it is assumed that the members are fully submerged. Furthermore, a surface roughness analogous to heavy marine growth on members has been adopted.

Box 7.27 Calculation of steady state current drag force exerted on the pontoon	
Current drag force on a single surface or member	
$F_{Di} = \frac{1}{2} \rho_w C_{Di} v_{cz}^2 A_i \quad (7.4)$	
F_{Di}	= Drag force normal to the axis of a single member or surface (N)
ρ_w	= Mass density of water: $\approx 1025 \text{ kg/m}^3$
v_{cz}	= Design current velocity at an elevation of “z” m below mean water level (defined in Chapter 5) (m/s)
C_{Di}	= Drag (shape) coefficient for flow normal to the member axis
A_i	= Projected area of the surface or member normal to the direction of force (m^2)
Total current drag force on the pontoon	
$F_D = \sum F_{Di} \quad (7.5)$	
* Note	1. For a particular current direction, F_D is the sum of individual current drag forces on all exposed surfaces, members and appendages of the pontoon projected on a vertical plane extending below the mean water line (and including the visiting ferry for the <i>Maximum Operating Condition</i> case). 2. Where a submerged object/member is effectively shielded from direct exposure to the current, consideration can be given to a reduction of the current force calculated on the shielded object/member. Unless physical or numerical modelling is undertaken to prove otherwise, no reduction is permitted for object/members located a horizontal distance > three times the representative dimension of the shielding object/member. For example, for a cylindrical tube (with horizontal axis), the representative dimension is the cylinder diameter; for a rectangular object the representative dimension is the lesser of the depth and width of the face exposed to the current. If objects/members are effectively shielded, according to the above, designers must justify the degree of reduction employed.

Box 7.28 Simple example of steady state current drag force calculation			
Current directed in <i>beam sea</i> direction (ie. normal to long side of facility)			
View of Submerged Portion of the Pontoon 			
$A_1 = 47 \times 1.2 \text{ m} = 56 \text{ m}^2$ $A_2 = 47 \times 1.2 \text{ m} = 56 \text{ m}^2$ $A_3 = 3 \times 4 \text{ m} = 12 \text{ m}^2$ $A_4 = 50 \times 0.4 \text{ m} = 20 \text{ m}^2$	$C_{D1} = 0.75$ $C_{D2} = 0.75$ $C_{D3} = 0.70$ $C_{D4} = 1.13$	$F_{D1} = 328 \times 0.75 \times 56 = 13.8 \text{ kN}$ $F_{D2} = 328 \times 0.75 \times 56 = 13.8 \text{ kN}$ $F_{D3} = 328 \times 0.70 \times 12 = 2.8 \text{ kN}$ $F_{D4} = 328 \times 1.13 \times 20 = 7.4 \text{ kN}$ $F_w = \Sigma F_{wi} = 37.8 \text{ kN}$	Design Current Speed = 0.8m/s $F_{Di} = (1025/2) .8^2 C_{Di} A_i$ $= 328 C_{Di} A_i \text{ (N)}$ $\alpha_i = 90 \text{ degrees (angle of current direction to plane of member surfaces)}$ C_{Di} values extracted from DNV, 1991
Estimated total steady state current force in beam direction on pontoon = 37.8 kN			

Wave drift

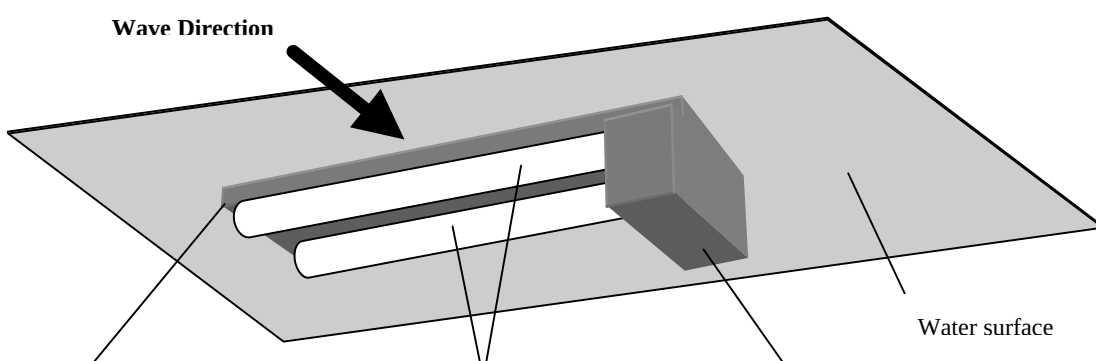
A conservative estimate of the contribution from wave drift effects on steady state forces is adopted in the simplified design procedure. The formula for mean wave drift force for irregular seas as presented in Section 2.4.4.3 of BS 6349, 1989 is used. This represents an estimate of the steady state wave force if full wave reflection from the vessel occurs.

The basis of the method used to compute the design wave drift force is presented in Box 7.29, along with a definition of terms. A simple example of steady state wave drift force calculation is presented in Box 7.30.

The adopted design wave height used in the calculations depends on the severity of the design environmental event. These are defined in Chapter 5 for the design *Cyclonic Condition*, *Maximum Non-cyclonic Condition* and *Maximum Operating Condition* environmental states.

As outlined above, the estimate of drift force is highly simplified, effectively independent of the actual draft and of the submerged profile of the vessel. If, alternatively, advanced studies are undertaken to numerically or physically model the true wave reflection characteristics, these improved results may be used to refine the above calculation of wave drift force. In the simple example calculation (Box 7.30), steady state drift force is computed on a pontoon for waves approaching in the *beam sea* direction.

Box 7.29 Calculation of steady state wave drift force exerted on the pontoon	
Total wave drift force on the pontoon	
$F_v = \frac{1}{16} \rho_w g H_s^2 L \quad (\text{BS 6349, 1989}) \quad (7.6)$	
F_v	= Drift force normal to the horizontal dimension L of the pontoon (N)
ρ_w	= mass density of water: $\approx 1025 \text{ (kg/m}^3\text{)}$
g	= Gravitational acceleration = $9.81 \text{ (m/s}^2\text{)}$
H_s	= Design value of the significant wave height, in the direction under consideration (m)
L^*	= Horizontal dimension of the pontoon (at and below the water line) projected normal to the wave direction (m)
* Note Where this dimension varies significantly with depth, a weighted average that is heavily biased towards the dimension at, and immediately below, the water surface, should be used.	

Box 7.30 Simple example of steady state wave drift force calculation	
Wave directed in <i>beam sea</i> direction (ie. normal to long side of facility)	
View of Submerged Portion of the Pontoon  A_4 – Submerged Pontoon Decking Structure, 47 m long, 1.2 m deep A_1 & A_2 – Cylindrical Flotation Members Axis normal to current direction, length = 47 m, diameter = 1.2 m A_3 – Viewing Chamber, area normal to current direction = $3 \times 4 \text{ m}$, length parallel to current direction = 15 m	
$L = 50 \text{ m}$ (representative horizontal length) Design significant wave height for hypothetical <i>Cyclonic Condition</i> : $H_s = 3 \text{ m}$	$F_v = 1025 \times 9.81 \times 3^2 \times 50 / 16 = 283 \text{ (kN)}$ $F_v = 283 \text{ kN}$
Estimated total steady state drift force in beam direction on pontoon = 283 kN	

Combined steady state force

Total steady state force for a particular direction of loading and a particular environmental loading event is computed by adding the individual force components for wind, wave and current. For the simple examples illustrated above, the total force is computed in Box 7.31.

Box 7.31 Example calculation of combined steady state force exerted on the pontoon (<i>beam sea</i> direction)			
Combined (total) steady state force		Component forces	
$F_{SS(\text{tot})} = F_w + F_c + F_v$		F_w	= 91.4 (kN) Steady state wind force (from Box 7.26)
$F_{SS(\text{tot})} = 91.4 + 37.8 + 283 \text{ (kN)}$		F_c	= 37.8 (kN) Steady state current force (from Box 7.28)
$F_{SS(\text{tot})} = 412 \text{ (kN)}$		F_v	= 283 (kN) Steady state wave drift force (from Box 7.30)

Typically, the wave drift force will constitute the major component of the total steady state force, although it is possible for the wind force to be dominant if the geometry and architecture above deck provides large exposed surfaces.

Outputs: Step C – Determine Steady State Environmental Forces	
1.	The combined steady state force exerted on the pontoon shall be computed for each load case. The parameters of each load case and the total number of load cases, shall be set in accordance with the requirements of Step B.
2.	Output from Step C shall be presented in tabular form, listing each load case considered together with the associated calculated value of the combined steady state force.
3.	This table of steady state force outputs will form the basis of all subsequent analyses to design an acceptable mooring system.

Step D Undertake preliminary design of mooring line properties											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step D develops a preliminary estimate of mooring line properties for either conventional catenary mooring line or the composite mooring line (comprising the catenary chain and an elastic insert segment). The designer uses the estimated steady state force and maximum design wave height (for the extreme environmental loading) to derive mooring line lengths, line size and clump weight sizes that suit mooring line flexibility criteria. Procedures accommodate various combinations of multiple lines restraining pontoon movement in a particular direction of loading.											

Suitability of the *Simplified Mooring Design Procedure* for estimating peak mooring line loads and pontoon displacements, relies heavily on the assumption that a quasi-static approach is a reasonable approximation. If the mooring lines approach a condition whereupon they snatch during extreme loading, dynamic amplification effects can result in actual line forces, pontoon displacements and motions far in excess of what will be predicted by the *Simplified Mooring Design Procedure*. Hence, if this design tool is to be adopted, it is imperative that mooring lines be designed such that, under extreme loading, they are behaving in a flexible manner, i.e. the peak offset is a sufficient safety margin less than the offset for the line corresponding to a snatch condition.

This step provides a convenient means of obtaining a preliminary estimate of the requirements of mooring line properties. This is achieved by selecting line properties that will remain flexible (i.e. catenary lines will not reach the snatch condition; catenary lines with an elastic insert will not snatch and the insert will remain in the elastic zone) in the most extreme loading case. Guides for preliminary design are provided for the following mooring line restraint systems:

- Conventional catenary lines (with or without clump weights)
- Catenary lines with a rubber *bungy* elastic insert

Alternatively, the designer may elect to use a trial and error basis to select initial lengths and properties of mooring lines. In this case, the designer can proceed directly to Step E, skipping the preliminary design strategy outlined in the remainder of this Step. However, the final arrangement must still satisfy the same design criteria.

Design strategy

It is assumed that a conceptual layout of the number and preferred alignment of mooring lines has been completed, prior to undertaking this preliminary design. The techniques presented are based on solutions that are applicable where the principal restraint (for a particular load direction) is provided by either a single line or two symmetric lines, all of similar length and properties. Where, as occurs in many cases, more than two lines contribute to restraining the pontoon in any particular load direction or where there is significant asymmetry in the pattern and properties of lines chosen in the conceptual arrangement, approximate simplifications are introduced into the solutions to accommodate these complications. These preliminary designs will only provide indicative solutions (which in most instances will be conservative), and will require significant refinement during the detailed analysis stage of mooring line design.

In most instances, mooring lines will be provided with a nominal pre-tension at installation (to minimise movement during operational conditions), which means that, at equilibrium, the pontoon will have balancing horizontal forces applied by the attached lines. As environmental loads develop in one particular direction, the pontoon will drift in the direction of the environmental forces. As the pontoon responds to the loads, mooring lines aligned on the loading side will begin to flex and restrain further movement, whereas lines on the leeward side will go slack, reducing the horizontal tension in these (pre-tensioned) lines back towards zero. Consequently, a complete and detailed mooring analysis (as to be performed in subsequent Steps), needs to take into account the reduction

in horizontal force occurring on the leeward side as the pontoon moves. In the preliminary design technique espoused here, the nominal effect contributed by leeward lines going slack, is ignored.

The strategy behind the preliminary method for sizing mooring lines is summarised in box 7.32.

Box 7.32	Methodology behind the preliminary mooring line design method
Strategy	Maintain the peak line tension significantly less than that causing a snatch condition, rather than addressing pontoon or mooring line movements criteria. The necessary refinements to the mooring line properties that may be required to satisfy movement criteria can be incorporated later in the detailed design calculations. For simplicity, the effects of line pre-tensions are ignored in this preliminary assessment. This is reasonable because of the minor effects on peak line forces. The main effect is on the displacement that occurs under load, which is not the focus for the preliminary design.
Select the most heavily loaded line	Establish which line is expected to experience the heaviest loading for each load direction. This is based on the values calculated for (combined) steady state loading for the pontoon (for the extreme load case). For simplicity, only consider <i>head sea</i> and <i>beam sea</i> load directions. In the case where the pontoon weathervanes, four directions at 90 degrees apart should be considered. Proceed with the preliminary design process for this particular line, and adopt the resulting solution for design properties for all lines contributing in this load direction. Refinement in detailed design will permit adjustment to the properties and requirements of individual lines, as appropriate.
Basic criteria used to facilitate the preliminary design	The preliminary design focuses on the heaviest loaded line for the pontoon under the most extreme load case. The combined effects of the calculated steady state load on the pontoon (ie. a steady state offset), plus a superimposed horizontal displacement equal to half the maximum wave height for this extreme case, must satisfy the following criteria: Conventional Catenary Mooring Line Under the load condition described above, the gradient of the mooring line at the point of connection to the seabed anchor is to remain horizontal. This prevents development of an inclined load at the anchor, which in the shallow water conditions prevailing at most sites, would produce a catenary that is too close to snatching. This rule may be relaxed in cases where mooring lines are anchored in relatively deep water (ie. > 30 m), provided the anchoring system is adequately designed to accommodate combined horizontal and vertical loading. The design must still ensure that there is a satisfactory margin from the snatching condition. Composite Mooring Line (Catenary Chain and Elastic Segment) Under the load condition described above, the maximum extension of the elastic line must be maintained at a satisfactory margin inside the manufacturer's specified elastic limit. The method assumes the stiffness of the elastic element is constant within the operational range of extension. In addition, the catenary section of the mooring line must not reach the snatch condition under the most extreme loading.

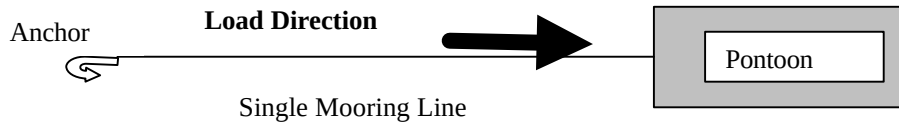
Solution steps

Box 7.33 illustrates the range of mooring line geometries for which preliminary design solutions have been developed. The procedure can be applied directly in these cases. The solution process for traditional catenary mooring systems that fall into one of the four arrangements described and illustrated in Box 7.33, is spelt out in Box 7.34. The solution process for a catenary + elastic insert mooring line system, that matches one of the four arrangements described and illustrated in Box 7.33, is spelt out in Box 7.35.

Box 7.33 Direct application of preliminary design method to simple mooring line geometries

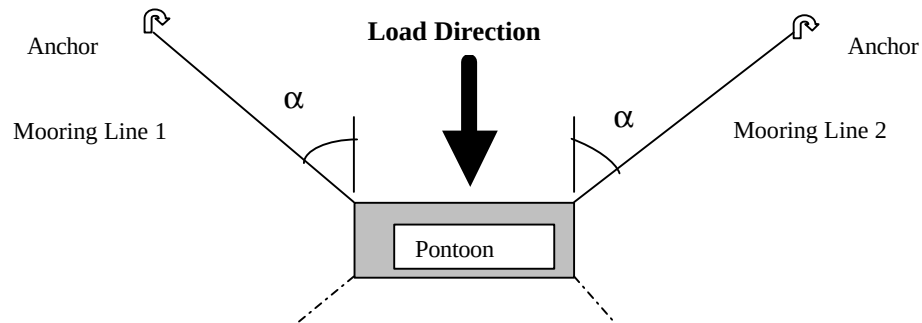
Case 1 Single Line

A single mooring line restrains the pontoon (pontoon weathervanes around the single anchor point)



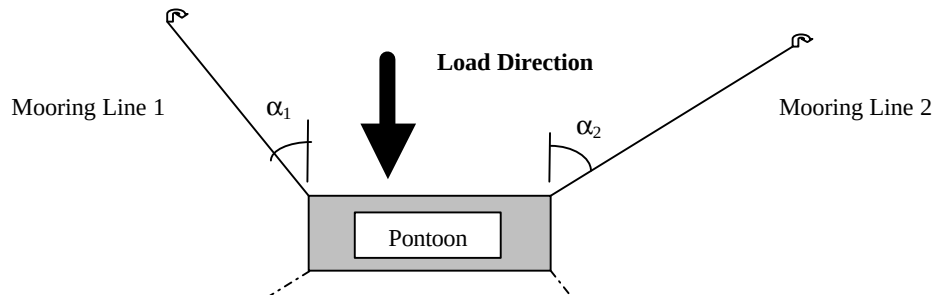
Case 2 2 Symmetric Lines

Two principal mooring lines in symmetrical formation restrain the pontoon



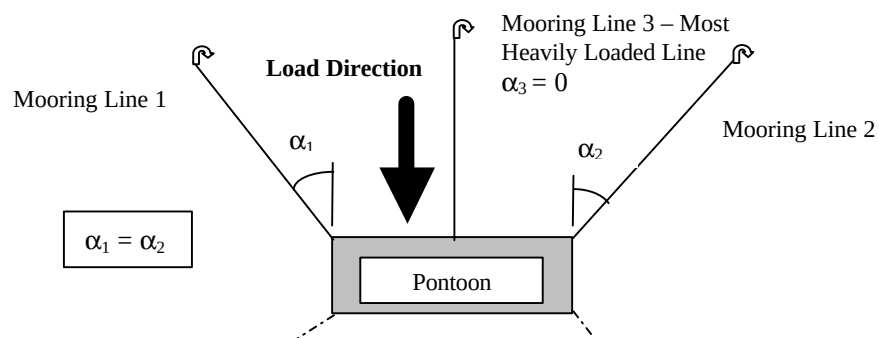
Case 3 2 Asymmetric Lines

Two principal mooring lines in asymmetric formation restrain the pontoon

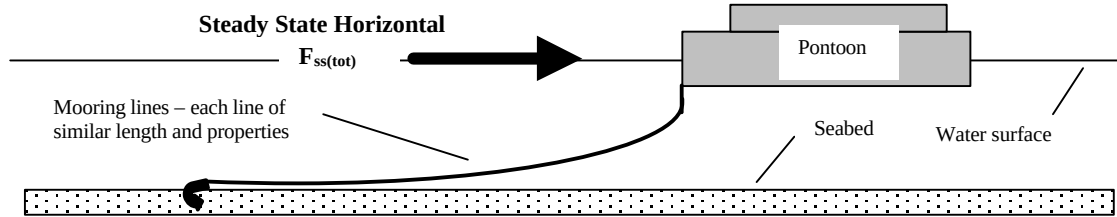


Case 4 3 Symmetric Lines

Three principal mooring lines in symmetric formation restrain the pontoon

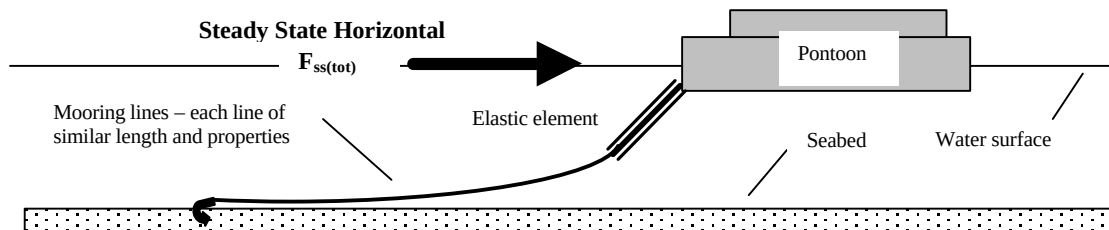


Box 7.34 Preliminary design for conventional catenary mooring line



Design Parameter	Depth of water	h (m)
	Total mooring line length	S _l (m)
	Viable range of mooring line lengths	Typically minimum 4 times h
	Horizontal scope of mooring line	X _l (m)
	Orientation of heaviest loaded line to load direction	α (degrees)
	Horizontal oscillation of pontoon about its mean position	Δξ _{osc} (m) ^{\$}
	Average buoyant mooring line weight/length	q (kN/m) *
	Buoyant weight of Clump Weight	CW (kN)
	Design significant wave height (extreme event)	H _s (m)
	Total Steady State Horizontal Force (most extreme event)	F _{ss(tot)} (kN)
Step	Description	Design Equations
Step 1	Estimate the proportion of F _{ss(tot)} carried by the heaviest loaded line (refer Box 7. for configurations)	
Case 1	Single mooring line	$F_{ss(line)} = F_{ss(tot)}$ (kN)
Case 2	Two symmetric lines	$F_{ss(line)} = F_{ss(tot)} / (2\cos(\alpha))$ (kN)
Case 3	Two asymmetric lines	$F_{ss(line)} = F_{ss(tot)}\sin(\alpha_2)/\sin(\alpha_1+\alpha_2)$ (kN)
Case 4	Three symmetric lines	$F_{ss(line)} = F_{ss(tot)}K$ (kN)
		Where K ≈ .33 to 0.5 for α ₁ = α ₂ in the range 0° to 45°
		Where K ≈ 0.5 to 1.0 for α ₁ = α ₂ in the range 45° to 90°
Step 2	Ensure that, at the peak steady state horizontal load, the mooring line remains horizontal at the anchor connection (ie. no inclination angle at the anchor). Select a range of possible line lengths (S _l), and compute the required (uniform or average) design weight/length (q _{des}) of the line for each length.	$q_{des} = F_{ss}/[(S_l)^2/2h - h/2]$
Step 3	Select a convenient combination of q _{des} and S _l , and select a practical size of chain, such that the actual weight/length q _{act} > q _{des} . It is necessary to assign a q _{act} value > the calculated q _{des} , because the line must actually avoid the snatching condition under this steady state load, together with a further horizontal offset equal to half the maximum wave height for this extreme case.	
Step 4	For the adopted values, q _{act} and S _l , compute the maximum static horizontal force in the line at the stage the mooring line begins to lift above horizontal at the anchor connection.	$F_{max(line)} = q_{act} [(S_l)^2/2h - h/2]$ (kN)
Step 5	Compute the horizontal scope of the mooring line when the horizontal line force = F _{max(line)}	$X_{l(max)} = (F_{max(line)}/q_{act}) \sinh^{-1}(q_{act}S_l / F_{max(line)})$ (m)
Step 6	Compute the horizontal scope, X _{l(act)} of the mooring line when the horizontal line force = F _{ss(line)}	$S_c = (2h(F_{ss(line)} / q_{act} + h/2))^{1/2}$ (m) $X_c = (F_{ss(line)} / q_{act}) \sinh^{-1}(q_{act}S_c / F_{ss(line)})$ (m) $X_{l(act)} = (S_l - S_c) + X_c$ (m)
Step 7	Ensure that the difference in horizontal offset at F _{max(line)} and at F _{ss(line)} adequately exceeds the design value for horizontal oscillation of the pontoon due to wave motion about its mean position (= Δξ _{osc}) ^{\$} .	$X_{l(max)} - X_{l(act)} > \Delta\xi_{osc} \cos(\alpha)$ [#] (m)
If the inequality in Step 7 is satisfied, the arrangement can be adopted for preliminary design. Otherwise revise design by either increasing S _l or q _{act} , and return to Step 4 .		
^{\$} Note	Refer to Step F for determination of Δξ _{osc} , which is a function of the design sea state and water depth.	
[#] Note	This equation works for Cases 1 through to 4. (For Cases 1 and 4, α will = 0, and for Cases 2 and 3, α will generally be non-zero).	
[*] Note	Where Clump weights are used along the mooring line, as a first order estimate of line requirements, use the average or uniform mooring line buoyant weight/length, ie. spread the mass of the clump weight along the total length. Example for 1 clump weight:	
	$q_{av} = (q_1 S_{l1} + q_2 S_{l2} + CW) / (S_{l1} + S_{l2})$ (kN/m)	
	Where q ₁ & S _{l1} represent properties of the line between the anchor and the clump weight, and q ₂ & S _{l2} represent properties of the line between the clump weight and the pontoon.	

Box 7.35 Preliminary design for composite catenary chain and elastic element mooring line



Design Parameters	Depth of water	h (m)
	Total mooring line length	S_l (m)
	Unstretched length of elastic element	l_0
	Maximum permissible stretched length of elastic element	l_{max}
	Viable range of mooring line lengths	Typically minimum 4 times h
	Horizontal oscillation of pontoon about its mean position	$\Delta \xi_{osc}$ (m) ^s
	Average buoyant mooring line weight/length	q (kN/m) *
	Buoyant weight of Clump Weight	CW (kN)
	Design significant wave height (extreme event)	H_s (m)
	Total Steady State Horizontal Force (most extreme event)	$F_{ss(tot)}$ (kN)

Step	Description	Design Equations
Step 1	Estimate the proportion of $F_{ss(tot)}$ carried by the heaviest loaded line (refer Box 7. for configurations)	
Case 1	Single mooring line	$F_{ss(line)} = F_{ss(tot)}$ (kN)
Case 2	Two symmetric lines	$F_{ss(line)} = F_{ss(tot)} / (2\cos(\alpha))$ (kN)
Case 3	Two asymmetric lines	$F_{ss(line)} = F_{ss(tot)} \sin(\alpha_2) / \sin(\alpha_1 + \alpha_2)$ (kN)
Case 4	Three symmetric lines	$F_{ss(line)} = F_{ss(tot)} K$ (kN)
		Where $K \approx .33$ to 0.5 for $\alpha_1 = \alpha_2$ in the range 0° to 45°
		Where $K \approx 0.5$ to 1.0 for $\alpha_1 = \alpha_2$ in the range 45° to 90°
Step 2	Establish the manufacturer's permissible extension limit for the elastic element, and define and quantify the extension ratio limit, e .	$e = l_{max} / l_0$
Step 3	Determine the required length of the elastic element on the basis that the permissible extension must safely accommodate the design horizontal oscillation of the pontoon ($\Delta \xi_{osc}$ ^s). Adopt a safe extension = 70 % of the permissible value. The equation below is based on a horizontal elastic element. Whilst this is incorrect, even if it is at an angle of 25 degrees to the horizontal, the horizontal projection is 90 %, hence the error is insignificant.	$l_0 \geq \Delta x_{osc} / [0.7(e - 1)]$
Step 4	Determine the properties of the catenary section. Conservatively (under-) estimate the vertical height of the fully stretched elastic element, and subtract this from the depth of water. Then using this modified depth, design the properties of the catenary line such that the angle of the line at the anchor connection remains horizontal, for a horizontal steady state force = $F_{ss(line)}$ (applied at the top of the catenary section). Select a range of possible line lengths (S_l), and for each length compute the required (average or uniform) design weight/length (q_{des}) of this line from the equation below. Choose the preferred combination of q_{des} and S_l for the preliminary design. Assume that under the most extreme loading condition, the elastic element has an angle to the horizontal of around 15 degrees.	Vertical height of elastic element = $0.7el_0/4$ Modified depth of water, $h' = h - 0.7el_0/4$ $q_{des} = F_{ss} / [(S_l)^2 / (2h') - h'/2]$
^s Note	Refer to Step F for determination of $\Delta \xi_{osc}$, which is a function of the design sea state and water depth.	
* Note	Where Clump weights are used along the mooring line, as a first order estimate of line requirements, use the average or uniform mooring line buoyant weight/length, ie. spread the mass of the clump weight along the total length. Example for 1 clump weight:	$q_{av} = (q_1 S_{l1} + q_2 S_{l2} + CW) / (S_{l1} + S_{l2})$ (kN/m)
	Where q_1 & S_{l1} represent properties of the line between the anchor and the clump weight, and q_2 & S_{l2} represent properties of the line between the clump weight and the pontoon.	

Guidance for preliminary design of more complex arrangements

Where there are several mooring lines in an asymmetric arrangement or two or more symmetric lines with significantly different lengths and/or properties, engineering judgement is needed to facilitate preliminary design. The line expected to carry the greatest proportion of the applied environmental load (for the load direction being considered) must be selected and then an estimate of the proportion of load taken must be assigned. In most cases, the most heavily loaded line will be the one which has its alignment closest to the direction of loading. However, this may not be the case if, for example, a line at a skew angle to the load direction has a significantly shorter scope than lines with an alignment closer to that of the load direction.

This strategy for preliminary design reinforces the preference for incorporating as much symmetry into the mooring arrangement as possible, since it makes preliminary and final design so much simpler as well as enhancing the efficiency of the system and increasing the predictability of performance. Box 7.36 (*Minimising the number of mooring lines*) illustrates how the number of mooring lines that need to be considered in the preliminary design can be minimised for simplicity.

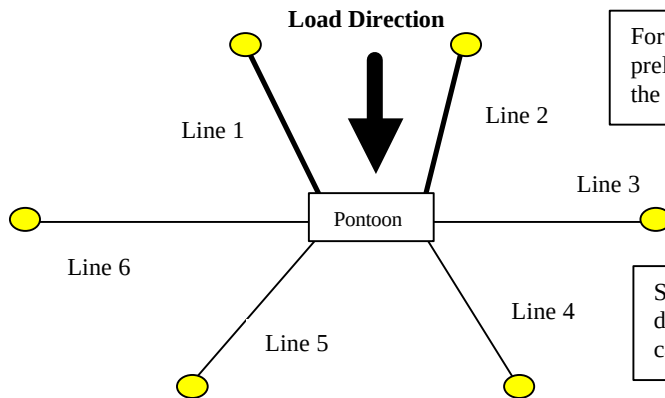
For the case shown in Box 7.36 (*Branched Mooring Lines*), where a particular mooring line is connected at one end to the pontoon and at the other end splits into two legs, the behaviour and hence the analysis process is quite complex and difficult to resolve. It may be suitable in the first instance to undertake the preliminary design treating Legs 1a & 1b as though they were a single element, extending in a straight line from the pontoon, and with a total length equal to $(\text{Line 1}) + (\text{Leg1a}) \cdot \cos(\alpha)$. The preliminary weight/length determined in this manner for the hypothetical single leg, can be conservatively adopted for both branches of the leg. This will provide a reasonable first estimate of line properties, which can then be analysed in full and refined in the detailed design phase.

In instances where an Admiralty type mooring system is employed (to permit weather-vaning in extreme weather conditions), it will normally be supplemented with lighter sacrificial or temporary connecting lines to hold the pontoon in place during mild (operational) conditions. (Refer to the illustrations of Systems 2 and 3 in Section 7.1) Preliminary design for each leg of the Admiralty system can proceed based on the *Cyclonic Condition* loading, ignoring the existence of the supplementary lines and permitting the pontoon to weather-vane in the direction of load being considered. In this manner, preliminary design of the Admiralty system lines can be achieved by assuming 100 % of the environmental force is restrained by a single line. Refer to Box 7.36 (*Admiralty Mooring Lines*).

A preliminary design for the connecting lines is shown in Box 7.36 (*Connecting Mooring Lines*). For convenience environmental loading can be applied in the direction indicated (the intensity of environmental loading should correspond to the most severe conditions at which the connecting lines are to remain intact, i.e. *Maximum Non-Cyclonic Condition*). In this manner, conservatively, lines 1 and 2 can be designed assuming they provide 100 % of the required restraint. It is noted that it is possible that loading in a direction perpendicular to that depicted in Box 7.36 may be more severe on lines 1 and 2. However, this is too complex to compute for preliminary design and can be resolved and the design refined in the final design analysis.

Box 7.36 Application of preliminary design method to complex mooring line geometries

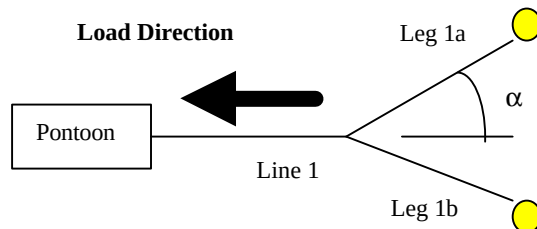
Minimising the number of mooring lines



For the load direction shown, the preliminary design procedure can ignore the load contributions from Lines 3 to 6.

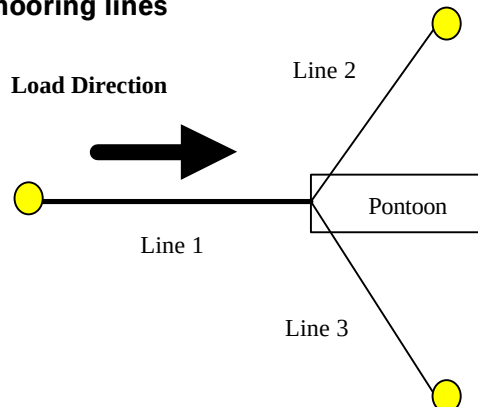
Similarly, if the load is from the direction of Line 6, preliminary design can ignore Lines 2 to 4.

Branched mooring lines



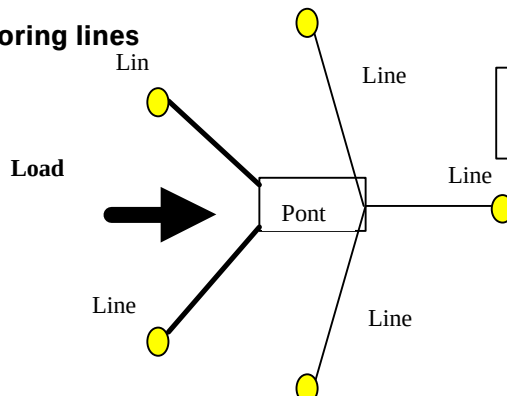
Legs 1a & 1b can be considered as a single element, with a total length equal to: $(\text{Line 1}) + (\text{Leg 1a}) \cdot \cos(\alpha)$.

Admiralty mooring lines



Assume Line 1 provides 100 % restraint for the environmental load.

Connecting mooring lines



Assume Lines 1 and 2 provide 100 % restraint for the environmental load.

Step E Develop mooring force-offset relationships											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step E develops the horizontal force – offset curves for mooring lines for particular load cases. The relationship for individual mooring lines is presented and two methods are given for generating the resultant line forces and pontoon offsets for multiple lines. Method 1 – Simplified component lines is used in simple configurations to generate a <i>system</i> force-offset curve representing multiple lines. Method 2 – Numerical model, which uses a computer package, accommodates the different orientations of individual lines in complex configurations, and allows for both translation and rotation displacement of the pontoon.											

Relationship for Individual Mooring Lines

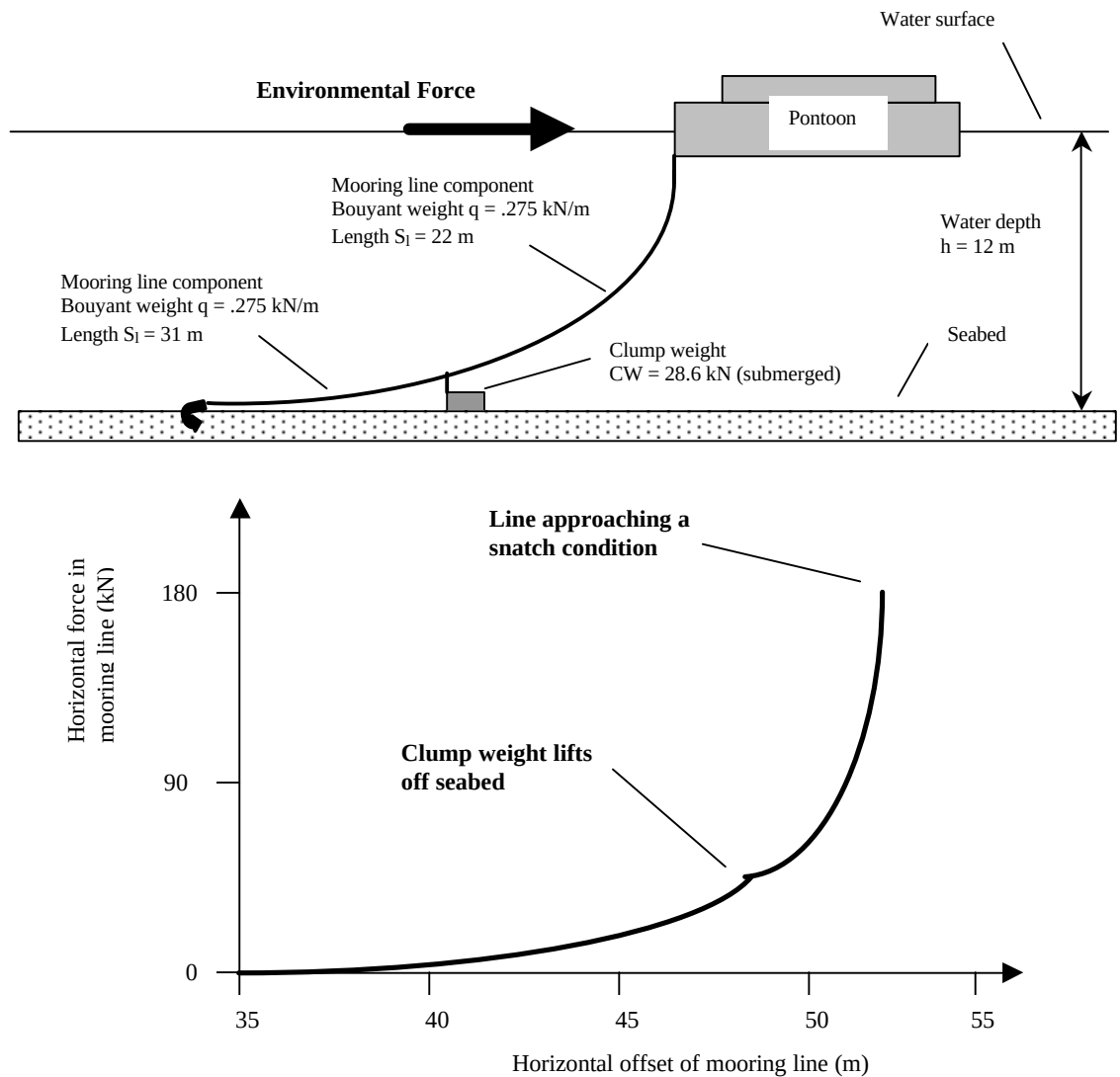
Utilising the preliminary designs of the mooring line lengths and properties, force-offset relationships must be constructed for each individual line. These relationships allow the tension in the line at the connection to the pontoon or the horizontal line force to be represented as a function of the horizontal distance the line is stretched from its equilibrium position (i.e. when the pontoon is at its rest condition).

For a simple catenary line that has uniform properties and no clump weights, or for a full length taut rubber bungy line, the force-offset relationship can be developed using simple theoretical solutions for catenary curves and for constant stiffness stretch lines respectively. However, lines most often comprise composite units and/or multiple lines, e.g.:

- Catenary Lines:
- with one or more clump weights
 - composed of two lengths, which are of a different grade of chain/wire
 - comprising a single line that branches into two or three legs
 - consisting of three legs in an admiralty system arrangement
 - that include a rubber stretch insert segment

As such, the force-offset relationship is usually a much more complex task to derive, and in practice, commercial software packages (e.g. refer Cox, 1982 and GMOOR, 1995), are usually employed to compute the solutions and provide a graphical representation. Box 7.37 displays a typical force-offset curve for a catenary line mooring system.

Box 7.37 Typical force-offset curve for a conventional catenary mooring line (single clump)



Developing a force-offset relationship for a chain and block catenary line

- 1 The effects of elastic stretch of chain and wire rope can be ignored where line lengths are relatively short (ie. where water depths are less than about 30 m).
- 2 The buoyant weight/length of the mooring line used in calculations should take account of the potential long-term reduction in size associated with thrashing of lines against the seabed. For areas where thrashing effects are likely (eg. around the seabed touchdown point), and in the absence of documented evidence, the buoyant weight/length used in calculating the force/offset relationship can be reduced by 10 % (to account for future wear).

It is convenient to express force-offset relationships both in terms of the line tension at the connection to the pontoon as a function of horizontal offset, and in terms of the horizontal line force as a function of horizontal offset. The latter relationship can be used to evaluate the horizontal offset applying to a particular steady state applied horizontal (environmental) force, while the former relationship permits the peak line tension to be read once the horizontal offset has been obtained. It is also useful to develop a relationship for the magnitude of load and inclination of load applied to the anchor as a function of the horizontal offset of the end of the line connected to the pontoon.

This enables the vector force applied to the anchor to be easily established once the peak horizontal offset of the pontoon has been determined.

The extent of horizontal offset, the peak line tension and the vector force applied to the anchor primarily determine the engineering and environmental acceptability of the chosen mooring system. Where design assessment requires that load cases consider performance in both maximum and minimum design water levels, it will usually be necessary to produce separate individual line force-offset relationships for each state.

Solution process for multiple mooring lines

Once the individual line force-offset relationships are produced, analysis can proceed so that the maximum offset, peak line tensions and anchor vector forces can be predicted. The analysis process can be performed within the *Simplified Mooring Design Procedure* at two levels of sophistication (Box 7.38).

Box 7.38 Design methods for developing force-offset curves for a multiple line mooring system	
<i>Design Method 1 – Simplified component lines *</i>	
This method combines the individual line force-offset relationships to yield a <i>system</i> horizontal force-offset relationship. Produce a separate <i>system</i> force-offset relationship for each direction of environmental loading that is to be examined. Each of these system force-offset relationships represents the net force exerted by all mooring lines in the direction of the applied load, as a function of the horizontal offset distance of the pontoon.	
<i>Design Method 2 – Numerical model</i>	
This method uses a purposely-designed numerical model (eg. NAVFAC, 1985; SPACEGASS, 2000) to represent the geometry of the pontoon and mooring lines. The individual line horizontal force-offset curves and the magnitude of applied environmental loads are used to determine the resulting equilibrium pontoon position and rotation, and the offset and forces occurring in each individual mooring line.	
* Note	Pre-requisite conditions for using <i>Method 1</i> • high degree of symmetry in the configuration and relative stiffness properties of mooring lines • all mooring lines to comprise a single leg only, ie. lines do not break into two (or more) legs part way along the lines • assume that environmental load components (wind, wave and current) all act in a co-linear direction, for all load cases.

Method 2 is preferred because it offers the ability to account for characteristics that *Method 1* cannot accommodate. *Method 1* requires major simplifying assumptions in order to produce solutions. In view of the increased uncertainty and approximations that are made with *Method 1*, it is necessary to apply greater factors of safety to estimates of peak forces produced with this procedure.

Factors that complicate the process of determining a solution to the mooring response are:

- Non-symmetry in the orientation and/or properties of mooring lines which cause the pontoon to rotate in addition to undergoing translational displacement,
- Departure from symmetry in the pontoon profile (i.e. the asymmetry of the face exposed to wind, wave and current), will also introduce rotation of the pontoon,
- Application of environmental forces in directions other than *head sea* or *beam sea* (i.e. at oblique angles) will normally result in pontoon displacements not only parallel but also perpendicular to the direction of the environmental force.

Method 2 offers the ability to accommodate pontoon rotation and translation perpendicular to the direction of load, and to provide reasonable estimates of these, in addition to translation parallel to the direction of load. *Method 1* cannot provide estimates of these, which therefore affects the accuracy of the estimates of peak movements and line forces produced with this method.

In light of these shortcomings, it is appropriate that certain pre-conditions be met before *Method 1* is employed as an acceptable solution process. These prerequisites conditions are described in Box 7.38.

The solution process for *Method 1* requires generation of a set of mooring *system force-offset relationships*, which combine the contributions from individual mooring lines for each load direction and design water level. The remainder of this Step focuses on how these *system force-offset relationships* are developed in *Method 1*.

Method 1: System force-offset relationships

With *Method 1* it is necessary to assume that pontoon displacement under applied loads is only translational and only in the direction of the applied environmental force. On this basis, *system force-offset relationships* can be developed to enable simplified solutions to be obtained rapidly.

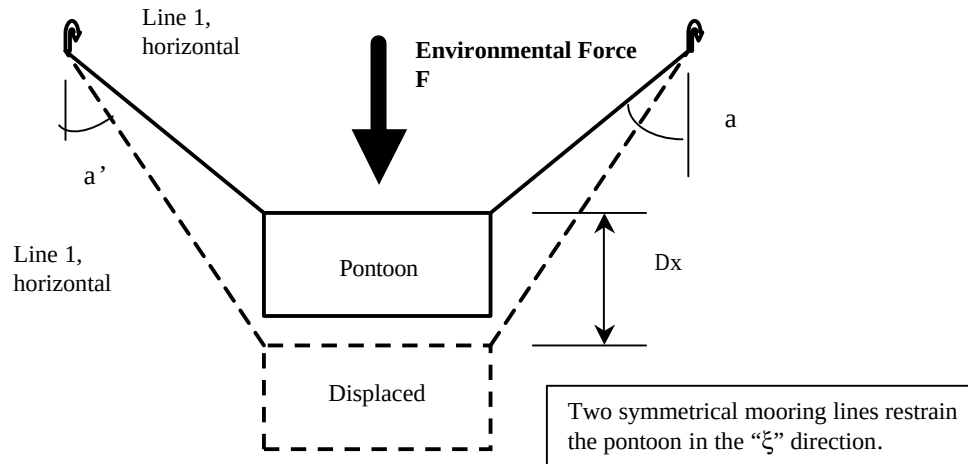
An example illustrating how these *system force-offset relationships* can be manually generated for *Method 1* is described in Box 7.39. This example is for a simple configuration comprising two symmetrical mooring lines resisting loading in a particular direction. For more complex configurations, computer applications (e.g. spreadsheets), can be utilised to generate the *system force-offset relationships*, based on the individual line force-offset curves and the line geometry and orientation.

A *system force-offset relationship* must be generated for all environmental load directions required in the design assessment. Furthermore, where design load cases require consideration of both minimum and maximum design water levels, it will be necessary to produce separate system force-offset relationships for each design water level, in each design load direction.

Outputs: Step E – Develop mooring force-offset relationships	
1.	A force-offset relationship for each of the pontoon mooring lines. These curves represent the maximum line tension in the line as a function of the extension of the line from the equilibrium pontoon position.
2.	A schematic diagram of all mooring lines, illustrating the length and properties of each element.
3.	If <i>Method 1</i> is followed, then system force-offset curves also are produced for each load direction and design water level considered. The system relationship represents the net horizontal restraining force imposed on the pontoon in a specific direction, as a function of the pontoon offset in that direction.

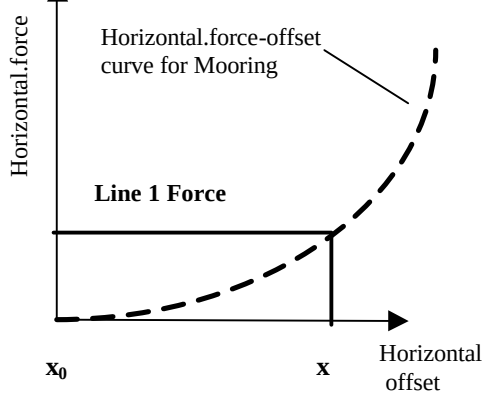
Box 7.39 Developing system horizontal force-offset relationships – Example using Method 1

Diagram 1 Pontoon and mooring displacement

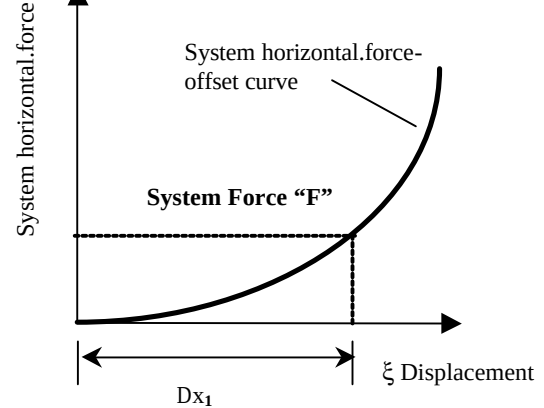


Design	Orientation of mooring lines to load direction	α, α' (degrees)
Parameters	Mooring system displacement	$\Delta \xi$ (m)
	Mooring line horizontal displacement	x_0, x_1 (m)
	Static horizontal environmental force	F, F_1 (kN)

Diag. 2 Force-offset for mooring Line 1



Diag. 3 Force-offset for mooring system



Force-offset relationships for Mooring Line 1 (Diagram 2)

Under the application of a static horizontal environmental force “F” in the “ ξ ” direction in the above example, the pontoon horizontal displacement is “ $\Delta \xi$ ”. In the process, the mooring lines rotate (around the anchor point), and extend from a horizontal distance of x_0 at orientation α , to distance x_1 at orientation α' . The force-offset curve for Line 1 indicates that, at distance x_1 , the line exerts a horizontal restraining force, F_1 .

Force-offset relationships for Mooring System (Diagram 3)

The *system force-offset relationship* is constructed by computing and plotting the resultant horizontal restraining force, “F” in the “ ξ ” direction, for a range of “ $\Delta \xi$ ” values. For a given translational displacement of “ $\Delta \xi_1$ ”, the new mooring line horizontal length is given as:

$$x_1 = [x_0^2 + \Delta \xi_1^2 + 2 x_0 \Delta \xi_1 \cos(\alpha)]^{0.5}$$

Hence, from the force-offset curve for line 1 above, at extension x_1 , the corresponding line horizontal force is F_1 . The resultant restraining force from the two lines, “F” in the “ ξ ” direction is as follows. The resultant value of “F” computed for “ $\Delta \xi_1$ ”, is one point on the system force-offset curve.

$$F = 2F_1 \cos(\alpha')$$

$$\text{where } \alpha' = \cos^{-1}[(x_1^2 - x_0^2 + \Delta \xi_1^2)/(2 x_1 \Delta \xi_1)]$$

Step F Determine mean pontoon offsets and oscillating motions											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step F uses the steady state force (Step C) and the force-offset relationships (Step E) to estimate the resultant mean pontoon offset for each load case. The maximum pontoon offset is determined by adding the maximum oscillation to the mean offset for the level of steady state loading. The maximum pontoon offset for each load case comprises pure translation, or translation and rotation, depending on the solution method adopted in Step E.											

Armed with the load case data from Step B (i.e. the magnitudes of horizontal environmental steady state loads for each direction and each design water level) and the mooring line force-offset relationships (from Step E), it is possible to compute the mean pontoon offset position for each load case. The *Simplified Mooring Design Procedure* assumes that the pontoon oscillation around this mean offset position is exactly the same as the horizontal trajectory of a water particle (at surface level). The maximum horizontal oscillation of the pontoon is therefore assumed to correspond to the water particle movement at surface for the maximum wave height condition operating in the environmental load intensity under consideration.

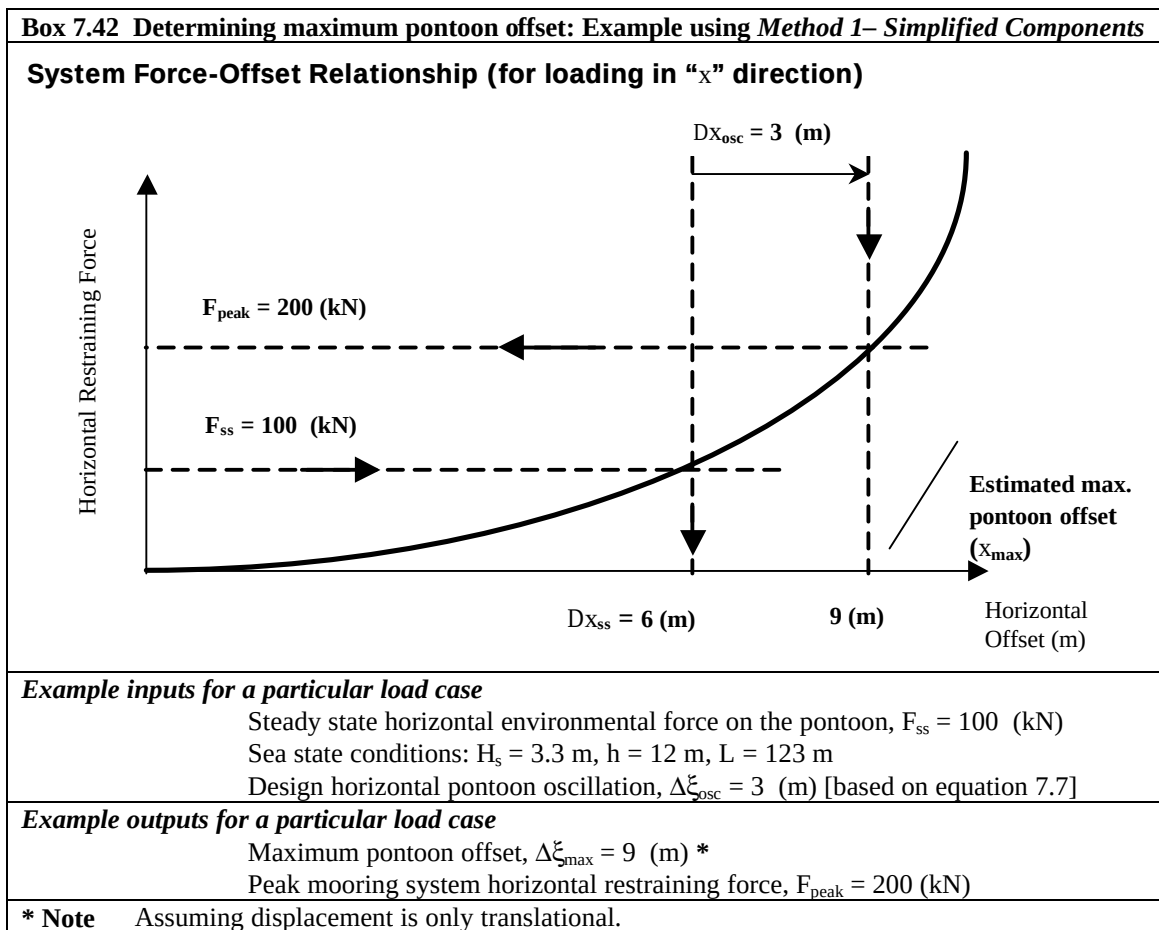
Once the mean pontoon offset has been determined (for a particular load case), the pontoon motions related to waves can be superimposed to allow estimation of the peak pontoon offset for each load case (Box 7.40). Typical values of maximum horizontal displacement about the mean position ($\Delta\xi_{osc}$) for several combinations of water depth and wavelength are given in Box 7.41.

Box 7.42 illustrates the procedure for determining the maximum pontoon offset when *Method 1* (refer Step E), is adopted. Box 7.43 discusses the solution process for the preferred *Method 2*.

Box 7.40 Calculation of pontoon horizontal displacement
For deep water waves, water particles at the surface move in a circle with a radius equal to half the wave height, ie. $H/2$. In shallower water the circle becomes an ellipse with the longer axis in the horizontal. The maximum horizontal displacement about the mean position is $\pm \Delta\xi_{osc}$ at the surface, given as: $\Delta x_{osc} = \frac{H}{2} \frac{1}{\tanh(2ph/L)} \quad (7.7)$ where h is water depth and L is wavelength, given as: $L = \frac{gT^2}{2p} \tanh\left(\frac{2ph}{L}\right) \quad (7.8)$ For mooring systems satisfying the requirements in Step I (maximum operating condition) and Step J (extreme conditions), relating to resonant behaviour, use: $H = H_s$, design significant wave height For mooring systems that do not satisfy the requirements in Step I and Step J, use: $H = H_{max}$, design maximum wave height H_s $H_{max} (\approx 1.8H_s)$

Box 7.41 Typical horizontal water particle oscillations for water depth and wave characteristics				
H (m) *	h (m)	T (s)	L (m)	Dx_{osc} (m)
1	8	8	64.9	0.77
1	8	12	102	1.1
1	12	8	75.8	0.66
1	12	12	123	0.92
1	15	8	81.8	0.61
1	15	12	135	0.83

*** Note** For values of H different to 1 m, $\Delta\xi_{osc}$ can be scaled by a factor equal to H. For example:
 If H = 3 m, L = 102 m and h = 8 m:
 $\Delta\xi_{osc} = 3 \times 1.1 = 3.3$ m
 In general, $\Delta\xi_{osc}$ increases as h/L decreases.



Box 7.43 Determining maximum pontoon offset: <i>Method 2 – Numerical Model</i>	
<i>Common inputs for all load cases</i>	
- Coordinates of the mooring line connection points onto the pontoon (in the “at rest” condition) and coordinates of the anchor points for each mooring line. - Force-offset relationships for each mooring line.	
<i>Inputs required for a particular load case</i>	
- Steady state force components from wind, wave and current on individual exposed pontoon surfaces, and orientation and position of the line of action of these force components relative to the pontoon centre of gravity (c.o.g.). - Design horizontal pontoon oscillation, $\Delta\xi_{osc}$.	
<i>Step 1</i>	The environmental forces are applied using the mooring design computer package, and the system is analysed until a balance is achieved with the mooring line restraining forces. This constitutes the equilibrium pontoon position and orientation, for this level and direction of steady state environmental loading. <i>Outputs</i> - New x & y coordinates and angle of rotation, θ_{ss} of the pontoon c.o.g. - New x & y coordinates of the mooring line connection points onto the pontoon.
<i>Step 2</i>	Superimpose the pontoon oscillation, $\Delta\xi_{osc}$ onto the new steady state pontoon position determined in Step 1. (Note $\Delta\xi_{osc}$ is in the same direction as that of the approaching waves, and therefore may have both a Δx and a Δy component). Assume that the oscillation produces a translational motion, without rotation. <i>Outputs</i> - Maximum pontoon c.o.g. offset, $\Delta\xi_{max}$ (which is equal to the steady state offset coordinates plus Δx & Δy), and the angle of pontoon rotation, θ_{ss}. - x & y coordinates of the mooring line connection points onto the pontoon, at the maximum pontoon offset position.
Outputs: Step F – Determine mean pontoon offsets and oscillating motions	
At the completion of this Step (regardless of whether <i>Method 1</i> or <i>Method 2</i> is followed), it shall be appropriate to produce a tabulated list of all load cases together with the calculated values of the maximum offset and (if <i>Method 2</i> is used) the angle of rotation of the pontoon centre of gravity.	

Step G Determine maximum line & anchor forces & line movements											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step G establishes the peak mooring design load, line movement, and anchor load for each mooring line, for each load case. The calculation procedure will depend on the method chosen in Step E. For Method 1 – Simplified component lines , peak line forces are determined from the individual line force-offset curves using the peak pontoon offset estimates. For Method 2 – Numerical model , individual line forces may be determined directly from the computer package. Alternatively, the same procedure for Method 1 can be applied, using the mooring line coordinates at their connection to the pontoon, for the maximum offset position.											

Once the position and rotation (if any) of the pontoon at the maximum offset is established for each load case (i.e. $\Delta\xi_{\max}$ & θ_{ss}), the coordinates of the connection point of each line to the pontoon can be determined. It is then possible to derive the peak line and anchor forces, as well as the degree of sweep of the mooring lines. The steps and example illustrations in Box 7.44 demonstrate the process required to determine these design values.

If *Method 2* has been utilised to determine displacements, the application program may automatically generate the peak line tensions and anchor loads, avoiding the manual process displayed in Box 7.44. However, it will still be appropriate to generate a plan illustrating the extent of pontoon movement and line sweep.

For each mooring line, the maximum line tension from all load cases will become the design value used for assessment of this line. Similarly, in the case of anchors, the maximum vector force (i.e. magnitude and inclination) is to be used for design assessment of anchor suitability.

Outputs: Step G – Determine maximum line & anchor forces & line movements	
1.	A table listing each load case. Under each load case, the calculated maximum line tension and anchor vector force shall be entered for each individual line.
2.	Where mooring lines comprise segments of differing properties and/or involve splits into multiple lines and anchors, it will be necessary to tabulate the calculated maximum force for each element.
3.	These tabulated values will be utilised in subsequent assessment of the suitability of mooring elements.

Diagram 1 Coordinates for pontoon

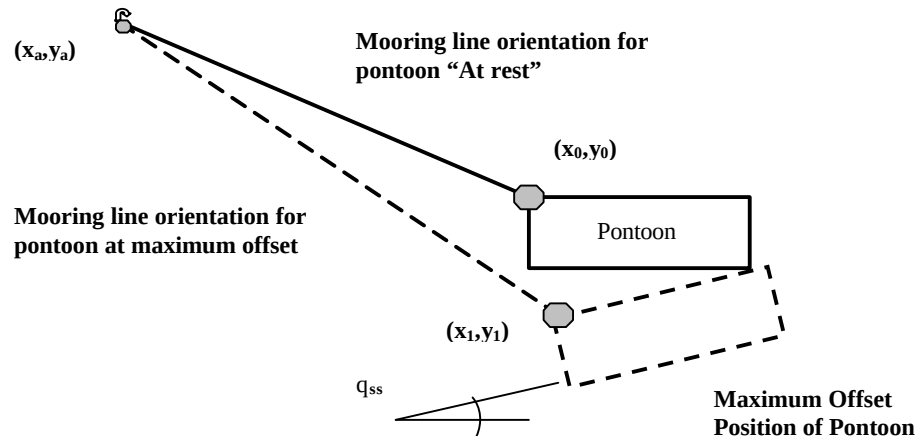
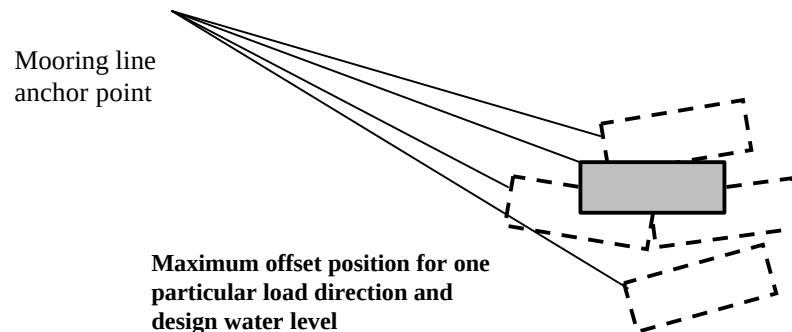


Diagram 2 Maximum pontoon offset positions



Step 1	For each load case: Calculate the coordinate points (x,y), of each mooring line connection point to the pontoon, at the calculated maximum pontoon offset position and rotation. This exercise is repeated for all load cases. Diagram 1 above illustrates the coordinate points to be determined for one particular line (of several securing the pontoon), under one load case condition.
Step 2	Calculate the horizontal distance to which each mooring line is extended in this maximum offset state, for each load case. In the example above, the horizontal length in the 'at rest' state and the maximum offset condition are given by: Horizontal length in the 'at rest' state: $S_{x0} = [(x_0 - x_a)^2 + (y_0 - y_a)^2]^{1/2}$ Horizontal length in the maximum offset condition: $S_{x1} = [(x_1 - x_a)^2 + (y_1 - y_a)^2]^{1/2}$ Horizontal extension at maximum offset: $\Delta S_x = S_{x1} - S_{x0}$
Step 3	The maximum line tension, the vector force applied to the anchor, and the maximum tension at a particular point along the line (if the line is made of composite segments), can be determined by reference to the individual force-offset curves and the computed ΔS_x values for each mooring line.
Step 4	Plot the 'at rest' and calculated maximum offset positions of the pontoon in plan view for each load case to represent the zone of pontoon movement in two dimensions. This plan will show the maximum extent of mooring line sweep for each line. Refer Diagram 2 (one mooring line). Prepare separate plans for the <i>Maximum Operating Condition</i>, <i>Maximum Non-Cyclonic Condition</i> (if applicable) and <i>Cyclonic Condition</i>, as separate movement criteria may apply for each of these states.

Step H Evaluate performance against design criteria											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step H evaluates the outputs from Step G with respect to limits placed on permissible pontoon movements, and movement or sweep of individual lines (Chapter 6). The peak line forces are checked to ensure they provide the required safety margin within the rated breaking strength of each line component. A check on flexibility is made to ensure this will be maintained in all mooring lines at the peak load condition. Means of rectifying the inadequacy are identified for the situation where the proposed mooring system fails to satisfy any criteria.											

Evaluation of the acceptability of the adopted pontoon and mooring arrangement, under the load cases examined in the preceding Steps, must be made against:

- The movement criteria established in Chapter 6 (Pontoon Siting, Layout and Configuration), for the pontoon and for the mooring lines
- Manufacturer certified strength capacities of mooring line elements
- Calculated design capacities of chosen anchor types and sizes (to be undertaken in accordance with Chapter 8 Anchor Design)
- Requirements to maintain flexibility of the mooring system, even under the severest loading.

Pontoon & mooring movements

With respect to pontoon and mooring line movements, the pontoon offset plan developed in Step G can be examined and compared against the allowable movement limits developed in Chapter 6. This assessment will ascertain whether or not the mooring configuration and component properties adopted in the preliminary design achieve the required restrictions to pontoon displacement from the ‘at rest’ position. It will also determine whether or not the degree of sweep of the mooring lines under the various load cases is permissible.

Capacity of mooring line elements

The preliminary designs adopted for mooring line properties must be checked to ensure that the applied loads are an adequate margin of safety less than the rated strength capacities of the various line elements. The factors of safety presented in Box 7.45 should be applied in checking the adequacy of line component strengths in respect to the different load cases considered.

In most instances, the required mass per length of individual mooring lines will be dictated by design criteria imposed to prevent snatching (i.e. maintain flexibility), of mooring lines under extreme loading conditions. As a consequence, the strength of lines will normally exceed the minimum requirements specified in Box 7.45, ie. in avoiding a snatch condition, the resultant gauge of mooring line will normally have excess strength capacity, and the requirements of Box 7.45 will be redundant for the lines (but not for the connections).

Note that anchors must be designed to satisfy the requirements in Chapter 8 before final acceptance can be given to mooring line capacities.

Mooring line flexibility check

A key aspect of the design philosophy behind this *Simplified Mooring Design Procedure* is the requirement to ensure flexible (non-snatching) behaviour of the mooring system is maintained for environmental loading up to the maximum design loading imposed. To verify suitability of the current mooring design, the following criteria are to be checked for each mooring line (Box 7.46).

Box 7.45 Factors of safety to be applied to strength capacity of all components of mooring lines			
Design environmental loading condition	Minimum factor of safety (FS)		
	Simplified Mooring Design Procedure (SMDP)		Numerical or physical model
	Method 1 [#]	Method 2 [#]	
Maximum Operating Condition	3.5	3.25	2.3
Maximum Non-Cyclonic Condition *	3.0	2.75	2.0
Cyclonic Condition	2.5	2.25	1.65
Determine the minimum breaking strength of mooring line elements as follows:			
	$P_b \geq T_{\max} FS$ (7.9)		
where	$T_{\max}$ = Maximum computed tension force in the mooring line element FS = Factor of safety (above) P_b = Minimum required breaking strength of the mooring line element		
* Note	This load condition will be applicable when: 1. A <i>System 2</i> mooring configuration is adopted (Section 7.1), ie. sacrificial lines are used to hold the pontoon in place, but are designed to break under a certain intensity of environmental load. In this case, the <i>Maximum Non-Cyclonic Condition</i> refers to the anticipated maximum intensity of loading experienced by the pontoon, just before the sacrificial lines break under the applied load. 2. A <i>System 4</i> mooring configuration is adopted (Section 7.1), ie. the pontoon is to be moved to a separate mooring system when severe weather conditions are imminent. In this case, the <i>Maximum Non-Cyclonic Condition</i> refers to the anticipated maximum intensity of loading experienced by the pontoon, before it would be relocated to the alternative mooring system.		
# Note	<i>Methods 1 & 2</i> (defined in Step E) relate to the technique used to compute the maximum offset position of the pontoon under applied environmental forces.		

Box 7.46 Criteria adopted to maintain flexible mooring behaviour	
Type of mooring system	Criteria to ensure flexible performance
Chain and block catenary mooring *	At the maximum computed offset distance for each line ($\Delta\xi_{\max} = \Delta\xi_{ss} + \Delta\xi_{osc}$), the angle of inclination of the line at the anchor connection must equal zero (ie. $\theta_{\text{anchor}} = 0$), for flat seabed conditions. If the seabed is sloping and the mooring line is inclined above horizontal when resting on the seafloor, flexibility can be assumed if the line (at the anchor connection) does not lift off the seafloor.
Composite catenary and elastic element mooring [#]	At the maximum computed offset distance for each line ($\Delta\xi_{\max} = \Delta\xi_{ss} + \Delta\xi_{osc}$), the line extension of the elastic insert element must be maintained at $\Delta l \leq 70$ % of the maximum permissible extension.
Taut mooring with elastic element [#]	At the maximum computed offset distance for each line ($\Delta\xi_{\max} = \Delta\xi_{ss} + \Delta\xi_{osc}$), the line extension must be maintained at $\Delta l \leq 70$ % of the manufacturer's maximum permissible extension).
* Note	Where moorings are placed in relatively deep water (i.e. > 30 metre depth), this criterion can be relaxed. Check to ensure that the line does not snatch under the severest loading.
# Note	If these arrangements impose inclined loads onto anchors, the anchors must be purposely designed to accommodate the combination of lateral and uplift forces that are involved.

Box 7.47 Summary of acceptance checks and corrective actions**Acceptance checks**

In all Load Cases, does the present mooring design satisfy the specified:

- Movement limits for pontoon offset?
- Movement limits for sweep of individual mooring lines?
- Strength capacities of mooring line elements?
- Controls to maintain individual line flexibility in the load case producing the maximum line extension?

Action if inadequacies are identified

If the preliminary design for the mooring arrangement fails to meet any of the movement, line tension and flexibility criteria specified, then a modification and/or re-design of the system will be required.

If the shortcoming is minor and limited to a specific element of a single line, then it may be possible to make minor adjustments to this specific mooring line in order to meet the full set of criteria. On this basis, refinements can be made to the line properties in Step D, and the modified system re-examined for conformance to the design requirements.

In instances where the preliminary design results in grossly excessive movements, and/or line tensions greater than can be practically accommodated by the adopted system and/or excessive inflexibility is evident, a serious re-assessment will be required. It will be necessary to reconsider the layout and configuration of the whole mooring line system and the designer should return to Step A with a revised arrangement. The inadequacies identified in the preliminary design will provide valuable insight into the areas that require adjustment and improvement in order to satisfy the design criteria. Progressive changes must ultimately produce a final system that satisfactorily meets all design criteria.

Following are a range of modifications that could be considered if the preliminary mooring design arrangement proves inadequate:

- (1) Use heavier lines or longer lines if geometry permits
- (2) Consider addition of multiple closely spaced clump weights or, alternatively, addition of a section of heavy chain (parallel to the primary line) [this secondary line does not contribute to strength capacity, it merely serves to add additional mass per length along the primary line – hence it could be second hand used chain]
- (3) Insert an elastic element, as a means of absorbing movement energy
- (4) Consider adoption of an alternative mooring system (eg. a taut mooring system)
- (5) Consider utilisation of a separate cyclone mooring system (allowing longer lines, weather-vaning and/or positioning further away from sensitive reef structures)
- (6) Relocate to a more protected location, or where more symmetry can be achieved

Outputs: Step H – Evaluate performance against design criteria

1. If the preliminary design satisfies the criteria outlined above, the arrangement can be adopted as the design solution. Some supplementary requirements relating to performance in operational and extreme conditions and during the installation and post-installation phases apply (Steps I and J). Generally, these supplementary aspects need no more than minor adjustments to the design solution.
2. If the preliminary design does not satisfy the criteria outlined above, modifications must be introduced and the system re-examined for conformance.
3. A summary of the checks and actions required for acceptance are provided in Box 7.47.

Step I Check pontoon stability during operational conditions											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
<i>Scope and purpose</i>											
Step I checks pontoon stability during operational conditions (including ferry berthing), to help ensure human comfort levels and safety are satisfied. A method is presented to ensure that resonant pontoon behaviour does not occur during operation. Simplified vibration theory is applied in order to check the natural frequency of the pontoon-mooring system against the wave frequency occurring at the maximum operating condition.											

It is not sufficient for the pontoon mooring system to be designed solely to resist safely the applied loads and prevent environmental damage; there are additional functional requirements that are needed to ensure adequate performance. While it is the fundamental responsibility of the proponent and operator to ensure that the pontoon provides adequate levels of human comfort during normal operating conditions, it is appropriate and necessary for certain functional performance characteristics to be specified in these *Guidelines*.

To maintain vessel motions at acceptable levels, it is imperative that the mooring system securing the pontoon during normal operational conditions is designed such that oscillatory movements are minimal and tolerable. In this respect it is critical to ensure that the natural frequency of oscillation of the pontoon-mooring system is not close to the range of operating wave frequencies. If the natural frequency of the system does coincide with the frequency of waves, the pontoon is likely to oscillate in full sympathy with the wave motion, which is likely to produce severe and uncomfortable vessel motions. In addition to the undesirability of this scale of motion (which could be expected to occur frequently), there is a much higher risk of fatigue failure occurring in key mooring components due to the repeated large-scale movements and the dynamic amplification of member forces. Hence, it is necessary to ensure that the design solution for the mooring system does not allow this mode of resonant oscillation response to occur.

Avoidance of resonant response during normal operations is achieved by ensuring that the mooring system has a natural frequency that is a satisfactory margin lower than the operating range of wave frequencies. Provided the system natural frequency is a safe margin outside the expected range of wave frequencies (under which normal operation continues), then resonant behavior can be avoided.

Where mooring lines are designed with intermediate clump weights, it is appropriate to impose a further restriction in regard to mooring system response during normal operating conditions. Clump weights shall be designed in such a way that they do not lift off the seabed in environmental conditions of a severity up to and including the defined *maximum operating condition*. Frequent lifting and movement of clump weights is highly undesirable because it: significantly increases the risk of fatigue failure of mooring line components; often contributes to unacceptable levels of coral damage, seabed disturbance and increased local turbidity; and also may pose a threat to the safety of divers.

Fortunately, in most instances, if the mooring design meets requirements for avoiding mooring system resonance in operating conditions, it is also likely that clump weight lifting would not result during operating conditions.

It is most important to appreciate that merely satisfying these requirements does not provide any guarantee that the mooring design proposed will restrict vessel motions during operation to desirable human comfort levels. The onus is on the proponent, designer and operator to develop a system that provides the necessary restraint to meet target comfort levels.

Below is a guide to how the properties of the mooring system can be assessed in order to check whether or not the current design adequately avoids resonant behaviour during normal operating conditions. Box 7.48 provides a simple illustration of the rationale used to test adequacy of the design. This test is to be applied to all load cases where the environmental load intensity equals that of the *maximum operating condition*.

Summary of minimum operational requirements

- Operational performance must be checked to ensure that resonant response is avoided. This check is satisfied if the mooring system has a natural frequency comfortably outside the anticipated range of wave frequencies during operation.
- In addition, clump weights (if used) must be positioned and designed such that they do not lift off the seabed during normal pontoon operation (unless extenuating circumstances exist).

Estimating system natural frequency

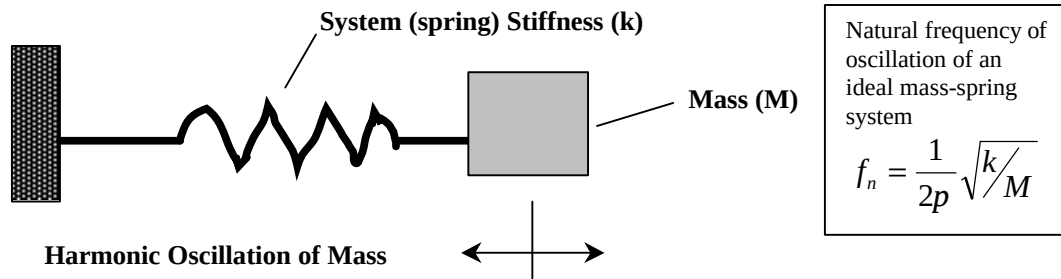
A simple one-dimensional degree of freedom vibrating system (for horizontal oscillation), can be used to derive a first estimate of the natural frequency of the pontoon-mooring system for each load direction examined. This simple system is analogous to a mass restrained by a spring, undergoing linear vibration. While in reality there are also contributions to system damping, these can be conveniently ignored in this model, since the damping only offsets the natural frequency by a small percentage (therefore the error is only minor).

Terms used in equation 7.11 can be extracted from the results of the analyses performed in Steps C and F. Note that in Step F, two solution approaches (i.e. *Method 1* and *Method 2*) were featured. Terms in the equation for determining representative stiffness can be extracted from Box 7.49 for *Method 1*, and Box 7.50 for *Method 2*.

Box 7.51 defines the design rationale that is adopted to provide reasonable assurance that resonant response will not develop during operating conditions.

Box 7.48 Pontoon-mooring system natural frequency and stiffness

Simple one-dimensional mass-spring vibration system



The mass used in this simple model for pontoon oscillation is the inertial mass of the pontoon (= mass of pontoon + an added mass of water). The stiffness corresponds to the average slope of the horizontal force-offset relationship for the mooring system (for the level of environmental loading and the loading direction being examined). The average stiffness used must be representative of the mooring system response characteristics when the pontoon is oscillated around the steady state offset position..

Representative stiffness

The horizontal offset for determination of representative mooring system stiffness should be evaluated over the following range:

$$\Delta\xi_{\text{range}} = \Delta\xi_{\text{ss}} \pm \Delta\xi_{\text{osc}} \quad (7.10)$$

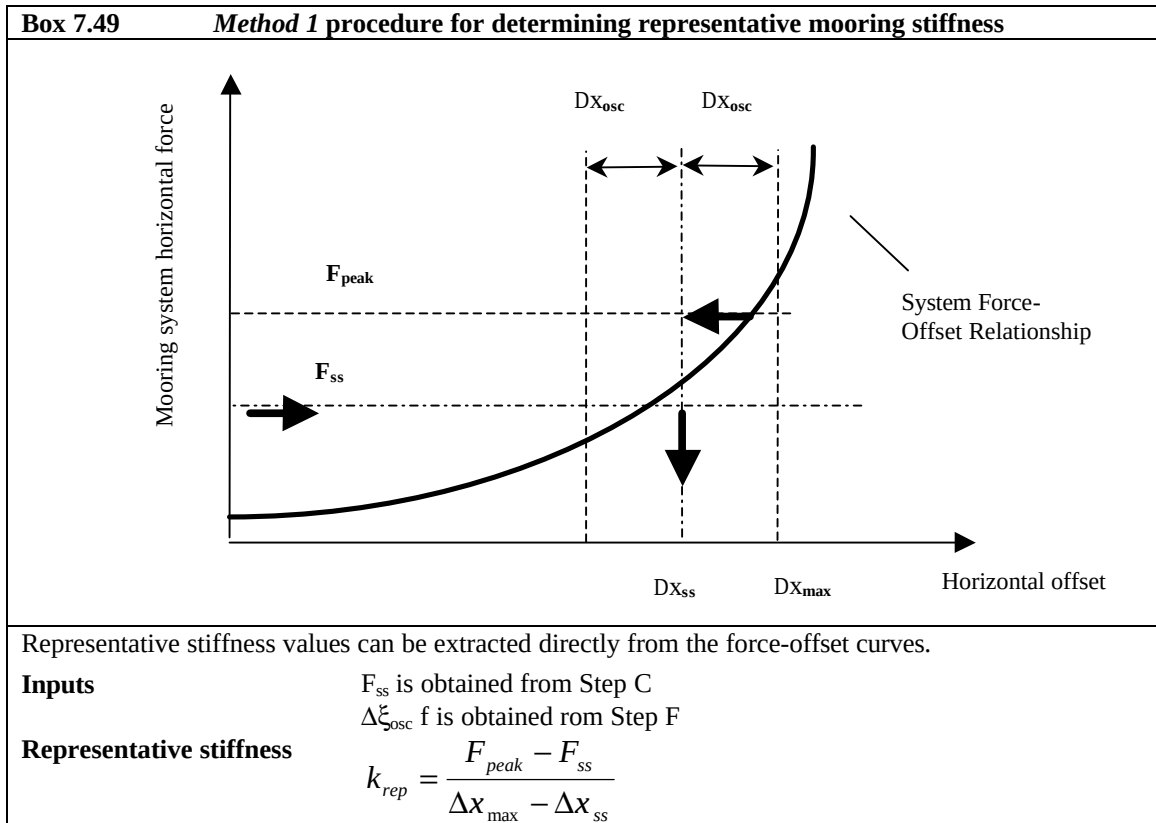
Representative horizontal mooring system stiffness (in a given direction, design water level and for a given environmental load intensity) should be estimated as follows:

$$k_{\text{rep}} = \frac{F_{\text{peak}} - F_{\text{ss(tot)}}}{\Delta x_{\text{max}} - \Delta x_{\text{ss}}} \quad (\text{Force/metre}) * \quad (7.11)$$

Where

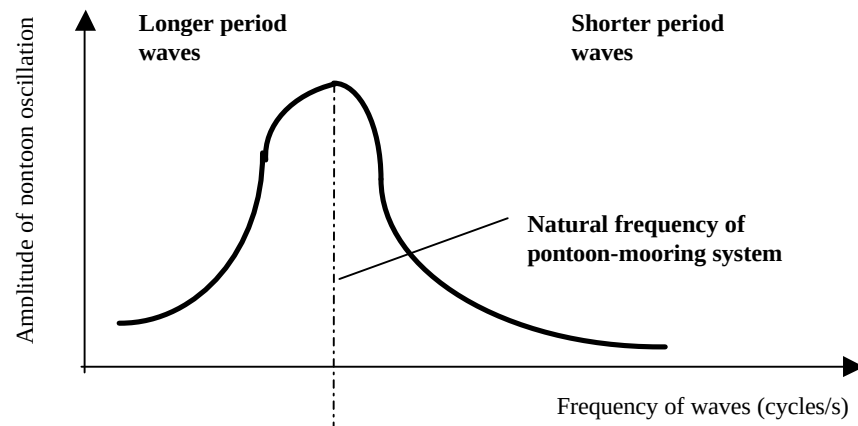
- F_{peak} = Estimated maximum horizontal mooring system restraining force at the maximum offset, $\Delta\xi_{\text{max}}$
- $F_{\text{ss(tot)}}$ = Steady state (wind, wave and current) horizontal force
- $\Delta\xi_{\text{max}}$ = $\Delta\xi_{\text{ss}} + \Delta\xi_{\text{osc}}$

*** Note** k_{rep} must be calculated for each design load direction and design water level, using the results from the *maximum operating condition* level of loading.



Box 7.50 Procedure for determining representative mooring stiffness	
Pontoon offset positions are developed from the numerical model for each load case. Parameters required for calculating stiffness from Equation 7.11 are obtained as follows:	
F_{ss}	The steady state horizontal environmental force for the <i>maximum operating condition</i> is produced in Step C.
$\Delta \xi_{ss}$	The steady state offset is an output of the <i>Method 2</i> application program, which evaluates the equilibrium offset position of the pontoon under the steady state loading.
$\Delta \xi_{osc}$	Defined in Step F as a function of the design significant wave height and wavelength (for the <i>maximum operating condition</i>) and the water depth at the site (Eqn. 7.7).
$\Delta \xi_{max}$	Estimated as the steady state offset plus the oscillation offset = $\Delta \xi_{ss} + \Delta \xi_{osc}$.
F_{peak}	The magnitude of the (quasi-static) maximum horizontal force is determined as the vector sum of all mooring line horizontal forces (Step F) for the pontoon in the maximum horizontal offset position.

Box 7.51 Typical pontoon response characteristics as a function of wave frequency



When wave frequency is close to the natural frequency of the pontoon-mooring system, the amplitude of pontoon oscillation is likely to exceed comfort levels. Consequently, it is important to ensure that the natural frequency has a safe margin outside the range of likely wave frequencies occurring in normal operations.

Short period waves will predominate in slight conditions, with the period of the wave increasing (frequency decreasing) as the intensity of environmental condition increases. To avoid a resonant response, it is necessary to ensure that the system natural frequency is either lower than the lowest expected wave frequency or higher than the highest expected wave frequency. For practical reasons, the designer must ensure that the system frequency is on the low side of the range of wave frequencies (attempting to operate on the high side would require an extremely tight mooring system which would induce very high line tensions).

A satisfactory design rationale is to ensure that the mooring system stiffness has a natural frequency lower than the lowest expected wave frequency occurring during normal pontoon operation. This requirement must be satisfied in all load cases representing *maximum operating conditions* (ie. covering each different load direction and design water level).

For simplicity, the lowest expected wave frequency in normal pontoon operation can be taken to correspond to the design significant wave height adopted for the *maximum operating condition*.

Target range of the representative mooring stiffness (for Maximum Operating Condition)

In accordance with the proposed rationale, the wave frequency in the *Maximum Operating Condition* must be above that of the system natural frequency to avoid excessive pontoon motion during these conditions. Therefore, the target representative mooring stiffness must meet the following criterion.

Assessment of the target range for representative mooring stiffness must be repeated for each environmental load direction and design water level.

If the k_{rep} calculated at the *maximum operating condition* does not satisfy the requirements of equation 7.13 (Box 7.52) for all load directions and design water levels, then there needs to be a modification to the mooring system.

Possible means of correcting mooring system characteristics to satisfy the above criterion are:

- Increasing the scope of mooring lines
- Changing the arrangement and positions of clump weights
- Adding additional mooring lines
- Adjusting the properties of mooring lines and/or incorporate composite lines

Box 7.52 Pontoon response characteristics as a function of wave frequency	
System natural frequency is given by:	
	(7.12)
	$f_n = \frac{1}{2p} \sqrt{\frac{k_{rep}}{M}}$
Where	f_n = Pontoon-mooring system natural frequency (cycles/s) at <i>maximum operating condition</i>
	M = Mass of pontoon + added mass of water *
Need to ensure that:	
	$f_n < f_{wave} / 1.25$
Where	f_{wave} = Frequency of the design significant wave height in the <i>maximum operating condition</i>
Substituting and replacing f_{wave} with $1/T_{wave}$	
	$f_n < f_{wave} / 1.25$
Where	T_{wave} = Period of the significant wave height (in seconds), in the <i>maximum operating condition</i>
Therefore, require the representative system stiffness:	
	(7.13)
	$k_{rep} < \frac{2.56p^2 M}{T_{wave}^2}$
Where	f_{wave} = Frequency of the design significant wave height in the <i>maximum operating condition</i>
* Note In the absence of physical or numerical model results, “M” can be taken to be equal to 1.5 times the pontoon mass.	

Functional stability during ferry berthing

To ensure safe and secure embarking/disembarking operations (i.e. tourists transferring between the floating pontoon and the ferry craft), designers must give due consideration to the scale of relative movements that are expected to occur. Particular attention shall be paid to the relative level of vessel movements associated with roll and heave motions of each craft. Appropriate aids (e.g. gang planks with underside wheels), shall be used to maintain safety in all operational conditions. Lines securing the ferry craft to the pontoon shall be designed to safely restrain the ferry under *Maximum Operating Conditions*.

Step J Address miscellaneous design requirements											
Design task sequence for Simplified Mooring Design Procedure											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step J checks whether resonant behaviour will occur during extreme environmental events (cf. operational conditions in Step I). Where resonant behaviour is likely, the designer assigns appropriate dynamic amplification factors to the estimated peak line forces, or justifies why this is not necessary. The methods of installing, maintaining and eventually salvaging the mooring system are established.											

Pontoon stability during extreme conditions

Pontoon stability during extreme conditions (either the *Maximum Non-Cyclonic Condition* if relocation of the pontoon to an alternate mooring system applies, or otherwise the *Cyclonic Condition*), is also an issue requiring examination. In Step I, the pontoon-mooring system was checked in relation to potential resonant behaviour in maximum operating conditions. Although extreme conditions occur rarely, it is prudent to ensure that resonant response is still avoided in these instances, since such a response can result in dynamic amplification factors (to forces and displacements) that are not accounted for by the SMDP.

It is therefore necessary to check whether resonant behaviour is likely in the extreme condition (i.e. check whether $f_n > f_{\text{wave}}$). This assessment follows the exact same procedure as enunciated in Step I, except that wave frequency at the significant wave height in the extreme condition is used, and k_{rep} is computed using the estimated forces and displacements for the extreme condition loading. If equation 7.13 (Step I) is not satisfied for the extreme condition loading, then the designer must justify why dynamic amplification factors should not be applied to increase the peak line forces and the pontoon displacements estimated with the SMDP. This check must be performed in at least four directions around the pontoon (i.e. both *head sea* and both *beam sea* directions).

Other issues influencing mooring design

In addition to the mooring design requirements spelt out in the preceding Steps (which are associated with structural integrity, environmental responsibility, and functional performance), there are a number of other related issues that must be taken into consideration in finalising an acceptable pontoon mooring design. These are the:

- ability to install the mooring system without damaging the environment
- practicality of accessing, inspecting and servicing the mooring system for maintenance,
- ease of salvaging the mooring hardware at the end of the design life of the facility, without causing significant environmental damage.

The designer must address these specific issues and provide documentation, which is to accompany details of the adopted mooring design. Also refer to Chapter 10 for additional guidance on requirements for these three issues.

Outputs: Step J – Address miscellaneous design requirements	
Documentation accompanying the proposed mooring design shall include:	
1.	A description of the plant to be used, methods to be employed and precautions to be taken to ensure limited disturbance and destruction during installation to the zones and levels allowed and specified in the Permit. The sequence of steps involved in the installation process should be included.
2.	Verification that access can be obtained to fully inspect all mooring hardware components and indicate what means would be used to undertake required repair/replacement maintenance works.
3.	Description of the methods and plant that could be used to recover all mooring hardware, and what specific precautions would be employed to prevent environmental damage.

Step K Confirm and review design											
Design task sequence for <i>Simplified Mooring Design Procedure</i>											
Steps	A	B	C	D	E	F	G	H	I	J	K
Scope and purpose Step K provides a comprehensive checklist to evaluate and verify conformance of the mooring arrangement with the SMDP design criteria. If requirements are not met, the designer must revise and adjust the system by altering the mooring type, configuration or properties of individual lines.											

Design of an acceptable mooring system for floating pontoons stationed in a sensitive reef environment where tropical cyclones prevail is a challenging task. Because of the many complexities and sensitivities involved with these projects, the design criteria applying to mooring design are manifold and will often appear daunting. However, provided a methodical approach is used in which all load cases are adequately examined, the procedures outlined in this Chapter provide a rational approach for developing an acceptable system.

A brief checklist is provided in Box 7.53, which serves as a guide to the completeness of the proposed design arrangement. If the arrangement fails to meet all criteria, then a revised arrangement must be investigated:

- Returning to Step D and adjusting the properties of individual mooring lines until a satisfactory solution is produced may address minor inadequacies.
- More significant shortcomings may warrant return to Step A and Chapter 6, with re-configuration of mooring lines and/or selection of an alternative mooring system type.
- If unsuccessful, consideration would need to be given to re-locating the pontoon to a more protected site and/or reducing the scale of steady state loads by reducing exposed areas.

Box 7.53 Checklist for mooring design adequacy	
1	Have all load cases been clearly identified and associated forces been calculated? Load cases must cover: • In most cases, environmental forces approaching from 8 different directions around the pontoon (covering all <i>head sea</i>, <i>beam sea</i> and <i>quartering</i> directions). In special cases (refer Step B), the number of directions may be reduced, but an absolute minimum of three directions shall be used. • Examination of both minimum and maximum design water levels • Consideration of loads associated with the <i>Maximum Operating Condition</i>, <i>Maximum Non-Cyclonic Condition</i> and the <i>Cyclonic Condition</i> • Where different mooring systems are used for normal operation and cyclonic conditions, a check of the normal operation system at the maximum environmental force experienced before movement to the cyclonic mooring would be initiated. Similarly, if sacrificial lines are used, the intact system must be checked at the maximum environmental condition before these sacrificial lines would be expected to break.
2	Does the system satisfy the specified limits on strength capacity of each mooring line and each element in the mooring line, for all load cases? Does the system satisfy the specified limits on permissible pontoon movement and permissible mooring line movements during: <i>Maximum Operating Condition</i> <i>Cyclonic Condition</i> <i>Maximum Non-Cyclonic Condition</i>, ie. the maximum environmental condition prior to relocation or expected breaking of sacrificial lines (if the pontoon is relocated for extreme conditions or has sacrificial lines).
3	Are the peak line forces exerted on anchors within the achievable limits of readily available anchor systems? If not, specialised anchors will be required. Anchor design is to be performed in accordance with the requirements of Chapter 8.

4	For each individual mooring line, is flexible behaviour maintained under the environmental condition causing the maximum load in the line? Flexible behaviour is considered to be achieved if: a) For conventional catenary mooring lines, the angle (to the horizontal) of the mooring line at the anchor connection is equal to zero [for flat seabed conditions]. However, if the seabed is sloping and the mooring line, when resting on the seafloor is inclined above horizontal, flexibility can be assumed if the line (at the anchor connection) does not lift off the seafloor. b) For a composite catenary line + an elastic insert element, if the extension of the elastic element remains ≤ 70 % of the rated permissible extension c) For a taut mooring system incorporating an elastic element, if the extension of the elastic element remains ≤ 70 % of the rated permissible extension
5	In the <i>maximum operating condition</i> , does the pontoon-mooring system satisfy the requirements to avoid potential resonant response?
6	Are safe conditions maintained for embarking/disembarking activities between the pontoon and the service craft, during <i>maximum operating conditions</i> ?
7	Are the potential effects of dynamic amplification of forces and movements during extreme conditions avoided?
8	Can the pontoon and the mooring system be installed such that site disturbance and coral damage is restricted to the specified and agreed levels?
9	Can access to, and maintenance of, the mooring system elements be readily achieved?
10	Can the mooring hardware be salvaged at the end of the service life of the facility, without causing site disturbance and coral damage?

7.4 Detailed design of individual components and connections

In the detailed design phase of a pontoon project, it is necessary to define, design and specify each individual component of the mooring lines. Each component used must be appropriate to the task required and must satisfy the same strength requirements imposed on the mooring line to which the component is attached. In the design and selection of components, consideration must be given to factors such as does the component/connection chosen:

- Satisfy best practice guides?
- Have an adequate strength rating?
- Have proven durability for the purpose at hand?
- Offer ease of access for maintenance and replacement?
- Provide compatibility with the adjoining mooring components?
- Allow the range of rotation needed for the connection to perform adequately?

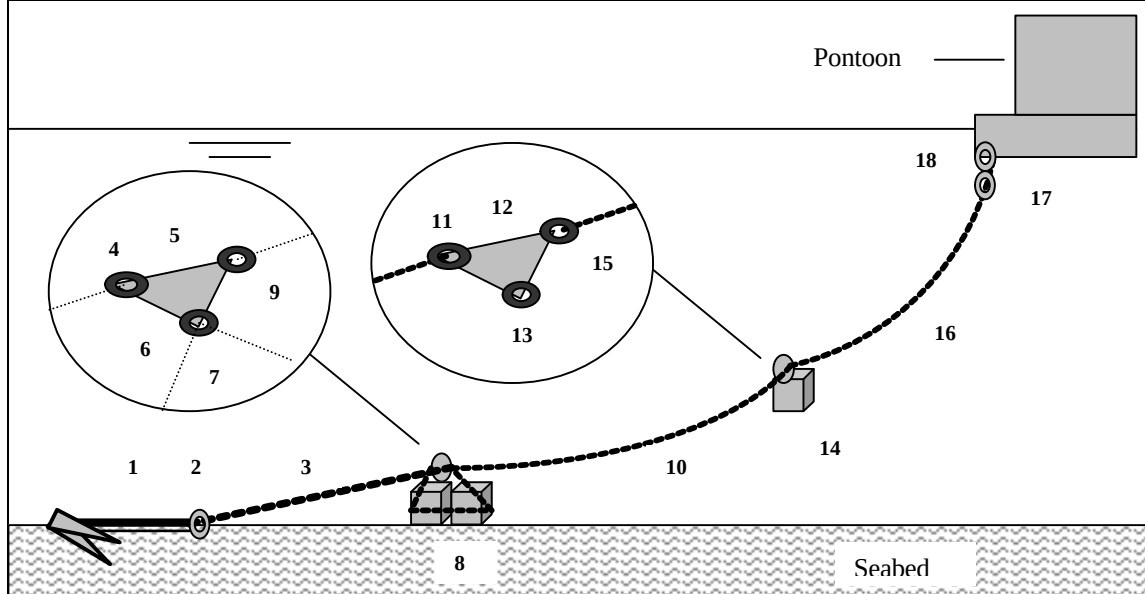
Reference is also made to recognised publications (e.g. NAVFAC, 1985 and BS 6349, 1989), for guidance on acceptable equipment and connections for moorings.

Designers should also note that:

- With respect to the strength rating of individual components and connections, the same factors of safety as presented in Box 7.45 (Step H) shall apply.
- All mooring chain shall be certified marine chain (not rigging chain), unless the non-certified chain is being used purely to add mass to the primary (certified) mooring line.
- The designer shall provide tolerances on the specified length of individual mooring line elements.

An example of details to be specified for a particular mooring line is illustrated in Box 7.54.

Box 7.54 Example specification and detailing of mooring line components



Component list for mooring line illustrated above

Item	Description	Component size/capacity
1	Anchor	2000 kg Danforth Drag Anchor
2	Shackle	25 t SWL capacity, safety pin type (galvanized mild steel)
3	Chain	27 m long x 52 mm diameter U2 studlink – minimum breaking strength = 620 kN
4	Shackle	25 t SWL capacity, safety pin type (galvanized mild steel)
5	Fishplate	40 t SWL fabricated fishplate (galvanized mild steel)
6	Shackle	35 t SWL capacity, safety pin type (galvanized mild steel)
7	Chain	52 mm diameter U2 studlink (bridle for deadweight blocks, length as required) – minimum breaking strength = 620 kN
8	Deadweight	2 no. x 3 t (submerged weight) concrete blocks
9	Shackle	25 t SWL capacity, safety pin type (galvanized mild steel)
10	Chain	54 m long x 32 mm diameter U2 studlink – minimum breaking strength = 620 kN
11	Shackle	25 t SWL capacity, safety pin type (galvanized mild steel)
12	Fishplate	40 t SWL fabricated fishplate (galvanized mild steel)
13	Shackle	25 t SWL capacity, safety pin type (galvanized mild steel)
14	Deadweight	1 no. x 1.5 t (submerged weight) concrete block
15	Shackle	25 t SWL capacity, safety pin type (galvanized mild steel)
16	Chain	27 m long x 32 mm diameter U2 studlink – minimum breaking strength = 620 kN
17	Shackle	25 t SWL capacity, safety pin type (galvanized mild steel)
18	Mooring lug	35 t SWL capacity, fabricated lug on pontoon flotation cylinders
Note	SWL = Safe Working Load	

7.5 How to do Mooring Design

This section provides a summary on how to go about mooring design in Steps 2, 4 and 6 of the 10-Step Planning, Design and Implementation Procedure. Box 7.55 outlines the data and design information that should be documented as part of each design phase. The anchor design documentation (Chapter 8) complements the documentation to be prepared on mooring design.

Box 7.55	Summary of mooring design information to be documented and submitted
Phase 1	Concept design
Formal mooring design calculations and analyses are unlikely to be required in the <i>Concept Phase</i>, but well-developed schematic plans of the mooring layouts at the proposed pontoon site should be prepared and submitted. Design information • Schematic diagrams showing features of the site, water depths and the intensity and direction of preliminary design values of the winds, waves and currents in each direction approaching the chosen pontoon site • Site plans superimposing the proposed position and orientation of the pontoon • Plans highlighting the intended access corridors for service craft • Plans highlighting zones and corridors suitable for laying of mooring lines and installing anchors • Schematic drawings showing the conceptual arrangement proposed for the number, geometry and configuration of mooring lines and indicating experienced based estimates of chain/wire rope sizes and lengths and anchor types	
Phase 2	Feasibility design
Mooring design is principally undertaken in the <i>Feasibility Phase</i>. The intention of this phase is to complete the design of an acceptable mooring system that meets the requirements of these <i>Guidelines</i> and defines the properties of the individual mooring lines that are to be used. Documentation is to be supplemented with a design report, which includes all the calculations undertaken to analyse the mooring system and to verify that the required criteria are satisfied. Design inputs • Design values that have been adopted for: water depth, wave height, wind speed and current speed for each direction and for each intensity of environmental loading. • Plan defining acceptable corridors/zones for location of mooring lines, plus details of permissible movement limits of the pontoon and of lines. Load cases • A list and description of all load cases that are being considered in the design Steady state loads • The combined steady state force exerted on the pontoon for each load case. Present results in tabular form, listing each load case considered, together with the steady force components calculated for wind, wave, current as well as the combined load. Mooring line force-offset relationships • Copies, in graphical form, of the force-offset relationship for each mooring line. • A schematic diagram of the mooring line, defining the length of elements and their size/grade and any add-ons such as clump weights. • If <i>Method 1</i> is followed (Step E), system force-offset curves for each load direction and design water level considered.	

Pontoon offset

- A tabulated list of all load cases considered, accompanied by the calculated values of the maximum pontoon offset and, if *Method 2* is used, the angle of rotation of the pontoon's centre of gravity.

Peak line forces

- A listing of each load case considered, together with the calculated maximum line tension and anchor vector force for each individual line. A corresponding list of the rated strength capacity of the chosen size/grade of each line.
- Where mooring lines comprise segments of differing properties and/or involve splits into multiple lines and anchors, tabulation of the calculated maximum force determined for each element and the rated strength capacity of the chosen size/grade of each line segment.

Movement limits and line flexibility

- A site location plan, which shows the pontoon position and superimposes the footprint of the predicted extent of pontoon movement. A separate plan for load cases associated with the *maximum operating condition*, *cyclonic condition* and if appropriate, the *maximum non-cyclonic condition*. All plans to show the permissible zone of pontoon movement for the respective load condition.
- A site location plan, which shows the pontoon position and layout of mooring lines, and superimposes the footprint of the predicted extent of mooring line sweep for each line. A separate plan for load cases associated with the *maximum operating condition*, *cyclonic condition* and if appropriate, the *maximum non-cyclonic condition*. All plans to show the permissible zone of mooring line sweep for each line, for the respective load condition.
- For each mooring line, verification that, at the maximum offset experienced by this line, the flexibility check in Step H is satisfied.

Minimum operational requirements

- Verification that for all load cases associated with the *maximum operating condition*, the mooring system satisfies the criterion in Step I with regards to avoiding resonant response.
- Unless extenuating circumstances exist and are justified and approved by GBRMPA, confirmation that clump weights (if used) are positioned such that they do not lift off the seabed during normal pontoon operation.

Supplementary data to be provided (some will be submitted as part of other documentation)

- A report on the issue of potential dynamic amplification of forces and displacements during extreme conditions. If dynamic amplification is deemed possible, an account of how it has been addressed or how effects have been quantified.
- Description of the plant to be used, the methods to be employed and precautions to be taken to ensure that during installation, site disturbance and coral destruction is limited to the zones and levels specified. Documentation should list the sequence of steps involved in the installation process.
- Verification that access can be obtained to fully inspect all mooring hardware components and an indication of what means would be used to undertake repair/replacement maintenance works when needed.
- Description of the methods and plant that could be used to recover all mooring hardware, and of the specific precautions that would be employed to prevent environmental damage.

Phase 3 Implementation - Detailed design

Each individual component and connection of mooring lines must be designed, specified and documented in the *Detailed Design Phase*. Documentation comprising schematic representation of each component in every mooring line, together with the specification of component material type and strength/grade is to be prepared and submitted.

Amendments made to the outcomes produced in the *feasibility design phase*

- If any changes or adjustments are made to the mooring design system that was documented and submitted in the *Feasibility Design Phase*, details are to be re-submitted covering the scope and format indicated in *Phase 2* above.
- If any changes or adjustments to the documentation submitted in the *Feasibility Design Phase* for mooring system installation, maintenance and eventual salvage are proposed, the required details are to be re-submitted for these activities, as set out in *Phase 2* above.

Mooring Line Components

- Full detailing, specification and documentation of all mooring components, sufficient to allow supply, fabrication and installation of all components. An example of required details for a single mooring line, is illustrated in Box 7.54.in Section 7.4.

How to do Mooring Design

refer Steps 2, 4 and 6 of 10-Step Planning, Design and Implementation Procedure (Chapter 3)

Inputs

- bathymetric plans and ecological and geotechnical information for the site
- alternative layouts and configuration of the pontoon, including mooring arrangements
- details of existing facilities (in the case of projects that are to be upgraded)
- tropical cyclone, wind and wave characteristics for the region
- wind, wave and current intensities for determination of mooring loads
- acceptable movement limits for the pontoon and mooring system under normal operation and severe conditions

Planning and design tools

- *Atlas of Tropical Cyclone Waves in the Great Barrier Reef Region* (Chapter 5)
- structural models for mooring system design
- product data and other literature to assess mooring requirements

Personnel

- coordination and preparation of required information by the proponent's project manager
- specialist input from a marine engineer/naval architect (experienced and competent in mooring design), geotechnical engineer or others as required
- input from the marine technician, particularly in site investigations
- management agency's interests represented by the GBRMPA delegate and project manager

Outputs (Box 7.55)

- indicative mooring layout and configuration, and types and sizes of mooring components for new or upgraded facilities – Step 2
- designs for mooring system components for the adopted mooring configuration and layout, including sizes, lengths, characteristics and installation data of major components – Step 4
- detailed designs, drawings, specifications, connection details and documentation of installation, maintenance and future salvage needs of the mooring system – Step 6

Associated tasks (including site investigation and characterisation)

- Select the preferred pontoon site and identify any alternative sites for new projects (Chapter 6).
- Undertake preliminary hydrodynamic studies for the site - Step 2 (Chapters 4 and 5).
- Undertake preliminary bathymetric surveys, geotechnical and ecological assessments of the site - Step 2 (Chapter 4).
- Prepare conceptual designs for the anchors - Step 2 (Chapter 8).
- Establish survey control markers and buoys at the preferred site to identify the location and orientation of the pontoon, mooring, anchors and other facilities - Step 2 (Chapter 4).
- Undertake detailed bathymetric surveys, geotechnical and ecological assessments of the site – Step 4 (Chapter 4).
- Prepare layouts and configurations of the pontoon facility, showing upgraded components for existing facilities (Chapter 6).
- Undertake detailed hydrodynamic studies for the site – Step 4 (Chapter 5)
- Set permissible movement limits for the pontoon and mooring lines at the site – Step 4 (Chapter 6)
- Identify coral substrate requiring relocation or sacrifice to suit mooring line and anchor location (Chapter 6).
- Determine the type, size, layout and configuration of the anchors - Step 4 (Chapter 8).
- Assess the stability of the pontoon body, check flotation requirements and undertake preliminary design of pontoon structural members (Chapter 9).
- Define the installation and salvage arrangements for the facility (Chapter 10).
- Define the operation and maintenance program for the facility (Chapter 10).
- Define the environmental monitoring program for the facility (Chapter 10).

7.6 Recommended reading

- American Petroleum Institute. 1987a. *RP 2P-87 Analysis of Spread Mooring Systems for Floating Drilling Units*. ANSI/API RP 2P-87, Approved 1993.
- American Petroleum Institute. 1987b. *RP 2A WSD Planning, Designing, and Constructing Fixed Offshore Platforms – Working Stress Design*.
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- Lloyd's Register of Shipping. 1989. *Rules and Regulations for the Classification of Fixed Offshore Installations*.
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- U.S. Department of Defense. 1999. *Mooring Design Handbook MIL-HDBK-1026/4A*.
- Rye H, Rynning S, Moshagen H. 1975. On the Slow Drift Oscillations of Moored Structures. *Proceedings Volume III of Offshore Technology Conference 1975*, Houston, Texas USA.
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8 ANCHOR DESIGN

	Summary
8.1	Anchor types
8.2	Design approach and design criteria
8.3	Estimating anchor capacities
8.4	Test load verification
8.5	Geotechnical substrate conditions for coral reef environments
8.6	How to do Anchor Design
8.7	Recommended reading

Summary

- **Designers** should use this chapter in the selection and design of anchors to be incorporated into the pontoon mooring system.
- Various anchor types and configurations are introduced, the design approach is outlined, and design criteria are presented.
- Methods for estimating anchor capacity using site data, design loading and mooring information from Chapters 4 – 7, are described.
- Guidance on test load verification and information on geotechnical substrate conditions are provided.
- Relevant personnel, planning and design tools, input and output data are described, and an outline of design documentation to be submitted for assessment by GBRMPA is presented.

Anchor design is a specialist marine engineering task, requiring competency in the fields of mooring system design and performance, geotechnical characterisation of the seabed, anchor design capacity, and installation and maintenance requirements. Practitioners involved in anchor design on the GBR must also recognise the particular nature and properties of coral reef structures and calcareous substrates, and be familiar with the variety of anchor types that may be employed to suit the shallow water conditions and the environmentally sensitive nature of the site. Inadequate design may lead to anchor failure, which can damage both the coral reef and the pontoon facility, affecting conservation and amenity value of the site, and causing substantial financial loss.

Little information has been published on anchor characteristics and performance in the GBR or other coral reef regions, and designers, to date, have sometimes applied design techniques ill suited and unproven in this environment. These *Guidelines* advocate a conservative approach to anchor design, which, rather than using merely theoretical estimates, is based on anchor capacities confirmed through test loading at the time and place of installation. This approach should be used until the marine industry has a better understanding of anchor and substrate behaviour in the coral reef environment.

Anchor design is usually undertaken in conjunction with mooring design (Chapter 7). As outlined in Box 8.1, anchor design tasks may be included in Step 2 (*Concept Phase*), Step 4 (*Feasibility Phase*) and/or Step 6 (*Implementation Phase*) of the *10-Step Planning, Design and Implementation Procedure*. This chapter describes various anchor types, and the approach and criteria recommended for design. Guidance on estimation of anchor capacity and on test load verification is provided, along with some background information on geotechnical substrate conditions for coral reef environments. Summary information on *How to do Anchor Design*, and a consolidated outline of design documentation to be submitted for assessment by GBRMPA is presented at the end of the chapter.

Box 8.1 Indication of project phasing for Anchor Design task <i>refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3, Box 3.2) and Project Planning and Design Task Schedule (Chapter 3, Box 3.3)</i>	
Purpose	Task Description
Phase 1 Concept	
Step 1 Initial Concepts	No significant activities.
Step 2 Concept Design Select preferred types and likely sizes of anchors.	Consider alternative anchor types and sizes to suit site conditions and the preliminary layout and configuration of the pontoon mooring system for new or upgraded facilities. Discuss proposals with GBRMPA, and document and submit information for assessment.
Step 3 GBRMPA Preliminary Assessment	Preliminary consideration of the suitability of the anchor types, and identification of non-conforming issues relating to anchor type and size etc.
Phase 2 Feasibility	
Step 4 Feasibility Design Determine anchor types and sizes to suit substrate conditions and to accommodate design loads.	Determine anchor capacities and compare with anchor design loads, and choose anchor types, configuration and sizes. Prepare detailed layouts and configurations of the anchors, showing upgraded components for existing facilities. Consider methods for installation and salvage, and operation and maintenance of the anchors. Discuss feasibility designs with GBRMPA, and document and submit information for assessment.
Step 5 GBRMPA Detailed Assessment	Confirm, reject or suggest modifications to anchor design, using expert advice if required.
Phase 3 Implementation	
Step 6 Detailed Design Prepare detailed drawings and specifications for all anchor components and connections.	Finalise dimensions and positions of individual anchors. Complete detailed designs, drawings and specifications of anchor components and connections. Document anchor capacities, nominated test loads at installation, installation and test load procedures, and maintenance requirements.

8.1 Anchor types

Only a sub-set of the large number of anchor systems available for floating vessels, are used to secure tourist pontoon facilities on the Great Barrier Reef. Choice of anchor types is governed by proximity to the reef, substrate conditions, environmental sensitivity, installation methods, and relative costs. Descriptions of anchor system categories, their characteristics (load capacity, aesthetic values etc), and their possible applications are presented in Box 8.2. The various anchor types are illustrated in Box 8.3, and design and installation provisions to be considered in selecting an anchor system are presented in Box 8.4.

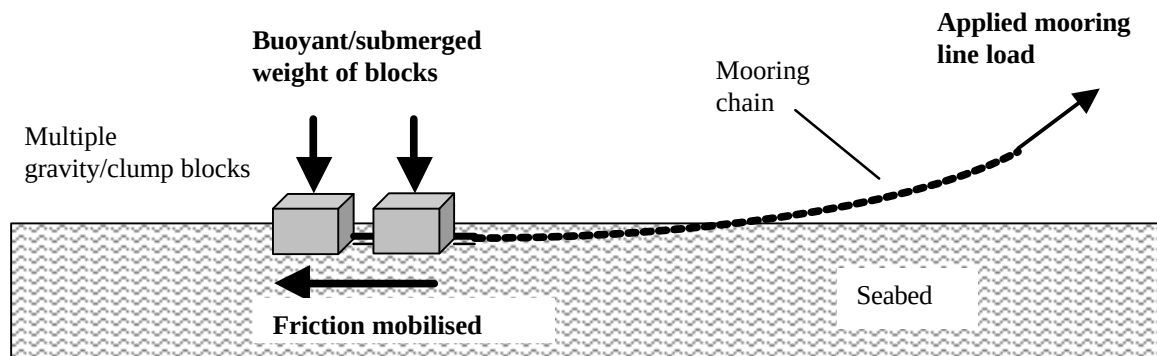
Box 8.2 Anchor types, characteristics and applications for tourist pontoons on the Great Barrier Reef (refer diagrams in Box 8.3)			
Description	Load capacity	Other characteristics (aesthetics, installation, maintenance etc)	Applications
<i>Deadweight (Gravity/Clump Block) Anchor</i>			
Blocks, pieces, or clumps of concrete, steel or similar material, primarily relying on self-weight and friction to resist forces applied by mooring lines. The blocks may be precast, with protrusions or fins provided to maximize resistance to movement when the block is embedded in the seabed.	Loading capacity (resistance) is based on buoyant weight and base friction, and can be reliably estimated. Designers cannot rely on a component of resistance from anchor embedment (due to movement and potential scour). Loading capacity is inefficient when uplift (vertical) forces are applied.	These blocks are often large and visually obtrusive and may take up valuable space adjacent to underwater recreation activities. Gravity anchors are simple and quick to install and remove using conventional equipment, and can be placed relatively easily in restricted areas. Installation may require relocation or removal of corals. Take care to minimise damage to the seabed and to corals.	These anchor types are used extensively for GBR pontoons. They are best suited to well-protected sites where mooring line loads are relatively small. Gravity anchors are frequently used in combination with other anchor types or as intermediate clump weights in order to reduce dynamic forces and vertical force components imposed on the primary anchors.
<i>Drag Embedment Anchor</i>			
Conventional ship anchors that rely on embedment into the seabed to mobilise resistance to applied mooring line forces. Various types are available (eg. Danforth and Stockless).	The anchors provide a relatively high resistance to horizontal loads (equivalent to several multiples of buoyant weight). Resistance is developed through mobilisation of substrate shear strength as a result of anchor movement and increased embedment. Effectiveness drops sharply when the mooring line is inclined to the horizontal, transferring uplift forces to the anchor. Embedment may be compromised by variability in substrate conditions and the presence of cemented sediments. Installation effectively pre-loads the anchor. Anchors will usually have some residual capacity after initial failure, as they will usually be embedded as they are dragged along the seabed.	These anchors are relatively simple and quick to install and remove using conventional equipment and can be readily replaced. Embedment and accurate location of anchor points is difficult to achieve in confined areas. Movement may affect corals. Periodic retrieval and inspection of anchors is required.	These anchor types are used extensively for GBR pontoons. Drag embedment anchors can be effective in both sand and clay mud substrate profiles. Capacity is limited where the depth of embedment is restricted by hard strata at shallow depths (eg. cemented calcareous deposits). Long rode lengths are usually required to ensure proper embedment. Adequate area is required during installation to achieve anchor embedment.

Box 8.2 Anchor types, characteristics and applications for tourist pontoons on the Great Barrier Reef (refer diagrams in Box 8.3)			
Description	Load capacity	Other characteristics (aesthetics, installation, maintenance etc)	Applications
<i>Grouted Screw Anchor</i>			
This anchor is developed by advancing a helical auger stem into the seabed and by <i>insitu</i> grouting to form a pile-type cylinder of typically 600 mm diameter, and up to 3.5 m in length.	The anchors provide a degree of vertical resistance due to mobilisation of substrate skin friction as well as lateral loading capacity due to mobilisation of substrate shear strength. The load capacity of the anchor is uncertain, particularly under inclined or dynamic loads. Overload and failure of the anchor results in permanent failure of the mooring leg. Satisfactory performance under load is heavily reliant on correct detailing of connections to the mooring line.	The anchors are unobtrusive, with good aesthetic values. Once installed, grouted screw anchors are less destructive to the seabed than deadweight anchors. Mooring chain drag associated with anchor movement is unlikely to occur. Careful supervision and quality control is required during installation and testing.	Grouted screw anchors have been used on several GBR pontoon sites. Only limited capacities can be achieved with a single anchor. Multiple anchors have increased capacity. They are normally effective in both weak and strong sand-calcareous substrate types. They are not appropriate for fine grained (mud) substrate conditions. Grouted screw anchors can be installed in relatively confined locations.
<i>Driven Pin Cluster Anchor</i>			
This anchor system comprises clusters of pins driven into the reef face.	Moderate resistance to axial and lateral loads can generally be achieved by mobilisation of skin friction in the reef framework. The load capacity of the anchor is uncertain, particularly under inclined or dynamic loads. The installation may not work in poorly cemented substrate, and it may be impractical to install the anchor in strongly cemented deposits. Overload and failure of the anchor results in permanent failure of the mooring leg.	These anchors are less obtrusive than deadweight anchors. The driven pins may not be acceptable where fixing to live coral is required. If carefully undertaken, they cause minimal disturbance to the seabed during installation and testing.	The method has been used on some pontoon installations on the GBR. Driven pin anchors can be an effective system when anchoring directly to a solid reef face. Application is generally limited to well protected sites. Pin anchors are normally installed in clusters and tied together.

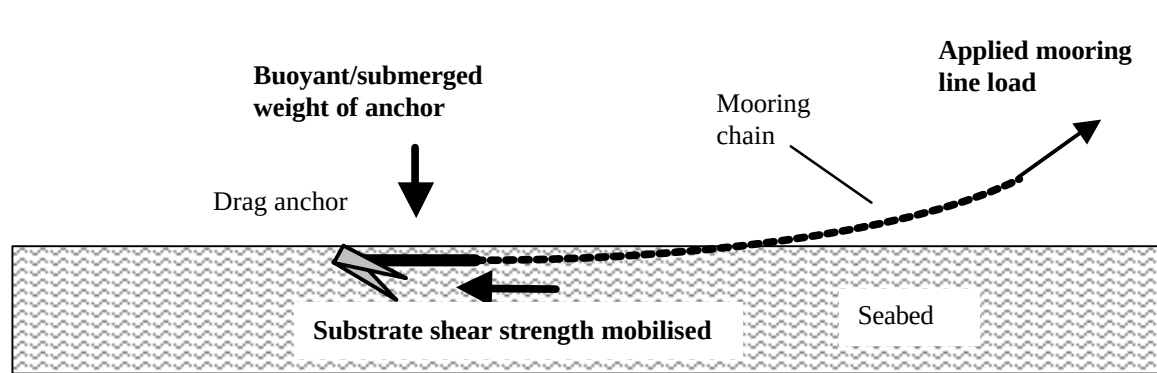
Box 8.2 Anchor types, characteristics and applications for tourist pontoons on the Great Barrier Reef (refer diagrams in Box 8.3)			
Description	Load capacity	Other characteristics (aesthetics, installation, maintenance etc)	Applications
<i>Driven Plate Anchor</i>			
This anchor system comprises a steel shaft driven into the seabed with a plate rotated at the base. The plate anchors are often installed in clusters.	Moderate vertical load capacity is achieved through mobilisation of substrate pull-out resistance. Minor capacity to resist lateral loading is achieved through mobilisation of substrate shear strength. Capacity can be reasonably predicted if the substrate is known and a record of installation is available. Satisfactory performance under load is heavily reliant on correct detailing of connections to the mooring line.	These anchors are less obtrusive than deadweight anchors. If carefully undertaken, they cause minimal disturbance to the seabed during installation and testing.	This method has not been used significantly to date for pontoon moorings on the GBR. These anchors are usually restricted to situations with only moderate vertical and minor horizontal loads. Increased capacity can be achieved by multiple installations, tied together via a purpose built crown. Plate anchors are easily and quickly installed in confined locations.
<i>Bored Cast-in-situ Reinforced Concrete Pile Anchor</i>			
This anchor is a conventional bored pile, usually constructed of reinforced concrete with steel. It may comprise a single pile or a group of piles, and may be either completely subsurface or protruding above the seabed.	These anchors achieve resistance by mobilizing lateral shear strength against the sides of the pile and substrate skin friction along the length of the pile. Capacities can be reasonably predicted using conventional geotechnical engineering principles. Extensive geotechnical information on substrate conditions must be collected.	The subsurface type pile anchors are unobtrusive, with good aesthetic values. Once installed, pile anchors are less destructive to the seabed than deadweight anchors. Mooring chain drag associated with anchor movement is unlikely to occur. Careful supervision and quality control is required during installation and testing.	Bored piles have not been used significantly to date for pontoon moorings on the GBR. They may be appropriate where moderately high lateral mooring loads are involved, or where significant combined vertical and lateral loading occurs. Expensive mobilisation of a piling rig is required. Open space is required for installation access.

Box 8.3 Conventional anchor types used in the GBR

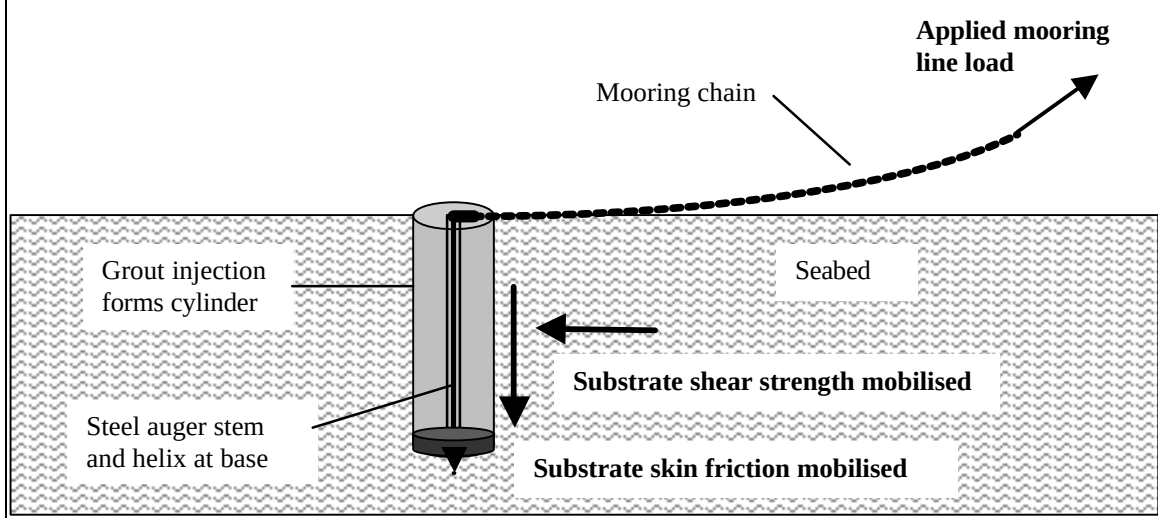
Deadweight (Gravity/Clump Block) Anchor



Drag Embedment Anchor

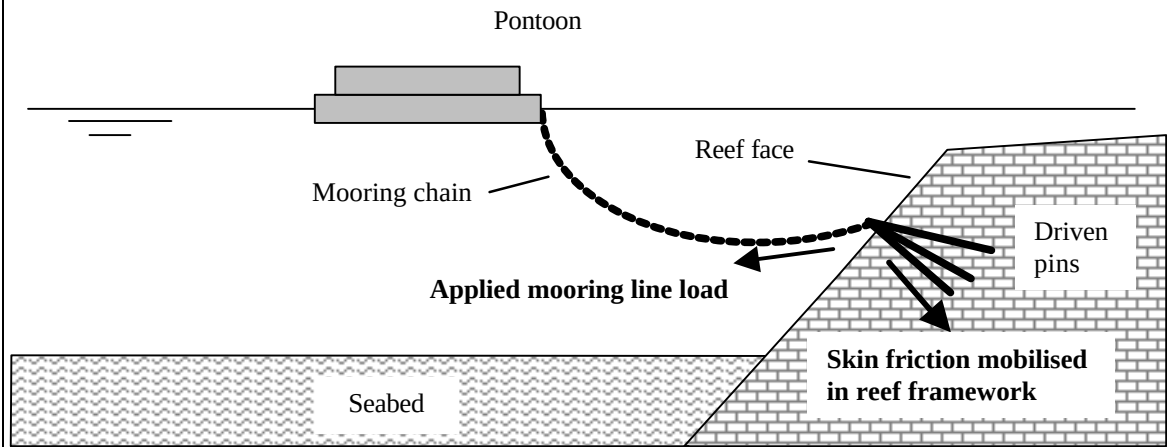


Grouted Screw Anchor

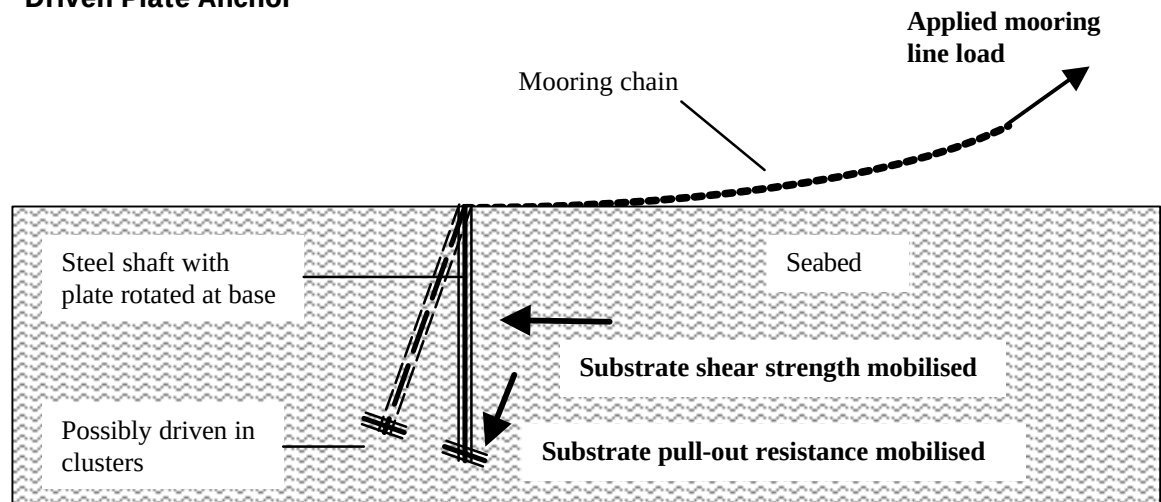


Box 8.3 Conventional anchor types used in the GBR

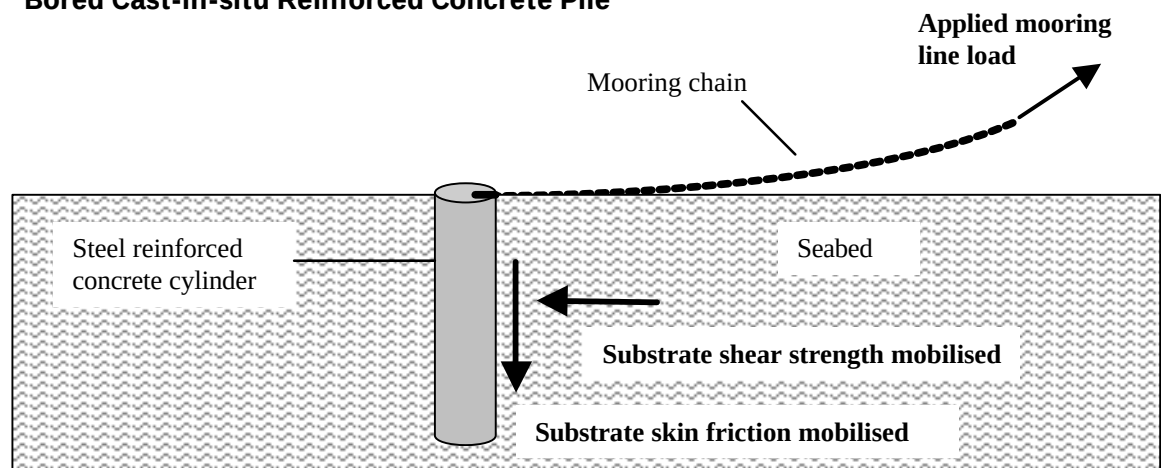
Driven Pin Cluster Anchor



Driven Plate Anchor



Bored Cast-in-situ Reinforced Concrete Pile



Box 8.4 Considerations in selecting an anchor system	
Issue to address	Design and installation provisions
Magnitude of mooring line loads	Deadweight anchors are unlikely to be suitable if relatively large mooring line forces apply.
Magnitude of vertical component of mooring line load	Drag embedment anchors alone are unlikely to be suitable if the mooring lines impose significant vertical forces (loads inclined to the horizontal).
Nature of substrate at the site	Drag embedment anchors will not be suitable if the substrate consists of a shallow veneer of loose sediments overlying strongly cemented calcareous deposits.
Space and access available at the site	Where open space on the seabed is restricted due to extensive coral cover or numerous bommies, drag embedment anchors are unlikely to be suitable, and it will be difficult to gain access for large (bored cast-in-situ) piling rigs.
Installation equipment requirements	If a particular anchor system requires expensive establishment of a pile-driving rig or involves a major delay, designers may favour an alternate system utilising more convenient locally available installation equipment.
Long-term integrity of each anchor type	Consider alternatives to anchor systems that are susceptible to long-term reduction in anchor capacity (eg. due to cyclical loading).
Local experience and expertise with specific anchor types	Designers may favour particular anchor systems (eg. grouted screw anchors) if they have performed satisfactorily in similar substrate conditions.
Relative economics of the various anchor types	Cost comparison of various options should allow for materials, installation, and future maintenance and salvage costs.

8.2 Design approach and design criteria

Design of anchor systems for tourist pontoons must cater for a number of uncertainties associated with dynamic loading on the system, variable substrate conditions, variable performance characteristics of the anchors, and difficulties in prediction of loads and anchor capacities. A simplified approach is presented here for the design and verification of capacity of the various anchor types discussed above. New approaches using innovative anchor systems and sophisticated design analysis models may be adopted where practitioners can demonstrate improvement in the performance and predictability of the behaviour of these anchor systems.

The dynamic loads on the anchors result from the combined effects of movement and strain in the pontoon structure and mooring components (under the action of winds, waves, currents and water levels). Conventional analysis models (of the anchor-subsoil system) do not routinely accommodate the cyclical characteristics of this type of loading, and practitioners are normally required to use simplified static methods. Safety or uncertainty factors adopted in design must compensate for this simplistic (static) approach and various other factors causing uncertainties in the capacity of anchor systems (Box 8.5).

Box 8.5 Factors causing uncertainties in the capacity of anchor systems
• variability in substrate conditions, vertically and laterally • potential disturbance to subsoil during installation and/or during verification loading • unknown integrity of installed pile and pile-subsoil interface • capacity reduction due to application of inclined loads from the attached mooring lines • impact of cyclical loading on long-term weakening of the foundation • variation in performance characteristics among anchor types • effect on capacity due to energy absorption provided by the mooring lines • difficulties in prediction of loads and anchor capacities

The basic requirement for anchor design is that the estimated anchor capacity exceeds the maximum applied design load by an appropriate margin. Applied loads (winds, waves, currents and water levels) are determined for the particular load conditions (maximum operating, maximum non-cyclonic, cyclonic) in accordance with the procedures outlined in Chapters 5 and 7. The simplified static approach used to determine the required anchor strength is based on safety or uncertainty factors, as outlined in Section 8.3. Anchor capacity is determined on the basis of a geotechnical model of the seabed substrate (see below), using methods outlined in Section 8.4 for the particular anchor types. Field test loading of the installed anchor system for verification of anchor capacity is required, as described in Section 8.5.

Two alternative approaches can be used to determine anchor capacity on the basis of the geotechnical model of the seabed substrate (Box 8.6). *Design Method 1* is based on *Surface Assessment* of site conditions, using a rudimentary investigation without detailed geotechnical data. This approach is usually appropriate for **Deadweight** anchors and **Drag Embedment** anchors, and is sometimes used for embedded foundations such as **Screw Anchors**. *Design Method 2* is based on *Intrusive Assessment* of site conditions. This approach, involving subsurface foundation investigation such as geotechnical drilling of the substrate, is usually appropriate for **Screw Anchors**, **Piles** or **Driven Anchors**.

Box 8.6 Alternative design approaches for determination of anchor capacity <i>refer Geotechnical/substrate aspects (Chapter 4, Section 4.5) and Geotechnical substrate conditions for reef environments (Section 8.5, this Chapter)</i>
Design Method 1 - Surface assessment of site conditions No intrusive geotechnical investigation of the seabed is performed, but indications are obtained from assessment of the seabed surface materials. The designer assesses the likely anchor holding capacity of the substrate from this surface assessment, and relies on a conservative anchor design. Surface assessment usually involves examination, sampling and probing of the seafloor surface to determine how much sand overlies the hard substrate. This shallow subsurface investigation is commonly undertaken by digging with a shovel or crowbar or by determining the depth of penetration of star pickets used for survey control. Subsurface site investigations will not normally be required where Deadweight or Drag Embedment anchors are to be used. Sufficient information is likely to be available from the surface assessments and hand-operated sampling and probing methods. It is likely to be much cheaper to provide additional or larger Deadweight blocks than to undertake an extensive geotechnical investigation, although such geotechnical information could be useful where placement of Deadweight blocks is restricted. The anchor system is subject to test load following installation to confirm that the required capacity is achieved.
Design Method 2 - Intrusive assessment of site conditions Design is based on the results of a formal geotechnical investigation of seabed substrata conditions at the pontoon site. Appropriate design properties of the supporting seabed are assigned, and anchors sized according to the capacities required, using appropriate geotechnical design models. This approach is usually warranted to establish anchor holding capacity when Screw Anchors, Piles or Driven anchors are used. The <i>Intrusive Assessment</i> method attempts to characterise seafloor and sub-seafloor conditions, and should allow a less conservative anchor design than is otherwise achieved. Whilst installation techniques for screw anchors usually provide subsurface information as drilling proceeds, this has limited value unless the data are used to adjust the anchor design characteristics. The anchor system is subject to test load following installation to confirm that the required capacity is achieved.

Design criteria

The principal criterion applying for the design of anchors is the choice of an appropriate factor of safety for use in determining the required characteristic strength of the anchor to resist the applied environmental loads. This section provides a basis for selecting the factor of safety, according to the particular design loading condition and the chosen design method.

As outlined in Chapters 5 and 7, anchors and other components of the mooring system should be designed for the loading conditions listed in Box 8.7.

Box 8.7		Design loading conditions for anchors
Maximum Operating Condition		The maximum environmental forcing under which the facility would be expected to remain fully operational
Maximum Non-Cyclonic Condition [#]		The maximum non-cyclonic environmental forcing
Cyclonic Condition		The design intensity of environmental forcing during tropical cyclones
# Note This design state only applies when a dual mooring system is used, ie. one system for operating conditions and a separate system for cyclonic conditions (Chapter 7). The Operating System Mooring is designed to withstand <i>Maximum Non-Cyclonic Condition</i> loading up to the point of transfer of load to the Cyclone System Mooring. A System 2 mooring configuration (Section 7.1) uses sacrificial lines, which hold the pontoon in place under operating conditions but are designed to break under this load, thus transferring load to the cyclone mooring. A System 4 mooring configuration (Section 7.1) provides for the pontoon to be relocated to a separate cyclone mooring system when severe weather conditions are imminent.		

For marine and geotechnical engineering structures, the conventional relationship between maximum applied design load, estimated anchor capacity and factor of safety (or uncertainty) is represented by Equation 8.1.

$$R = T_{\max} FS \quad 8.1$$

- Where R = Required characteristic strength or capacity of the anchor
Values of R are to be determined for each load state.
- $T_{\max}$ * = Maximum tension force applied to the anchor by the attached mooring line
Design values are obtained directly from analysis and design of the mooring system (Section 7.4). Separate $T_{\max}$ values apply for each relevant load state.
- FS = Assigned safety or uncertainty factor
Design values for factor of safety are presented in Box 8.7.
Separate FS values apply for each relevant load state.

- * Note** $T_{\max}$ is a vector, hence the inclination and direction (or likely range of inclinations and directions) must be specified.
- In most instances, the mooring system will be configured so that the mooring line forces applied to the anchors remain virtually horizontal through the full range of loading conditions. For example, development of inclined forces at the anchor point for conventional catenary mooring line systems in shallow GBR waters will usually mean that the line is close to a snatch condition – an arrangement that is unlikely to satisfy the mooring design criteria for flexibility specified in Chapter 7. An exception to the horizontal forcing may occur where the seabed profile is uneven, particularly where the anchor point is located on a steep reef face. In this case the catenary droops down below the level of the anchor point, and the mooring line force on the anchor is inclined below the horizontal. Where innovative mooring systems such as a taut mooring are used, purposely-designed pile foundations or other anchors would normally be required to accommodate the inclined line forces.

The *Required Characteristic Strength (R)* of the anchor should be determined for each load state using the relevant factors of safety for the various load states and design methods (Box 8.8). The load state producing the maximum *Required Characteristic Strength*, effectively becomes the critical design case for that particular anchor. The types, sizes and arrangements for anchors to meet this requirement can then be determined in accordance with Section 8.3. The anchor capacity should be checked and verified for each load state when the applied loads are at different inclinations to the horizontal.

The factors of safety presented in Box 8.8 are consistent with the factors adopted in the design of the mooring lines (Chapter 7). They are also comparable with recommended factors in the common Classification Society Rules (eg. DNV and Lloyds) and Marine Design Guides (eg. API). Where lower FS are used in these publications, they usually apply specifically to designs based on a full dynamic analysis of mooring response. Where a full dynamic analysis is used for design of the pontoon mooring system, consideration can be given to reducing factors of safety in accordance with an applicable set of Classification Society Rules.

Box 8.8 Factors of safety to be applied in determination of anchor capacity		
Design loading conditions for anchors *	Minimum factor of safety (FS)	
	<i>Design Method 1</i> #	<i>Design Method 2</i> #
Maximum Operating Condition	3.5	3.0
Maximum Non-Cyclonic Condition	3.0	2.5
Cyclonic Condition	2.5	2.0
* Note Refer Box 8.7 for explanation of loading conditions. The rationale for varying Factors of Safety according to the design load state is that higher FS are appropriate for more frequently-experienced loads (eg. <i>Maximum Operating Condition</i>) than for relatively rare loads (eg. <i>Cyclonic Condition</i>). This is due to the possibility of fatigue failure or strain softening effects as a result of the frequently-experienced loads.		
# Note Refer Box 8.6 for explanation of alternative design approaches for determination of anchor capacity. The rationale for using lower Factors of Safety for <i>Design Method 2</i> is that the geotechnical model used in this method is based on actual measurements of substrate properties, whereas the parameters used in <i>Design Method 1</i> are largely judgment-based.		

8.3 Estimating anchor capacities

Anchor capacity is a function of the anchor type, the nature of the seabed substrate, and the nature of the applied loading. For a secure pontoon installation, anchor capacity must equal or exceed the required characteristic strength determined from Equation 8.1 (Section 8.2).

A number of general references (listed at the end of this chapter in Section 8.7) are available to guide designers in estimating anchor capacities using conventional design procedures. Designers should review these references and carefully select the most appropriate technique for the particular anchor type and substrate condition. Specific guidance to complement the general design procedures is also provided in this section for the following principal anchor systems:

- Deadweight (Gravity) Anchors
- Drag Embedment Anchors
- Grouted Screw Anchors (GSAs)
- Driven Pin Cluster Anchors
- Alternative Anchor Systems.

Anchor capacity is determined on the basis of a geotechnical model of the seabed substrate using either *Design Method 1* (conservative estimation of strength parameters, based on limited site data, judgment and typical reefal characteristics), or *Design Method 2* (derived directly from the results of the investigations and testing). Some information on geotechnical substrate conditions for reef environments, which may be useful in determining anchor capacities, is presented in Section 8.5.

Little information has, however, been published or documented to date on the performance of anchor systems installed in the GBRMP. Many of the geotechnical substrate characteristics found on or adjacent to coral reefs are clearly different from the conditions encountered in non-reef environments. Until performance is better documented and studied, and until improved design techniques specific to the range of anchor types and typical substrate conditions encountered in reefal zones are available, design must continue to rely on:

- the conservative application of generalised and conventional design procedures for calculating load capacities for anchors
- experience gained from the *in situ* test loading of capacities of various anchor types and geometries installed in typical reefal conditions.

Deadweight (Gravity) Anchor

The deadweight anchor relies primarily on self-weight and friction to resist mooring line forces. Although blocks may be partially embedded into the seabed, no additional allowance should be made for this due to the possibility of movement and potential scour. Load capacities should be determined solely on the basis of sliding friction along the base, generated from buoyant weight. For a deadweight block of a specified mass, the available characteristic strength or capacity will be a function of the following attributes:

- block material type (density), ie concrete or steel or other
- representative friction angle of seabed material
- operating range of mooring line inclinations
- sea bed slope in the vicinity of placement.

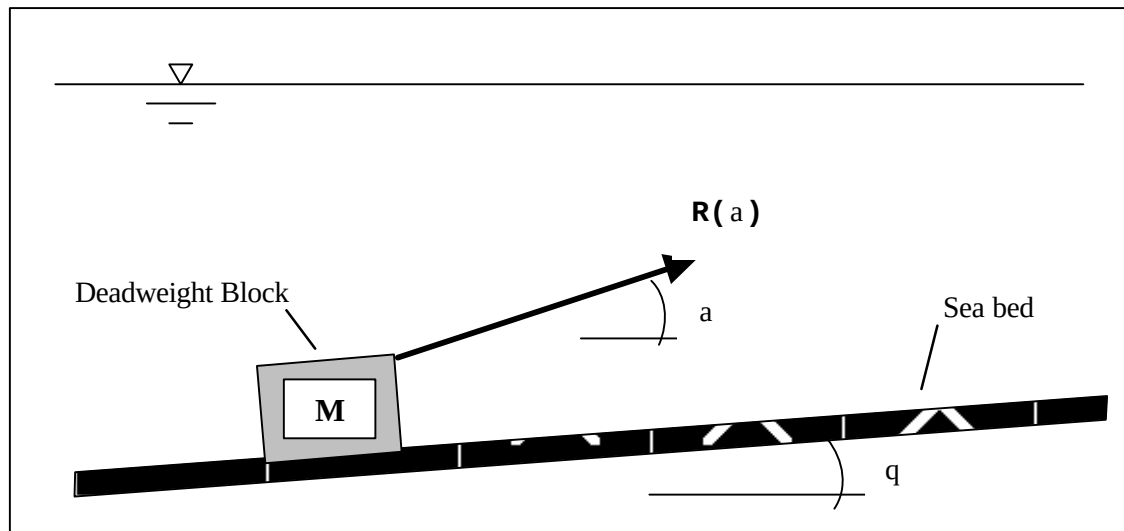
A simple procedure for estimating anchor block capacity is presented in Box 8.9 (the procedure assumes resistance is provided only by base friction rather than any positive effects from embedment). In view of the reasonably reliable (and usually conservative) means of estimating the capacity of an anchor block, verification test loading is not considered necessary for this type of anchor system.

Drag Embedment Anchor

Drag Embedment anchors generate holding capacity by mobilising the shear strength of the soil in which they are embedded. The manner in which anchor capacity is developed through mobilisation of resistance to mooring line loading, is a function of the following:

- type of Drag Anchor
- anchor configuration
- mass of Drag Anchor
- degree of anchor embedment achieved
- distance anchor dragged during installation
- type of connecting mooring line and its degree of embedment
- seabed conditions and layering
- seabed slope
- peak inclination (to the horizontal) of the loading applied to the anchor.

Box 8.9 Simplified estimate of characteristic strength (or capacity) of a Deadweight Anchor Block



Characteristic Strength of Deadweight Anchor:

$$R(a) = Mg \left(1 - \frac{r_w}{r_b}\right) \frac{[\cos(q) \tan(f) + \sin(q)]}{[\cos(a - q) + \sin(a - q) \tan(f)]} \quad (8.2)$$

Where	$R(\alpha)$	=	Characteristic Strength or Capacity of the block, for a load applied at angle “ α ” to the horizontal (N)
	M	=	(Dry) Mass of deadweight block (kg)
	α	=	Angle of inclination (to horizontal), of load applied to the block by the mooring line (degrees) [Positive measured anti-clockwise from horizontal]
	ρ_w	=	Density of water (kg/m^3)
	ρ_b	=	Density of material used in construction of the block anchor (kg/m^3)
	ϕ	=	Representative friction angle of seabed material (degrees)
	θ	=	Angle of inclination (to horizontal) of seabed surface in vicinity of block (degrees) [Positive measured anti-clockwise from horizontal]
	g	=	Acceleration due to gravity (m/s^2)

Example	M	=	3000 kg	Characteristic Strength available: $R(\alpha) = 23.9 \text{ (kN)}$
	α	=	15°	
	ρ_w	=	1025 kg/m^3	
	ρ_b	=	7800 kg/m^3	
	ϕ	=	30°	
	θ	=	20°	
	g	=	9.81 m/s^2	

Whereas the type and configuration of the drag embedment anchor, its mass, and the angle of inclination of loading can be quantified reasonably reliably, the remaining aspects relating to installation geometry and geotechnical conditions are difficult to establish and are rarely recorded. No rational design procedures are available to determine anchor capacity on the basis of all the above factors.

Conventionally, anchors have been selected for particular applications on the basis of published design information and experience gained by local operators and naval architects in a range of regional seabed conditions, using a variety of anchor types. It is anticipated that this approach to design will continue for the foreseeable future.

Operational capacity of the Drag Embedment Anchor is very sensitive to the type and configuration (including degree of embedment) of the connecting mooring line, and the loading applied to the anchor. These factors depend on the design arrangement adopted for the composite Drag Anchor/mooring line system (ie. what type and scope of line is selected, what inclusion of dumper/deadweight blocks is incorporated, and what type of connections are used). Hence, the selection of a suitable Drag Anchor for a particular application and site cannot be separated from design of the complete anchor/mooring line system. Design of these anchors should be undertaken by a naval architect or marine engineer conversant with reefal environments and with the types of drag anchors proposed. To ensure Drag Embedment anchors are capable of developing the required characteristic strength, verification test loading should be undertaken upon installation, as outlined in Section 8.4.

Some information on typical anchor capacities for Drag Embedment Anchors for granular and mud/silt substrate is presented below in Boxes 8.10 and 8.11. The United States Navy data (Box 8.10) relates to particular anchor sizes, whereas design capacity estimates from United States Department of Defense (Box 8.11) can be applied to a range of anchor sizes. Designers should use these estimates with caution, and before adopting the results, must understand the origin of the data, the basis behind the estimates, and the limitations that apply to use.

Box 8.10 Holding power efficiencies of typical drag embedment anchors <i>(United States Navy data presented in Glanville 1992)</i>				
Anchor type	Anchor mass (kg)		Anchor efficiency *	
	Nominal	Actual	Sand	Mud / silt
Navy Stockless	2270	2700	8:1	3:1
Stato	1360	1590	18:1	15:1
Stevfix	640	640	31:1	15:1
Stevdig	1000	1160	29:1	-
Stevmud	1000	1000	-	20:1
Hook	560	570	12:1	18:1
Bruce	600	600	25:1	-
* Note Anchor capacities are conventionally expressed in terms of “holding efficiency”, which is defined as the holding capacity expressed as a multiple of the anchor weight. The efficiencies indicated are unique to the specific sites and to the mooring line type/scope used for the test program, and the data should be applied with caution. The US Navy study did show that embedment of the mooring line significantly increased the total efficiency (defined as the combined holding capacity of anchor and embedded mooring line expressed as a fraction of anchor weight). Cable mooring lines achieved peak capacities similar to those of chain mooring lines, however, the chain lines reached peak capacity at significantly less depth of anchor embedment and drag distance than the cable lines. Anchors can be effectively placed in tandem to increase capacity, provided the chain from the rear anchor is connected to the shank shackle of the front anchor. A reasonable clear distance between the anchors must be maintained.				

Box 8.11 Drag Embedment Anchor Holding Capacity (<i>United States Department of Defense 1999</i>)				
Predicted static ultimate anchor holding capacity is given by:				
$H_M = H_R (W_A / W_R)^b$				(8.3)
Where	H_M	=	Ultimate anchor system static holding capacity (kN)	
	H_R	=	Reference static holding capacity (tabulated below)	
	W_A	=	Mass of the anchor in air (kg)	
	W_R	=	Reference anchor mass in air = 4536 (kg)	
	b	=	Exponent (tabulated below)	
Anchor Type ^a	Soft Soils (Soft clays/silts)		Hard Soils (Sands/ stiff clays)	
	H_R (kN)	b	H_R (kN)	b
Boss	934	0.94	1201	0.94
Bruce Cast	142	0.92	1112	0.8
Bruce Flat fluke twin shank	1112	0.92	c	c
Bruce Twin shank	841	0.92	934	0.94
Danforth	387	0.92	560	0.8
Flipper Delta	618	0.92	c	c
G.S. AC-14	387	0.92	560	0.8
Hook	841	0.92	445	0.8
LWT (lightweight)	387	0.92	560	0.8
Moorfast	520	0.92 ^d	267	0.8
			445 ^e	0.8
Navmoor	934	0.94	1201	0.94
Offdrill II	520	0.92 ^d	267	0.8
			445 ^e	0.8
Stato	934	0.94	1112 ^f	0.94
			845 ^g	0.94
Stevdig	618	0.92	1290	0.8
Stevfix	841	0.92	1290	0.8
Stevin	618	0.92	734	0.8
Stevmud	1112	0.92	h	h
Stevpris (straight shank)	841	0.92	934	0.8
Stockless (fixed fluke)	205	0.92	311	0.8
			196 ⁱ	0.8
Stockless (movable fluke)	107	0.92	311	0.8
			196 ⁱ	0.8
Notes	a Fluke angles set for 50 degrees in soft soils and according to manufacturer's specifications in hard soils, except where otherwise noted. b "b" is an exponent constant. c No data available. d For 20 degree fluke angle (from API 2SK, 1995). e For 28 degree fluke angle. f For 30 degree fluke angle. g For dense sand conditions (near shore). h Anchor not used in this seafloor condition. i For 48 degree fluke angle.			

Grouted Screw Anchor (GSA)

For design purposes, the Grouted Screw Anchor can be considered as a form of *pile*. Experience gained by local operators in the GBR, as well as from local research conducted in terrestrial test beds (where GSA prototypes have been extracted some time after installation), clearly confirm that the *in situ* grouting achieves a regular cylindrical pile. Typically, GSAs with a 400 mm diameter helix have produced cylinders with average diameters of around 600 mm (ie. 50 % > helix diameter). Installed lengths are nominally in the range of 1.8 to 3.5 m.

The cylindrical GSA develops its holding resistance in the same manner as conventional piles, by mobilising both skin friction in uplift loading, and lateral earth pressure in horizontal loading. Although design procedures for calculating uplift and horizontal capacities of *piles* are well established, these conventional approaches cannot be readily applied to GSAs in the marine environment. Some limitations in determining anchor capacities for Grouted Screw Anchors are presented in Box 8.12.

Box 8.12 Limitations in determining anchor capacities for Grouted Screw Anchors

Pontoons are almost exclusively positioned in reefal zones, which are dominated by *calcareous* deposits. Conventional pile design procedures have been developed for soils of *terrigenous* origin, and have shortcomings when applied to *calcareous* sediments. The shortcomings are often more pronounced in uplift loading than in lateral response.

The presence, degree and non-uniformity of cementation in *calcareous* sediments has a major influence on available anchor capacity. Whereas cementation can be expected to enhance lateral load capacities, it is likely to reduce uplift capacity as a result of disturbance during installation of the GSA. Installation weakens sediments locally around the pile circumference, whilst the surrounding intact cemented sediments can inhibit the build up of normal stresses. Both factors potentially reduce available skin friction.

Disturbance to the seabed surface surrounding the perimeter of the GSA during installation reduces the effective frictional shear strength in this zone, which is crucial in the development of resistance to lateral loading.

Conventional design categorises piles as either displacement types (eg. precast driven) or non-displacement types (eg. bored pier), and applies different factors in the calculation of uplift capacities. The GSA system has displacement and non-displacement type characteristics, and the relevant factor for use in determining anchor capacity cannot be clearly defined.

Anchors are subjected to cyclical loading, which can result in a progressive deterioration in anchor capacity. The theoretical estimate of static capacity and the static *in situ* test loads must therefore be significantly reduced. Unfortunately, appropriate factors have not been developed, and a conservative approach must be adopted at this stage.

Mooring line loads on anchors in conventional pontoon arrangements are generally either horizontal or inclined slightly to the horizontal. Initial research indicates that the horizontal capacity of GSAs may be reduced when subjected to inclined loads.

In lieu of more definitive design procedures and criteria for determining vertical and lateral load capacities for GSAs, designers should use the conventional pile design procedures recommended in the references (Section 8.7). In particular, the simplified design procedure for lateral capacity of pile and pier foundations developed by Brinch Hansen (1961) appears to provide a reasonable model for estimating the (horizontal) characteristic strength of GSAs. In view of the particular attributes of GSAs installed in a reefal environment (see Box 8.12), designers should take care before adopting capacities derived from these conventional methods or from other techniques related to terrestrial installations.

Where multiple GSAs are used in close proximity (via a single template crown connection), designers should consider a number of additional factors related to group effects. The interaction between individual piles should be considered and the distribution of applied loads between individual GSAs should be assessed. General principles and analysis techniques outlined in the Piling Code (AS 2159) and other prominent pile foundation design texts should be followed (eg. Poulos and Davis 1980; and Tomlinson 1994). Publications by Poulos *et al* (1988; 1991) related to the characteristics of pile foundations in marine calcareous deposits, are particularly useful.

To ensure GSAs are capable of developing the required characteristic strength, verification test loading should be undertaken upon installation, as outlined in Section 8.4.

Driven Pin Cluster Anchor

In certain instances, clusters of Driven Pins (small diameter steel rods driven into the reef matrix), can provide a viable means of anchoring mooring lines. This system can be useful where the chosen pontoon site is bound on one or more sides by coral reef faces, which restrict the use of other systems that usually require relatively flat and open seabed access. Driven Pins (in conjunction with other anchor systems in the open areas) may provide sound anchorage if the coral framework is competent and comprises remnant reefal structures. The Driven Pins may not be acceptable where fixing to live coral is required.

No specific design procedures are available to accurately compute the *Characteristic Strength* for Driven Pins. This is because the capacity is largely dependent on the strength and continuity of cementation in the reef structure and on the disturbance/destructive effects induced in installation. Furthermore, the small diameter of these systems and the spatial variation in cementation strength and porosity common in reef frameworks results in wide variations in the capacity of individual pins in a cluster. In the absence of more appropriate techniques, designers should obtain first estimates of Characteristic Strength by using recognised design procedures for conventional (terrestrial) driven piles (eg. Piling Code, AS2159 and other recognized foundation engineering texts). The likely range of capacities should be determined, based on broad upper and lower limits for relevant geotechnical parameters.

Where individual pins in a cluster are installed in close proximity, designers should give due consideration to “group” effects and interactions, demonstrating that a cluster can achieve the total capacity required. Designers should not assume that the capacity of a cluster of pins equals the sum of capacities of the individual pins.

Notwithstanding the above methods for estimating anchor capacities, verification test loading must be undertaken upon installation, as outlined in Section 8.4. Test load verification must check the combined capacity of the entire cluster (rather than simply that of a single pin). Serious consideration should also be given to installing and testing prototypes on site prior to adoption of the Driven Pin anchor system.

Alternative Anchor Systems

Although conventional pontoon anchorage systems have been largely confined to the types discussed above, alternative and innovative systems are likely to be introduced in the future. For alternative systems such as conventional driven pile or drilled pier systems, designers should use the appropriate design procedures recommended in the references (Section 8.7). Once again, in view of the particular attributes of the calcareous deposits typically encountered close to reefs in the GBR, designers should take care to not simply adopt procedures developed for terrestrial conditions.

Driven Plate anchors and Propellant Driven anchors are innovative systems that may be adopted in the future. Until further research is undertaken and *in situ* test data assessed, designers must rely on the limited (overseas) design information found in the reference publications.

Verification test loading after installation, or the testing of prototypes, will be extremely important for any of these alternative anchorage systems.

8.4 Test load verification

Test load verification after installation is a fundamental element of the design rationale for all mooring anchors other than for deadweight anchors. This is because the available predictive design methods are presently very limited and, apart from drag embedment anchors, are generally of terrestrial origin. All design methods, including those for drag anchor design, need further adaptation to adequately accommodate the characteristics of the marine loadings applied by floating pontoons in shallow water environments on the GBR.

Anchors shall be tested for their capacity to withstand the maximum predicted design force, in accordance with the procedures outlined in Box 8.13 (refer to Chapter 10 for further information on site testing). In certain special instances, the testing of prototype anchors at the project site may be permitted in lieu of compulsory test verification of each anchor.

Box 8.13 Procedures for anchor testing load verification

1. Subject each anchor to a test load of magnitude equal to twice $T_{\max}$ - the calculated maximum tension force exerted by the attached mooring line (for all load cases). $T_{\max}$ (Section 8.2) is determined in design of the mooring system (Chapter 7).

$$\text{Required test load} = 2 \times T_{\max}$$
2. Orient the applied force on the anchor to match that of the calculated maximum mooring line force. This orientation should match the design value to an accuracy of +/- 5 degrees.
3. Increase the test load intensity gradually until it reaches the maximum value (to a tolerance of +/- 5 %), and then maintain the load at this level for a minimum of 20 minutes.
4. Record any movement of the anchor in the test loading and estimate the magnitude of movement.
5. Gradually release the load.
6. Maintain records, including details of the test location, anchor type and number, together with the maximum test load and orientation and measurements of anchor movement both at peak load and at the completion of the test.

8.5 Geotechnical substrate conditions for coral reef environments

Information on geotechnical conditions for reef environments is used to develop a geotechnical model of the seabed substrate, which in turn provides a basis for determining anchor capacities (Section 8.3). This section provides some background information on reef geomorphology and the nature and composition of reefal deposits. Geotechnical classification systems are introduced and the typical engineering behaviour and properties of reefal deposits are described. The suggested extent and timing of geotechnical investigations that may be undertaken at various stages of a tourist pontoon project are discussed in Chapter 4.

Preferred pontoon sites are typically shallow water zones within or adjacent to major reef structures. In these environments, substrate materials are dominated by reef-derived deposits, which contain the remnants and debris from former active coral framework structures, in a matrix that may also display varying amounts of cementation and contain impurities from either terrigenous (eg. siliceous) or biogenic (calcareous) origins. It is necessary to understand the basic processes and origins of components in this matrix, before explicit geotechnical properties can be assigned to represent engineering performance.

Geotechnical assessment should be undertaken within the context of the regional geology and geomorphology, and field activities should be carefully coordinated with any geomorphological field work. Conventional geotechnical investigation techniques and procedures used in terrestrial environments are not suited to the marine environment due to equipment requirements, mobilisation difficulties, weather dependence and cost. The approach to the geotechnical investigation will depend largely on site-specific characteristics and the type and value of the facilities to be installed.

The intention is to develop a geotechnical model of representative seabed conditions covering the proposed anchor sites by undertaking a sufficient number of test holes of adequate depth. Although it is desirable to obtain specific information for each individual anchor site, this may not always be possible. The geotechnical model will only be valid if the discrete information at the chosen test locations can be considered representative of the various substrate types encountered across the heterogeneous substrate. Even with subsurface drilling, substrate conditions may be poorly identified if substrate conditions vary significantly over small distances on site. The more extensive site investigations may involve sub-seafloor profiling, *in situ* testing, sampling and laboratory testing at several locations across the project site, including the nominated (approximate) anchor locations. The extent of the laboratory testing will depend on the type of materials encountered, and results from the field investigations and sampling. Material classification tests should be undertaken wherever suitable samples are available. Laboratory strength tests are not likely to be required where *in situ* measurements have been obtained.

Coral reef geomorphology

Coral reefs are built in clear, warm, shallow waters primarily by Anthozoan corals of class Scleractinia which, in the presence of calcium rich waters, have the ability to construct massive skeletal structures of calcium carbonate. Other corals and reef-dwelling organisms also make minor contributions of calcium carbonate to the reef structure. Calcite crystal cement can form around individual grains and can eventually change loose sediments to rocks. Individual reefs vary considerably in size and form, ranging from small patch reefs to large platform reefs, enormous wall and cusped complexes, and dissected and deltaic reefs - all of which characterise different physiographic zones and regions of the continental shelf.

In geological terms, the GBR is extremely young (possibly less than 500, 000 years old). It was formed during a period of fluctuating sea levels, when, for most of the time, glacially lowered sea levels exposed the reef and allowed it to erode. During shorter periods of higher sea levels (< 20% of the time), the reef was able to grow. Subsequently, sea levels rose to approximately their present height, and the existing reefal formations were drowned, recolonised and stacked with new calcium carbonate deposition. This process of erosion and rebuilding produced outer reefs with a layer-cake structure. The thickness of the uppermost (Holocene) veneer (overlying the Pleistocene foundations) varies throughout the GBR. For example, in the Southern GBR it is around 10-15m thick; in the Northern GBR mainly <15m thick; and in the Central GBR generally > 20m thick.

Reef types are distinguished according to a classification system based on the evolutionary concept of recolonisation of Pleistocene reefal foundations during the Holocene transgression. Eight fundamental forms exist:

- Unmodified Antecedent Platform Reefs
- Submerged Shoal Reefs
- Irregular Reef Patches
- Crescentic Reefs
- Lagoonal Reefs
- Planar Reefs
- Ribbon Reefs
- Fringing Reefs.

Exploratory drilling through Holocene reefal deposits indicates an enormous amount of heterogeneity through the reef tract. The underlying Pleistocene foundation consists of re-crystallised reefal limestone, which in some cases is little different in engineering properties to the Holocene. Occasionally, narrow soil horizons are encountered and, more frequently, and particularly on the outer shelf, the top of the Pleistocene and possibly the base of the Holocene are marked by 1-2m of lightly cemented Halimeda gravels. Characteristically, 1 to 3m of fragmented corals overlay the Halimeda, followed by the main Holocene framework. Notably, in high energy situations (southern reefs and the outer shelf), Holocene deposits are dominated by cemented gravels with up to 40% of the voids filled with sand and/or gravel. On mid-shelf reefs the *in situ* framework is less dominant and reef detritus forms most of the Holocene thickness.

Variations in structure and form occur not only with reef location but also across individual reefs. Windward margins are more dominated by reef framework structures than are leeward margins. The sheltered reef sections are typically sediment-dominated and lacking cementation, whereas cementation can be expected to be greatest on the windward margins on high-energy reefs. Some reef debris generated by physical disturbance on the high-energy reefs accumulates as a wedge-shaped apron of talus in deep water at the foot of the fore-reef slope.

Nature and composition of reef deposits

Present-day reef structures have formed as calcareous framework units on older foundations of Pleistocene, and comprise inter-digitated terrigenous and biogenic detrital fill within and behind the basic framework. The proportion and composition of detrital fill within this framework is dependent on many factors. Two prominent influences are the proximity to coastal influences (eg. sources of terrigenous sediments), and prevailing wind/wave energy at the particular position within the reef (eg. windward or leeward zone).

The distribution of sediment types over the continental shelf progresses broadly from terrigenous sediment domination near the coastline to carbonate sediment domination near the outer reef. Although significant regional variations occur, sediments encountered on the continental shelf floor, can in general terms, be considered to loosely comprise three main belts (Box 8.14).

Since physical and chemical properties differ markedly between siliceous (terrigenous) and calcareous (biogenic) materials, the resulting engineering behaviour also differs. Consequently, it is most important that designers and constructors establish the origin of fragments in the bioclastic mass and determine their relative proportions.

Box 8.14 Broad sediment distribution across the continental shelf		
Shelf zone	Composition	Proportion of carbonate deposits
Inner Shelf, 0 to 20m water depth,	Terrigenous materials (sands and muds) dominate nearshore	< 30%
Mid Shelf, 20 to 40m water depth	Intermediate mixed terrigenous/carbonate composition	30 to 80 %
Outer Shelf, 40 to 80m water depth	Carbonate (mainly sand) sediment on main reef tract	> 80 %

Calcareous materials have a highly variable nature, encompassing five major grain types (skeletal; detrital; pellets; coated grains; and lumps). Even at the same stratigraphic level, carbonate sediments may differ, according to the particular environment at the time of deposition and the large variety of post depositional changes. These bioclastic and clastic carbonate sediments are mechanically deposited, producing a particulate texture consisting of a matrix of various grains forming a rigid framework. This creates a pore system that allows the storage and transmission of fluids. Depending on the depositional environment, the pore system could fill partially or completely by chemical precipitant (cement) or by a fine-grained carbonate mud (micrite). The relative proportion of micrite to cement is an index of the water turbulence or mechanical energy during deposition. High energy environments (eg. surf zone), produce clean, well-sorted, coarse-grained carbonate sediments. Low energy environments (eg. sheltered lagoons and deeper sea basins), produce fine-grained, muddy deposits.

Of these rock-forming (cemented) carbonates, calcite and dolomite ($\text{CaMg}[\text{CO}_3]_2$) are the most abundant, accounting for approximately 90% of natural carbonates. These minerals can occur with impurities, such as terrigenous quartz and clay minerals, and, locally, with minor amounts of common non-calcareous authigenic minerals. Cementing is the most important element in the rock-forming process, and calcite (CaCO_3) is the most common mineral cement. Naturally, the degree of cementation can extend from minor development (essentially unconsolidated deposits, eg. recent detrital fragments), through to highly developed cementation, such as older deposits in a high-energy environment).

Terrigenous sediments may appear either as impurities in the cemented carbonate formations or, alternatively (along with carbonates), as unconsolidated detrital fill found in zones within, beside or overlying the bioclastic mass. These terrigenous sediments (derived from land) are deposited principally in the Inner Shelf zone, via transport from river systems into coastal waters. Composition is dominated by Siliceous materials, with the main inorganic components comprising Quartz, Clay minerals, Lithic fragments, Ooids, and Authigenic materials.

Geotechnical classification

The main objective of a geotechnical investigation is to produce a conceptual model of the substrata profile and conditions, and to provide direct or indirect measurements of relevant engineering properties for each major stratum. The crucial geotechnical parameters for pontoon mooring anchors will depend on the anchor types to be installed and the foundation characteristics for the site, but will generally relate to: 1) seafloor strength profile expressed in terms of representative material properties (eg. friction angle and cohesion); 2) characteristics that may influence anchor resistance (eg. particle sizes and calcareous content); and 3) properties that may affect installation techniques (eg. degree and uniformity of cementation). For anchor foundation design at a particular site, investigation of substrate must attempt to establish the characteristics of the foundation materials that will enable prediction of engineering properties and mechanical behaviour under load.

To adequately characterise the nature and composition of the reefal substrate, attention must focus on the following attributes:

- extent and proportion of unconsolidated fill zones within the substrate mass
- ratio of terrigenous to carbonate proportions in these detrital/sediment fill zones
- composition of terrigenous and biogenic sediment infill (eg. mud/sands/gravels)
- degree of cementation existing in the host/underlying framework structure
- density (or, alternatively, porosity) of the framework structure
- heterogeneity and stratification of the entire bioclastic matrix.

Standardised classification systems are adopted to characterise subsurface materials and to aid in the determination of their engineering properties. With respect to terrigenous sediments, once the extent and proportion in the substrate mass is established from investigation, the Unified Classification System for soils can be used to categorise the type and composition of these materials (Refer AS1726 1993). For carbonate sediments, a variety of systems are commonly used, although some are intended more for geomorphological classification than for engineering purposes. The engineering characteristics of coralline deposits are affected by six basic physical properties (Box 8.15). Refer to King et al (1980), for further discussion and presentation of classification systems for carbonate deposits.

Box 8.15 Classification system for coralline deposits	
Primary properties	composition * grain size degree of induration (ie. cementation)
Secondary properties	framework cavities cavity filling.
* Note	Establish whether the mineral composition is mainly carbonate, and, if so, if it is calcite, aragonite or other. Also determine whether carbonate is admixed with terrigenous clay minerals or quartz.

Typical engineering behaviour and properties of reefal deposits

Two characteristics of reefal deposits embody the challenge confronted in accurately representing engineering behaviour and in predicting geotechnical properties. These are, firstly, the inherent variability of deposits, and, secondly, the extreme range of values that can be encountered for such fundamental properties as strength and compressibility. The extreme heterogeneity in structural characteristics due to lack of continuity in both the horizontal and vertical directions means that site-specific exploratory investigation must be undertaken if reasonable representations of geotechnical properties are to be achieved. Furthermore, unless elaborate investigation programs are undertaken, designers should conservatively adopt values representative of the weaker zones found in the subsurface profile.

The strength and compressibility of reefal deposits are largely determined by the composition and degree of cementation existing in the bioclastic mass. Both of these characteristics can vary widely over short distances. Cementation is common and, if modestly developed, may only act to preserve an initially loose soil structure, even after it is buried by subsequent deposition. Light cementation consequently results in poor (potentially weak and highly compressible) foundation materials, whereas intense uniform cementation produces dense and competent rock-like formations capable of supporting heavy loads with minimal deformation.

Furthermore, improvement in this understanding is hampered by an absence of methods of identifying and quantifying the degree or uniformity of cementation (Datta et al 1982), and by the destruction of moderate degrees of cementation induced by routine sampling/*in situ* testing procedures.

Where deposits are moderately to strongly cemented, strength is usually represented in terms of the unconfined compressive strength. At low levels of cementation, the deposits will tend to behave as a soil. In this situation strength is usually represented in terms of cohesion and/or friction angle, depending on the composition and grain sizes. Designers should consider whether the presence of any cohesion is associated with light cementation, and hence whether it could potentially be destroyed during installation of anchor systems.

The highly brittle and compressible behaviour of uncemented or weakly cemented calcareous sediments is particularly significant in the design of anchor systems. These substrate characteristics can cause excessive deformations under load, and in the case of piles/piers, can cause major reductions in shaft friction capacity due to crushing during installation. Some of the key features that set calcareous sediments apart from traditional terrigenous-based soil mechanics are the susceptibility to crushing of grains, and the tendency for cementation to be random. Initial void ratio also plays a key role in determining the behaviour of calcareous sediments, but if due account is taken of this, then some differences in behaviour between calcareous and non-calcareous sediments become far less significant.

Sample (1988) has suggested that the behaviour of bioclastic sands is similar to sensitive clays, ie. failure of contact points at relatively low shear stresses tends to cause particle slip and large volume matrix strains or excess pore pressures. In broad terms, the effect of increased cementation on the geotechnical strength and deformation properties of calcareous sediments produces:

- an increase in peak strength
- a decrease in axial strain to peak strength
- an increase in the rate of dilation at failure
- increased stiffness
- a decrease in Poisson's ratio
- little apparent change in friction angle
- an increase in cohesion.

A generalised comparison of the geotechnical characteristics of calcareous and siliceous deposits is presented in Box 8.16. Box 8.17 lists typical ranges of geotechnical properties for these materials that may provide some guidance in design.

Box 8.16 Generalised characteristics of calcareous and siliceous deposits		
Characteristic	Comments - Calcareous	Comments - Siliceous
Individual grains	Typically tend to be very angular, brittle, and low strength.	Not as angular, and individual grains are harder than calcareous materials.
Density	Overburden stress does not appear to increase density appreciably. Void ratios remain high with depth, regardless of cementation.	Tend to increase approximately linearly with depth of overburden.
Strength	Comparatively low due to the presence of soft crushable particles, variations in the size and shape of particles, intraparticle voids, and variable cementation (Allman & Poulos 1988). Improves substantially as degree and uniformity of cementation increases.	Whilst the peak friction angle of siliceous deposits is frequently less than that of calcareous materials, strength is often superior due to better volume stability and less particle crushing.
Compressibility	Deposited in much looser state than siliceous soils and hence are more compressible and have poor foundation performance. High compressibility may be a function of the angularity of particles, weak nature of grains, and voids.	Deposited in denser state than calcareous soils.
Volume change under load	Tend to dilate only at relatively low confining pressures, and contract at moderate to high confining pressures.	The dilatancy of particularly quartz minerals (at even moderate confining pressures) when shear-tested tends to increase confining pressure and hence improve <i>in situ</i> soil strength.
Saturation	Saturation of particles does not significantly affect shear strength of soils. (Al-Douri & Poulos 1991)	Saturation can reduce shear strength markedly, due to softening of fine-grained components and generation of pore pressures.
Shaft friction	Skin friction is lower than siliceous materials due to its high compressibility.	Skin friction higher than calcareous materials.
Permeability	Porosity is high and corresponding density is low, but the restricted connections between the voids results in a relatively low permeability.	Permeability is a direct function of the grain sizes and distribution, as well as the plasticity properties of fines.
Performance under cyclic loading	Shear load carrying capacity of weakly cemented sediments can degrade rapidly with cycles of loads. Well cemented, generally coarser grained samples suffer less deformation due to pore space reduction or crushing of cement during testing. That is, they tend to behave as a heterogeneous but isotropic rock.	Generally much more stable than calcareous sediments, although loose and very sensitive fine-grained soils can experience strength degradation.

Box 8.17 Typical geotechnical properties for calcareous and siliceous deposits		
Property	Typical range of values	
	Calcareous	Siliceous (loose to dense sands)
Grain hardness	Calcium carbonate has hardness of 3	Quartz has hardness of 7
Peak friction angle	35 - 50 degrees	28 - 45 degrees
Porosity	Can exceed 40 % in uppermost (Holocene) veneer	20 – 50 %
Void ratio	0.8 - 1.4 *	0.25 – 0.95
Density	1.24 t/m ³ to 1.35 t/m ³ *	1.3 – 2.1 t/m ³
Permeability	10 ⁻⁶ m/s to around 10 ⁻⁹ m/s *	10 ⁻² - 10 ⁻⁷ m/s
Unconfined compressive strength	minimal to 2 Mpa (depending on degree of cementation)	minimal
Deformation #		
* Note	These ranges correspond to values for uncemented deposits through to a strongly cemented material.	
# Note	Bio-clastic sands tend to arch and are very stiff in unloading, consequently, nearly all strains are irrecoverable.	

8.6 How to do Anchor Design

This section provides a summary on how to go about anchor design in Steps 2, 4 and 6 of the 10-Step Planning, Design and Implementation Procedure. Box 8.18 outlines the data and design information that should be documented as part of each design phase. Anchor design is closely associated with mooring system design, and the anchor design documentation supplements the documentation to be prepared on mooring design.

Box 8.18	Design documentation for anchor design
Phase 1	<i>Concept design</i>
Minimal documentation is likely to be required for anchors in this phase. It may include description of the preferred type of anchors, likely sizes and preliminary indications of seabed substrate types.	
Phase 2	<i>Feasibility design</i>
Anchor types, sizing and position will be finalized In this phase. Documentation would include: • The position of each anchor and a description of seabed substrate conditions at each location. • A list of all anchors, defining the type, size and arrangement of each. • Design calculations of capacity, specifying the geotechnical properties and the design procedure that have been used, and any relevant anchor performance data. • Preliminary information on installation techniques and plant to be used. • Likely maintenance and future salvage requirements for the anchors.	
Phase 3	<i>Implementation - Detailed design</i>
Designs would be finalised and full detailing and documentation completed to allow fabrication / installation. Documentation would include: • Detailed drawings and specifications for all anchor components and connections. • Drawings locating the position of anchors, together with dimensions of an acceptable target box (in plan view) for anchor placement. This box specifies the designer's tolerance on accuracy of placement position. • The design capacity (ie. required characteristic strength) of each anchor, together with the test load to be used for verification of capacity at installation. The inclination of the load at design capacity and the test load should also be specified. • Details of permissible construction tolerances (eg. for pile foundations: limits on pile verticality, deflection and rotation). • The method of installation and the plant required, on-going maintenance requirements, and how the anchors can be salvaged in the future.	

How to do Anchor Design
<i>refer Steps 2, 4 and 6 of 10-Step Planning, Design and Implementation Procedure (Chapter 3)</i>
<i>Inputs</i> • bathymetric plans and ecological and geotechnical information for the site • alternative layouts and configuration of the pontoon, including mooring arrangements • details of existing facilities (in the case of projects that are to be upgraded) • magnitude and orientation of mooring line forces for determination of anchor loads • acceptable movement limits for the pontoon and mooring system under normal operation and severe conditions <i>Planning and design tools</i> • product data and other literature on anchors • geotechnical model for foundation design <i>Personnel</i> • coordination and preparation of required information by the proponent's project manager • specialist input from a marine engineer/naval architect (experienced and competent in mooring design), geotechnical engineer or others as required • input from the marine technician, particularly in site investigations • management agency's interests represented by the GBRMPA delegate and project manager

How to do Anchor Design

refer Steps 2, 4 and 6 of 10-Step Planning, Design and Implementation Procedure (Chapter 3)

Outputs (Box 8.18)

- indicative positions, types and sizes of anchors for new or upgraded facilities – Step 2
- designs for anchor systems for the adopted mooring configuration and layout of the mooring system, including sizes, characteristics and installation data of major components – Step 4
- detailed designs, drawings, specifications, connection details and documentation of installation, maintenance and future salvage needs of the anchor system – Step 6

Associated tasks (including site investigation and characterisation)

- Select the preferred pontoon site and identify any alternative sites for new projects (Chapter 6).
- Undertake preliminary hydrodynamic studies for the site - Step 2 (Chapters 4 and 5).
- Undertake preliminary bathymetric surveys, geotechnical and ecological assessments of the site - Step 2 (Chapter 4).
- Prepare conceptual designs for the mooring system - Step 2 (Chapter 7).
- Establish survey control markers and buoys at the preferred site to identify the location and orientation of the pontoon, mooring, anchors and other facilities - Step 2 (Chapter 4).
- Prepare layouts and configurations of the pontoon facility, showing upgraded components for existing facilities (Chapter 6).
- Identify coral substrate requiring relocation or sacrifice to suit anchor placement (Chapter 6).
- Consider specialised features such as innovative mooring arrangements (Chapter 7).
- Undertake detailed bathymetric surveys, geotechnical and ecological assessments of the site – Step 4 (Chapter 4).
- Define the type, layout and configuration of the mooring system (Chapter 7).
- Analyse the structure to determine forces and movements in the pontoon and mooring system, determine forces exerted on the anchors, and design mooring components to accommodate wind, wave and current loads (Chapter 7).

8.7 Recommended reading

This section provides a general list of references relating to anchor design. Selected references relating particularly to design procedures for estimating anchor capacities is provided in Box 8.19. Designers should obtain guidance on design of particular anchor systems from Section 8.3.

Box 8.19 Selected references: Design procedures for estimating anchor capacities

Reference	Application/comments
<i>Lloyd's Register, Rules and Regulations for the Classification of Fixed Offshore Installations</i> (amended 1995):	
• Part 3, Chapter 2	Advice on investigation of substrate conditions and design and installation of pile and gravity foundation systems
• Part 9, Chapter 5	Advice on design of drag anchors and anchor piles
<i>API RP 2 SK, Recommended Practice for Design and Analysis of Station-keeping Systems for Floating Structures</i> (1995):	
• Section 5	Design procedures and design charts for calculating capacity of drag embedment anchors
• Appendix B	Commentary on drag anchor performance evaluation for different substrate conditions
<i>G. A. Glanville & Co Pty Ltd, Recommendations for Mooring Categorisation in the Great Barrier Reef Marine Park and an Analysis and Comparison of Mooring Components</i> (1992).	
	Geotechnical design properties of substrate materials Discussion of anchor types and characteristics, and design capacity for various anchor types and conditions
<i>Hinze, E. R., The Complete Book of Anchoring and Mooring</i> , Cornell Maritime Press, Centreville, Maryland (1986).	
	General guide on anchoring

Box 8.19 Selected references: Design procedures for estimating anchor capacities	
(US) Naval Civil Engineering Laboratory (NCEL) publications:	
• <i>Interaction of Anchors with Soil and Anchor Design</i> • <i>Drag Embedment Anchors for Navy Moorings</i> (1987) • <i>Handbook for Marine Geotechnical Engineering</i>	Guidance on geotechnical properties of seabed materials and anchor capacities
AS 2159 - 1995 Australian Standard: <i>Piling – Design and Installation</i> .	Australian Standard Code for the design of pile foundations
Poulos, H. G. & Davis, E.H., <i>Pile Foundation Analysis and Design</i> (1980), Published by Wiley, New York.	Comprehensive text on all aspects of pile foundation design (principally applies to terrestrial conditions)
Tomlinson, M. J., <i>Pile Design & Construction Practice</i> , 4 th ed. (1994), Published by E & FN Spon, London.	Comprehensive text on all aspects of pile foundation design (principally applies to terrestrial conditions)

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9 PONTOON BODY AND ANCILLARY FACILITIES

	Summary
9.1	Design requirements and objectives
9.2	Structural design
9.3	Pontoon flotation and stability
9.4	Materials and coatings
9.5	Storage vessels, waste management and independent ancillary facilities
9.6	How to do pontoon body design
9.7	Recommended reading

Summary

- **Proponents** and **designers** should use this chapter in the configuration, design and specification of the pontoon body and other miscellaneous aspects of the pontoon facility.
- Design requirements and objectives are outlined, and design tasks relating to the structural integrity of the pontoon facility are described.
- Recommended practices for miscellaneous design aspects relating to material selection, waste management and ancillary facilities are described.
- Relevant personnel, planning and design tools, input and output data are described, and an outline of design documentation to be submitted for assessment by GBRMPA is presented.

The pontoon body, like other aspects of the pontoon facility, must meet requirements relating to serviceability, function and safety; structural integrity; environmental protection; and amenity. A typical modern pontoon structure incorporates a tubular-steel, perimeter-frame hull, supporting aluminium section bridging beams and an aluminium deck superstructure of extruded planks. A series of watertight bulkheads subdivides the pontoon hull to provide positive buoyancy, and a viewing chamber/ballast tank structure is usually built into the hull at one end. Vinyl shade roof sails are often fitted to the pontoon superstructure. Ancillary pontoon facilities will typically comprise attachments such as loading/swimming/diving platforms and walkways, and access stairwells to the viewing chamber and pontoon decks. Lifeguard towers, stowage, tables and bench seats are provided; along with a food/service counter and shower/change rooms; ventilation, freshwater, gas, wastewater, and electrical systems; and miscellaneous features such as anti-bird netting.

Pontoon body design is usually undertaken in conjunction with mooring design (Chapter 7). As outlined in Box 9.1, pontoon body design may be included in Step 4 (*Feasibility Phase*) and Step 6 (*Implementation Phase*) of the *10-Step Planning, design and implementation procedure*. The proponent would be expected to develop preliminary designs of key aspects of the pontoon body and ancillary facilities in Step 4, sufficient to confirm layout and configuration, and to provide an estimate of cost. Detailed designs, including workshop fabrication drawings, will be undertaken in Step 6. GBRMPA will require a marine classification approval for the pontoon body design (eg. Lloyds Register of Shipping) in the *Implementation Phase*, and may engage expert assistance to undertake a design audit and technical review of this component.

This chapter provides basic information for proponents and designers to use in the configuration, design and specification of the pontoon body and other miscellaneous aspects of the pontoon facility. Principles and recommended practice for selection and design of materials, coatings, storage vessels, waste management and other facilities are provided. Summary information on *How to do Pontoon Body Design*, and a consolidated outline of data and design information that should be documented as part of each design phase is presented at the end of the chapter.

Box 9.1 Indication of project phasing for <i>Pontoon Body and Ancillary Facilities design</i> task <i>refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3, Box 3.2) and Project Planning and Design Task Schedule (Chapter 3, Box 3.3)</i>	
Purpose	Task Description
Phase 1 Concept	
Step 1 Initial Concepts	No significant activities.
Step 2 Concept Design	No significant activities.
Step 3 GBRMPA Preliminary Assessment	No significant activities.
Phase 2 Feasibility	
Step 4 Feasibility Design Develop preliminary designs for the pontoon body for new or upgraded facilities.	Prepare preliminary designs sufficient to confirm layout and configuration and to provide an estimate of cost. Assess the stability of the pontoon body, check flotation requirements and undertake preliminary design of key pontoon structural members. Consider mooring system design, and preliminary design of ancillary facilities such as viewing chambers, snorkelling platforms, pontoon superstructure etc. Consider methods for installation and salvage, and operation and maintenance of the pontoon facility. Discuss designs with GBRMPA, and document and submit information for assessment.
Step 5 GBRMPA Detailed Assessment	Confirm, reject or suggest modifications to pontoon body design, engaging specialist assistance if necessary for complex projects.
Phase 3 Implementation	
Step 6 Detailed Design Prepare detailed designs for the pontoon body.	Comply with rules of approved marine classification society and relevant shipping structures code for the particular survey class for the pontoon body. Finalise sizes, material requirements and construction method. Prepare workshop fabrication drawings, specifications and tender documents for the pontoon body. Prepare and submit details for the pontoon body design to an approved marine classification society (eg. Lloyds Register of Shipping). Document and submit information for assessment by GBRMPA. GBRMPA may engage expert assistance to undertake a design audit and technical review of the design.
Step 7 Baseline Monitoring	No significant activities.
Step 8 Construction and Installation	No significant activities.

9.1 Design requirements and objectives

Pontoon body design shall be in accordance with good engineering and marine practice. It shall comply with the rules of an approved marine classification society (eg. Lloyds Register of Shipping) and relevant shipping structures codes (eg. Uniform Shipping Laws Code – USL Code) for a particular survey class (eg. *Restricted Offshore Operations* or *Partially Smooth Water Operations*). [Note: Survey class is dependent on the size and level of exposure of the pontoon]. Pontoon design and construction must meet Queensland Department of Transport survey requirements and is subject to further requirements under Workplace Health and Safety Regulations for use as a dive platform. The facility must be designed by a marine engineer/naval architect of demonstrated competence and experience.

The pontoon body should be designed to provide adequate freeboard under full design loading conditions due to dead loads (eg. structure weight), live loads (eg. passenger loading and berthing loads from visiting craft), and environmental loads (eg. wind, wave and current). [Refer Chapter 5 for loading conditions]. Pontoon stability (eg. rotation or roll during operating conditions) should be maintained within acceptable limits. Internal bulkheads, dividing the structure into watertight compartments, will provide reserve buoyancy to prevent sinking in the case of flooding. Individual pontoon members should be designed for a combination of dead, live and environmental loads, and the connections to mooring lines should be designed to support the breaking loads of the lines attached. Fenders, bollards, mooring and towing lugs etc. should be provided for docking, mooring and towing the pontoon.

Other miscellaneous aspects of the pontoon facility must conform to best practice requirements and ensure safety and protection against environmental damage. Appropriate and approved materials and coatings shall be used for construction of pontoon body members and components, in order to protect the facility, minimise maintenance and prevent environmental pollution or damage. Because discharge of wastes into the sea is usually not permissible, wastes will generally be transferred to the transit ferry, and will not be stored or treated on the pontoon. The design of ancillary features (eg. floating swimming or helicopter platforms) will normally comply with the same general provisions applying to the design of the pontoon body and pontoon structural members.

Design objectives, criteria and constraints

Various design **objectives**, and quantitative and qualitative design **criteria** apply to design of the pontoon body and ancillary facilities (Box 9.2). Semi-quantitative criteria relating to *serviceability, function and safety*, and quantitative criteria relating to *structural integrity*, are generally defined in terms of legislative requirements, marine classification society rules and shipping structures codes, and the various design states and loadings (eg. operating conditions; cyclonic loads) identified in Chapter 5. Criteria for *environmental protection*, and *amenity and cultural values*, derived principally from policy and management provisions for the Marine Park (Chapter 2), are mainly qualitative in nature. The proponent and designer should account for relevant legal, physical, environmental, social, political and economic **constraints** that apply to pontoon body and ancillary facility design.

Box 9.2 Design objectives and criteria for pontoon body and ancillary facility design	
Design objective	Criteria/constraint
<i>Serviceability, function and safety</i>	
Ensure visitor comfort.	Satisfy minimum requirements for visitor amenities (eg. ablution; showers; access; seating; viewing areas)
Ensure visitor safety and adequate space for operations.	Comply with all requirements of the Queensland <i>Workplace, Health and Safety Act</i> , marine classification society rules, and shipping structures codes. Provide adequate safety facilities (eg. rails and non-slip walkways; stable and safe embarking/disembarking; ladders and guardrails; lifebuoys; navigation aids). Provide suitable emergency facilities and procedures.
Ensure ease of maintenance.	Incorporate facilities and components that can be readily cleaned, serviced, repaired and replaced without pollution or damage to the environment.
<i>Structural integrity</i>	
Withstand environmental and other applied loads.	Meet Code requirements for structural strength of members and components.
Ensure adequate pontoon buoyancy.	Satisfy appropriate guidelines for freeboard and flotation for various load cases.

Box 9.2 Design objectives and criteria for pontoon body and ancillary facility design	
Design objective	Criteria/constraint
Ensure adequate pontoon stability during roll motions.	Satisfy requirements for vessel stability when subjected to roll, and confine roll motions to tolerable levels.
Ensure survival in a damaged condition.	Satisfy requirements for survival if the pontoon is damaged in various compartments.
Provide adequate restraint for tender craft.	Provide bollards with adequate strength to restrain the full range of tender craft.
Environmental protection	
Maintain clearance from coral and seabed.	Design the pontoon body and size components to maintain the specified clearances from coral structures and the seabed.
Provide safe storage of fluids.	Design storage vessels (eg. fuel, gas) to the appropriate Code requirements.
Manage waste.	Satisfy regulatory requirements for waste handling, storage and disposal.
Use appropriate materials and coatings.	Select approved materials and coatings that avoid environmental pollution or damage. Select materials to minimise maintenance needs and to maximise corrosion protection.

Design tasks

Pontoon body and ancillary facility design involves the following discrete tasks, as outlined in subsequent sections of this chapter:

- structural engineering of all pontoon members, components and ancillary facilities
- design a suitable arrangement of flotation units and satisfy pontoon stability requirements
- correct selection, application and specification of materials and coatings
- engineering of acceptable storage systems and waste management systems
- design of independent ancillary facilities at the project site.

9.2 Structural design

All structural elements comprising the substructure and superstructure of the pontoon, must be designed in accordance with the relevant design standard for that particular member or component. Box 9.3 lists the principal structural elements found in a typical pontoon project.

Box 9.3 Principal pontoon structural elements	
<i>A pontoon project will contain most, or possibly all, of the following.</i>	
Structural grouping	Description
Pontoon substructure	Flotation compartments, deck support beams, decking, viewing chambers and ballast tanks
Pontoon superstructure	Fixed frames, supports, walls, flooring and roofs
Berthing facilities	Fenders and bollards
Mooring and towing connections	Mooring connection lugs and towing lugs
Canopy roof structures and sails	Fixed columns, shade roofing/fabric and support cables/ropes
Storage vessels	Storage for fuel, gas, potable water and wastes
Ancillary facilities on the pontoon	Walkways, gangways, stairwells and (fixed or fold-up) platforms for loading/swimming/diving

The design process can be considered in two basic steps:

1. Estimation of design load on a member or component for a range of load cases (ie. various combinations of dead, live and environmental loads)
2. Sizing the individual member or component to satisfy strength and serviceability limits, appropriate to the material used, the operating environment and the function/role of the member or component.

Design forces exerted on individual pontoon members and components are determined from appropriate combinations of dead, live and environmental loads, as described in Box 9.4. These forces are used to determine member/component sizing. In calculating design loads, the designer should note the requirements outlined in Box 9.5. The designer must also select the appropriate vessel classification (refer USL Code, Section 1, Part 3) for the pontoon body. Most facilities are likely to be classed as either *Restricted Offshore Operations* or *Partially Smooth Water Operations*. Only pontoons in well-protected sites would be classified as *Smooth Water Operations*.

Structural design, including the estimation of design loads and the determination of member/component sizing, shall follow the requirements of:

- The chosen classification society rules (eg. Lloyds of London; Det Norske Veritas)
- USL Code Section 5 (sub-section relating to the applicable material).

Conventional design practice in marine engineering follows a Working Stress Design approach, as outlined in the various classification society rules and the USL Code. All pontoon members and plating shall be designed to satisfy permissible stresses and deflection requirements specified in these documents. Steel shall be designed in accordance with USL Code Section 5, Sub-Section L and structural analysis should confirm that stress levels are within those defined by AS 3990 WSD. Aluminium shall be designed in a similar manner, in accordance with USL Code Section 5, Sub-Section H and AS4132 Part 2.

Box 9.4 Design load contributions	
Load category and type	Load descriptions
<i>Dead loads</i>	
Fixed elements of the pontoon	Self weight of pontoon members, components, permanent fittings, vessels/chambers (empty), including any permanent ancillary facilities (eg. diving platform).
<i>Live loads</i>	
Hydrostatic forces	Water pressure exerted on the hull of the pontoon.
Human loading	Distributed load from passengers and service personnel.
Storage loads	Materials, equipment, contents of storage vessels, baggage, catering products and temporary storage of service craft.
Biological growth	Weight of biological organisms attaching and growing on the hull of the pontoon.
Berthing loads	Impact forces exerted on the pontoon by tender and visiting craft and loads on bollards exerted by restraining lines.
Water on the deck	The additional weight contribution by water over the deck.
Flooding loads (for damaged condition)	The additional weight contribution by water spilling into damaged buoyancy compartments.
<i>Environmental loads</i>	
Wind	Direct effect of wind loading on exposed elements above the water line.
Waves	Varying water level changes the water pressures exerted on submerged members. Wave wash-over may also occur.
Current	Drag effects exerted on the hull and viewing chambers below the water line.

Box 9.5 Requirements to note in calculating design loads	
• Design values for dead and live loads shall be determined directly in accordance with the procedures spelt out in the adopted Classification Society Rules and the USL Code Section 5. • For environmental loads, the intensity of winds, waves and currents used for calculation of forces, shall be taken from <i>Chapter 5 Design Environmental Loads</i> and shall correspond to intensities for the <i>Cyclonic Condition</i> (unless a lesser intensity is specifically appropriate, eg. roof canopies designed to collapse in certain conditions). • With respect to the calculation of wind drag forces, the design wind speed used for the design of structural members/components shall be the intensity of wind averaged over a 3 second gust, ie. the standard 10 minute average wind speed shall be multiplied by a factor of 1.26 to convert the intensity to the equivalent average 3 second gust speed. • Whereas the standard wind speed specifically applies at a height of 10 m, it is not normal to scale down the design wind speed for elevations less than 10 m above mean water level. • Forces for environmental loads shall be calculated using the intensities from <i>Chapter 5 Design Environmental Loads</i> and using the procedures set out in the adopted Classification Society Rules and the USL Code Section 5. • Design load cases, comprising different combinations of dead, live and environmental forces, shall be determined according to the requirements set out in the adopted Classification Society Rules and the USL Code Section 5.	

The principles and criteria to be used in the design of docking/mooring facilities for visiting craft (eg. covering fenders; bollards etc.), and the design of mooring line connections to the pontoon, shall follow the general requirements of the adopted classification society rules and the USL Code Section 5. The designer should also follow the guides provided in Box 9.6.

Some general guidance on common arrangement of pontoon elements and good practice for detailing, is presented in Box 9.7.

Box 9.6 Guidelines for design of berthing facilities and mooring connections to the pontoon	
Component	Design provision
Berthing facilities	To accommodate impact forces, increase the thickness of side plating of the pontoon in accordance with applicable sections of the adopted classification society rules and the USL Code Section 5. Berthing bollards and bollard connections should be designed for a load of 20 tonnes, or twice the maximum breaking load of the berthing lines to be attached, whichever is the greatest. Bollards should be fitted at four points along each side of the pontoon. A wooden rubbing strip or rubber fender should be fitted to the sides of the pontoon to avoid direct contact with the berthing vessel. These fenders should be sized as appropriate for the berthing vessel.
Mooring line connections to the pontoon	All mooring points (comprising pontoon lugs and their supports, used to connect the pontoon to mooring lines) shall be designed to a capacity $\geq 1.2 \times$ breaking load of the mooring chain or wire (Refer BS 6349 Part 6).
Towing lugs	All towing points (comprising pontoon lugs and their supports) shall be designed to a capacity $\geq 1.2 \times$ breaking load of the grade of chain or wire to be used for towing.

Box 9.7 Guidelines on arrangements and good practice for pontoon body design	
Component	Typical arrangements and good design practice
Pontoon flotation	The pontoon hull is typically constructed of welded mild steel. Watertight compartments are used to subdivide the pontoon hull. Large saddles are welded atop flotation tubes to support transverse decking (aluminium) 'I' beams. Provide access manholes in the top of each watertight compartment (comprising steel covers, neoprene gaskets and stainless steel nuts and bolts), and provide air-holes to assist welder and painter during construction (flange and seal with blanking plates, neoprene gaskets and stainless steel fasteners).
Viewing chamber	Usually locate the viewing chamber / ballast tank structure into the hull at one end and provide pontoon towing lugs at the end away from the viewing chamber. Provide two sets of access stairwells. Provide aluminium hatches complete with pneumatic cylinder openers to close off stairwells. Install non-skid finish for stairs down to viewing chamber. The chamber is commonly internally painted and not lined. Handrails are installed on both sides of stairwells and along the length of the viewing chamber. Supply fans and ventilation registers to deliver and distribute fresh air to the viewing chamber. Provide sumps in the bottom of the viewing chamber.
Deck	The main deck is typically constructed from extruded aluminium planks. Provide removable panels for access to hull manholes.
Canopy / shade roofs	Shade structures comprising vinyl or fabric sails have been commonly used on pontoon facilities to provide some protection from the sun. These sails are typically white PVC coated, woven polyester cloth secured by stainless steel wires to upright frames or stay uprights, with post bases fixed to the pontoon deck. Conventionally, some of these sail structures have been designed to fail/collapse/blow off during mild cyclonic wind conditions, thereby reducing the total wind load imposed on the pontoon in extreme conditions. These (intended) collapsible systems have not always been adequately designed or tested, and unless a proven system is installed, the designer must assume they remain intact for the full intensity of the design cyclonic wind loading state. For a proven collapsible mechanism, the peak design wind load exerted on the sail structures can be reduced to that corresponding to the collapse force. This will only be acceptable provided the integrity of the pontoon base (ie. fixed frames, decking and substructure) is maintained For an approved collapsible system, operation manuals for vessels must prescribe superstructure component strengths such as the ropes attaching the sails.
Ancillary facilities	Ancillary facilities that could break free or compromise the integrity of the pontoon should be designed to survive the design wind loads, pontoon motions and wave wash-over.
Other fittings	Anti-bird netting is often fitted, and monofilament

9.3 Pontoon flotation and stability

In determining the design arrangement and configuration for the pontoon substructure, the designer must provide for adequate flotation and stability, as well as meeting requirements relating to amenity (eg. aesthetics and visitor viewing). Firstly, adequate freeboard must be provided between the deck and the mean water level, and positive buoyancy must be maintained in all possible load cases. Secondly, the buoyancy elements must be distributed and compartmentalised to maintain flotation if limited damage occurs. Thirdly, the pontoon substructure arrangement must assist pontoon stability (ie. limit the tendency to roll; restrict the degree of roll; resist capsizing). General provisions and good design practice for the pontoon body to ensure pontoon flotation and stability are outlined in Box 9.8.

Box 9.8 Design provisions and good design practice to ensure pontoon flotation and stability									
Design aspect		Design provision							
Hull		Subdivide the hull into a series of watertight compartments. Ensure that if the pontoon was broken in half, the two halves would float. Incorporate ballasting into any viewing chambers, to facilitate correct levelling (and fit the ballast tank with a dump valve capable of releasing ballast water in the event of an emergency). Provide all buoyancy compartments with watertight inspection manholes (in accordance with AS 1016 or equivalent).							
Support of anchor chains and other equipment		Size the pontoon to ensure adequate flotation and stability in support of the weight of the anchor chains, and all other equipment mounted on or to the pontoon. The following minimum freeboard values should be achieved. Assume the full design dead and live loads apply in assessing these conditions. <table><tr><td>Neutral Position</td><td>Intact stability condition</td><td>Freeboard ≥ 1.0 m</td></tr><tr><td></td><td>Damaged stability condition</td><td>Freeboard ≥ 1.0 m</td></tr></table>		Neutral Position	Intact stability condition	Freeboard ≥ 1.0 m		Damaged stability condition	Freeboard ≥ 1.0 m
Neutral Position	Intact stability condition	Freeboard ≥ 1.0 m							
	Damaged stability condition	Freeboard ≥ 1.0 m							
Intact stability *		Comply with the following minimum intact stability criteria: • The metacentric height shall be greater than 0.5 m • The area under the righting moment curve to the second intercept, or lesser angle, shall be more than 40 % in excess of the area under the heeling moment.							
Pontoon heel *		Ensure gravitational moment (GM) is sufficient to ensure that, with the effect of passenger crowding, heel is less than the angle equivalent to half the freeboard, but is always less than 5 degrees.							
Ocean wet tow and installation		Provide sufficient buoyancy and internal compartmentalisation to prevent the following during ocean wet tow and installation: • Capsizing or sinking due to pull of the suspended anchor chains • Capsizing due to pull of the remaining anchor chains, when any one chain is removed • Sinking in the event of any two adjacent watertight compartments being damaged or flooded.							
Department of Transport survey requirements		Comply with specific requirements of the Queensland Department of Transport in relation to vessel stability and safety of tourist pontoons.							
Other provisions of the USL Code		Comply with the additional requirements and means of assessment of pontoon stability in Sections 5, 7 and 8 of the USL Code. This Code provides advice on watertight sub-division and guidance on the various stability design cases that should be considered in sizing the pontoon and determining the range in the number of passengers. It also provides guidance on estimating loads associated with passengers and the typical areas occupied by passengers							
* Note Naval architecture terminology follows the provisions of USL Code.									

9.4 Materials and coatings

Materials and coatings used in the construction of pontoon facilities must be appropriate for marine applications, taking account of the sensitive reef environment where the pontoons are located. Selection should give due consideration to:

- type and purpose of structure and design detailing
- structural integrity of material
- material costs and availability
- maintenance and serviceability (including potential for corrosion resulting from construction processes)
- construction and installation techniques
- aesthetic and environmental suitability.

Box 9.9 outlines the key factors that must be considered in selecting materials and coatings for pontoon members and components.

Box 9.9 Design provisions for selection of suitable materials and coatings for pontoon construction	
Design aspect	Design provision
General nature of products	Products must not contain any properties that have caused, are causing, or are likely to cause harm to the local or regional environment. Refer to products recommended by GBRMPA as suitable.
Approved materials and coatings	Only those materials and coatings approved for construction and maintenance of the permitted facility are acceptable.
Painting system to suit marine applications	The pontoon shall be painted with a system suitable for marine applications. Inside surfaces can be coated with a rust-preventative primer and outside surfaces with anti-corrosive primer coats and an epoxy finishing coat. Alternative systems, giving similar or enhanced integrity, may be considered if approval is sought.
Antifouling paints	Antifouling paints will not generally be permitted. In special instances they may be approved for very restricted usage with ancillary craft.
Tar-epoxy paint	Underwater sections of the pontoon, as well as catamarans, platforms and associated support vessels can be coated with two-pack epoxy hard finish enamel. These paints can be used on pontoon hulls since growth can be accepted.
Cleaning pontoon and vessel hulls	The pontoon hull should be left un-cleaned to promote marine growth, corals, etc and to support marine ecosystem. Catamarans and support craft will be regularly subjected to underwater cleaning (eg. hulls brushed clean with the aid of an underwater hydraulic hull cleaning unit). No paint flakes/material from the pontoon or other vessels will be allowed to fall onto the seabed floor.
Corrosion protection	Adequate corrosion protection must be provided, and maintenance and replacement needs clearly documented. Consider use of sacrificial anodes on the pontoon and on the mooring lines (anodes secured by stainless steel bolts to backing plates welded to hull to facilitate easy replacement). Sufficient cathodic protection must be provided for anchor piles, mooring chain and the pontoon.

Materials such as steel, aluminium, timber, plastic and rubber are commonly used in pontoon facilities. A wide variety of plastics and rubber have been used in the marine environment (eg. butyl, natural rubber, neoprene, polyethylene, polypropylene, polystyrene, polyurethane, PVC). Box 9.10 describes the typical applications, advantages and disadvantages of the main categories of construction materials used in the tropical marine environment.

Box 9.10 Materials used in construction of pontoon facilities	
Material type and application	Advantages/disadvantages
<i>Stainless steel</i>	
Rarely used in the coastal zone (with the exception of frequently adjusted fasteners and fittings).	Relatively high cost. Corrosion susceptibility in warm ocean waters.
<i>Mild steel</i>	
Typically used for the pontoon superstructure. Common practice is to provide a corrosion thickness allowance (factor of safety) in steel design strength calculations. Inside surfaces require coating with a rust-preventative primer. Outside surfaces require anti-corrosive primer coats and an epoxy finishing coat.	Prone to corrosion, requiring a surface coating or cathodic protection.
<i>Aluminium</i>	
Often used for the construction of pontoons and gangways. Polyurethane paint system are required to protect aluminium submersed in seawater. Protection by anodising or resin coating recommended for aluminium exposed to air. Only aluminium alloy Series 5000 or 6000 should be used near seawater. Welding and application of protective coatings should be undertaken in a factory-controlled environment, wherever possible.	High strength to weight ratio. Expensive material that is generally only used where strength and weight limitations need to be considered. Aluminium suffers from extreme electrolytic corrosion in the presence of metals of different electric potential.
<i>Plastics and rubber</i>	
Numerous plastics and rubbers are used in the coastal zone, for a variety of applications	Provide resistance to corrosion. Provide flexibility. Many are susceptible to damage from exposure to ultra violet light. Some are vulnerable to attack from petroleum based products.
<i>Epoxy or polyester based paint systems</i>	
Used to protect steelwork. Useful for submerged steel that can be removed for re-application of paint.	Some products provide good corrosion protection to steel.
<i>Timber</i>	
Useful for fenders and other similar structure components. Timber should only be used where it can be readily replaced upon wear.	Susceptible to damage from exposure to the sea.

9.5 Storage vessels, waste management and independent ancillary facilities

Storage Vessels

Pontoon facilities often require onboard storage of fluids/gases for purposes such as:

- Potable water (for drinking)
- Fuel (for tender/service craft and generators)
- Gas (for cooking)
- Temporary waste storage and/or treatment.

All pressure and non-pressure vessels, water and fuel tanks, together with associated systems, shall be designed and installed in compliance with the nominated classification society rules (where applicable), USL Code Section 9 Part 3, and with any applicable state Government regulations.

Any special design requirements for specific storage vessels must be outlined in the design documentation, and submitted for approval. Additional design safeguards (beyond normal regulatory requirements) may be imposed in order to protect the sensitive reef environment against pollution. This may take the form of conservative design of storage vessels, use of redundancy in design, provision of a back-up or a containment system, and special warning systems to prevent or limit spillage or leakage of contents. Specific inspection and maintenance needs must be provided and emergency procedures fully documented.

Waste management

Wastes generated at pontoon facilities must be strictly contained and controlled to prevent pollution damage to the environment and to maintain satisfactory hygiene. Wastes generated by pontoon operations may comprise:

- sewage
- low grade wastewater (such as shower run-off)
- liquid kitchen waste
- solid kitchen/catering waste
- general rubbish

In most instances, the pontoon operator shall not discharge wastes into the sea at the pontoon site. Box 9.11 summarises accepted practice applying to waste management on existing pontoon operations.

Proposals may be considered for the on-board treatment of human waste, however the standards for discharge of treated effluent into the sea are very high. Nutrients such as nitrates and phosphates encourage algae growth, which in turn can kill coral. Therefore the treatment process must remove nutrients (particularly the nitrates and phosphates) if discharge into the sea is proposed. A lower standard of treatment may be considered if the effluent is transferred to the transit ferry and discharged in approved areas (ie. remote from coral communities).

If on-board treatment and/or discharge of effluent into the sea is proposed, close consultation with GBRMPA and the Queensland Department of the Environment will be required at an early stage.

Box 9.11 Normal practice for waste management on pontoons	
Waste type	Normal practice for managing waste
Sewage	Ablution facilities are provided only on the transit ferry (ie. no sewage waste generated on the pontoon facility), or Sewage is temporarily stored in holding tanks on the pontoon, which are regularly pumped into similar holding tanks in the transit ferry (for transferal and disposal on shore).
Low grade wastewater (such as shower run-off)	In most instances, this is temporarily stored in holding tanks for transferal to the transit ferry, or directly diverted to holding tanks on the transit ferry. In special cases, permission may be granted for disposal of these wastes directly into the sea.
Liquid kitchen waste	These wastes are temporarily stored in holding tanks on the pontoon, and are regularly pumped into similar holding tanks in the transit ferry (for transferal and disposal on shore).
Solid kitchen/catering waste and general rubbish	Contained and transferred to the transit ferry (for disposal on shore).

Independent ancillary facilities

Pontoon projects may use a number of independent, ancillary floating platforms, which may be installed for recreational or transport purposes. Common additions include:

- Helicopter platforms
- Swimming and snorkeling platforms
- Diving platforms

In most cases, independent floating platforms must be designed to the same standard that applies to the pontoon itself. This is necessary because if the platform or its moorings were to fail, the platform may break free, be set adrift, and result in: collision with, and damage to the main pontoon; drifting into shipping lanes, posing a major threat to safety; or beaching on and damaging the reef.

As a general policy, all independent floating platforms shall be designed to meet the same serviceability, function and safety; structural integrity; and environmental protection objectives adopted for the main pontoon. The same load intensities and the same engineering standards applying to design of the pontoon, shall be used for these independent platforms.

An exception to this rule will only apply where the conditions of collision and drifting can be conclusively excluded (ie. the platform location is such that escape and collision is impossible), and where the likely damage caused to the reef environment by beaching can be reasonably tolerated. In this circumstance, the design of the platform and its moorings could proceed based on lower intensities for design wind, wave and current. Refer to Chapter 5 for further guidance on design levels for wind, wave and current.

In order to improve access to the reef in some projects, operators may consider development of fixed or floating walkways or jetties, extending across the reef flats. These independent facilities require special attention, and guidelines for their design are outside the scope of these *Guidelines*.

9.6 How to do pontoon body design

This section provides a summary on how to go about pontoon body and ancillary facility design in Steps 4 and 6 of the 10-Step Planning, Design and Implementation Procedure. Box 9.12 outlines the data and design information that should be documented as part of each design phase.

Box 9.12	Design documentation for pontoon body and ancillary facility design
Phase 2	<i>Feasibility design</i>
Pontoon body and ancillary facility design is mostly undertaken in the <i>Feasibility Design</i> . Design schematics of the pontoon facility should be produced, defining the layout and dimensions of the floor plan and the vertical profiles of the pontoon, both below and above the water line. These schematic drawings should show the preliminary sizing of the key structural members (eg. flotation cylinders; deck support beams, above deck frames etc.). The preliminary drawings and details of the pontoon body are to be submitted, together with other documentation, in the <i>Feasibility Design</i> (eg. layout and configuration of the pontoon and design of the mooring system).	

Phase 3	Implementation - Detailed design
Detailed design information and technical specifications will be prepared in the <i>Detailed Design</i> phase. Full structural detailing and specification of all members, components, plating, ancillary facilities and fittings will be required. In addition to these pontoon structural particulars, full schematics, drawings and specifications must be supplied for mechanical systems (eg. ventilation systems, sumps), electrical systems (eg. generators, lighting, electric power connections/wiring) and plumbing equipment (eg. water delivery lines, waste delivery lines). Detailed drawings, shop drawings and specifications must detail all construction requirements and must document the means to verify conformance of construction with the design, including the following: Key structural elements and their connections Hull flotation units; viewing chamber; deck support beams; decking; above deck frames, walls and roofs On-deck facilities Shower/change rooms; handrails; davit; storage areas; tables and bench seats; food/service counter unit; kitchen facilities; caretaker's unit; washroom; living area; housing for mechanical equipment, generator, electrical and plumbing equipment; sun-deck Ancillary facilities Swim platforms; divers platform; stairwells; gangways; loading platforms; ladders lifeguard towers Underwater facilities Detailing for touch tank; viewing chamber; ballast tanks Berthing and mooring Fender points; mooring eyes; gangway pads Engineering systems Freshwater system; gas system; waste water system; electrical system; machinery equipment and systems; plumbing Finishings and fittings Paint; insulation; cathodic protection of metals; glass; sealants; safety aids; navigation aids	

How to do Pontoon Body and Ancillary Facilities Design
<i>refer Steps 4 and 6 of 10-Step Planning, Design and Implementation Procedure (Chapter 3)</i>
Inputs • site physiography, bathymetry and features • proposed configuration and layout of the pontoon facility • wind, wave and current intensities for design of the pontoon substructure and superstructure • mooring line forces and orientation for design of connections to the pontoon body • tropical cyclone, wind and wave characteristics for the region Planning and design tools • design codes and marine classification guides and other data on pontoon body design • structural models to design pontoon body, ancillary facilities and other components Personnel • coordination and preparation of required information by the proponent's project manager • design input from a specialist marine engineer / naval architect • specialist input from marine electrical engineer • management agency's interests represented by the GBRMPA delegate and project manager

Outputs (Box 9.11)

- preliminary designs defining the configuration and layout of the pontoon body – Step 4
- detailed designs, fabrication drawings, specifications and tender documents for the pontoon body – Step 6
- Marine Classification approval for the facility

Associated tasks

- Define the layout and configuration of the pontoon facility (Chapter 6).
- Define the type, layout and configuration of the mooring system, considering specialised features such as innovative mooring arrangements (Chapter 7).
- Analyse the structure to determine forces and movements in the pontoon and mooring system, and design mooring components to accommodate wind, wave and current loads (Chapter 7).
- Define configuration and layout of pontoon ancillary facilities, including platforms, walkways, water storage, waste storage and disposal as required.
- Define the installation and salvage arrangements for the facility (Chapter 10).
- Define the operation and maintenance program for the facility (Chapter 10).
- Obtain necessary licences and approvals for implementation of the project.

10 PONTON INSTALLATION, OPERATION, MAINTENANCE AND MONITORING

	Summary
10.1	Installation and salvage
10.2	Pontoon operation
10.3	Pontoon maintenance
10.4	Environmental monitoring
10.5	Recommended reading

Summary

- **Operators, designers and managers** should use this chapter in post-design aspects of the pontoon project relating to installation, operation, maintenance and monitoring.
- The scope and provisions for installation, operation and maintenance are presented, and the manner in which these aspects are incorporated into project planning and design tasks and management plans, is described.
- The requirements for monitoring both the facility and the environment throughout the installation and operation phases are described.

Multipurpose requirements for serviceability, function and safety, structural integrity, environmental protection, and amenity and cultural values must be addressed through all phases of a tourist pontoon project, from planning and design to installation, operation, maintenance and monitoring. Proponents, designers and environmental managers must make provisions for installation, operation and maintenance early in the project, and recognise how planning and design decisions affect these aspects of a project. For example, **installation** requirements related to mooring chain placement, coral relocation, construction equipment and method must be considered in the conceptual and feasibility design studies, and provisions must be built into the detailed design. Similarly, **operational** provisions for craft access and wastewater disposal, and **maintenance** requirements and schedules for mooring lines and anchors will guide planning and design requirements.

This chapter outlines the installation, operation, maintenance and monitoring aspects incorporated in Steps 7 to 10 of the *10-Step Project Planning, Design and Implementation Procedure* (principally *Phase 3: Implementation* and *Phase 4: Operation, monitoring and review*). Reference is also made to relevant planning and design provisions incorporated in Steps 1 to 6 (principally *Phase 1: Concept* and *Phase 2: Feasibility*). Relevant statutory provisions for payment of fees, inspections and approval times for Marine Park permit assessment and management are outlined in Chapter 3.

Provisions for installation and salvage, operation, maintenance and monitoring of the facility are incorporated in *Management Plans (MPs)*, initially prepared by the designer on the proponent's behalf as part of the *Feasibility Design* (Step 4). The MPs embody planning and design objectives for the project, and incorporate operation, maintenance and monitoring provisions and strategies to minimise environmental harm and achieve agreed environmental standards (Box 10.1). They are updated with final design details prior to commencement of construction, operation and maintenance, and are used by the operator to manage these activities in an integrated manner. The *MP for Installation* forms part of the construction contracts, and the *Operation and Maintenance MP* forms part of operation and maintenance manuals. The installation and salvage, operation, maintenance and monitoring provisions for the facility are, in turn, incorporated in the marine parks permit issued by GBRMPA.

Box 10.1 Scope of management plans for <i>Installation and Operation & Maintenance</i>	
• background to plan, including scope and context for implementation (eg. project outline) • expected outcome (eg. installed pontoon; successful pontoon operation) • performance requirement or objective (eg. meet design and specification standards) • implementation strategy to achieve performance requirements (eg. proposal for installation including transportation, placement, testing etc.; plan for pontoon operation) • guidelines for best environmental practices for operators, installation contractors and others (eg. activities to minimise environmental impact; compliance with public health and safety standards) • monitoring requirements to measure actual performance (eg. facility monitoring for installation or operation) • potential construction and operational impacts (eg. coral damage; chemical spill) • corrective action to be implemented in case performance requirement is not reached (eg. relocate anchors; alter dive route) • person(s) responsible for the action (eg. construction superintendent; maintenance manager) • format, timing and responsibility for reporting and auditing monitoring results (eg. construction report; annual monitoring report)	

Each of the installation, operation and maintenance activities has a major monitoring component that is related to the environment or to the facility itself (Box 10.2). **Environmental monitoring** incorporates biophysical measurements of the pre-installation condition as part of *Baseline Monitoring* (Step 7), inspections and observations during *Installation* (Step 8), and biophysical measurements during *Performance Monitoring* (Step 9). **Facility monitoring**, which relates to function, safety and structural integrity aspects, incorporates inspection and testing of structural components during pontoon installation (Step 8) to ensure satisfactory installation procedures and outcomes; and inspection during pontoon operation (Step 9) as part of the maintenance requirements for the facility.

Box 10.2 Environmental and facility monitoring tasks <i>refer 10-Step Project Planning, Design and Implementation Procedure (Chapter 3)</i>	
Environmental monitoring (Section 10.4) <i>Biophysical environment affected by pontoon</i>	Facility monitoring (Section 10.1 – 10.3) <i>Function, safety and structural integrity aspects</i>
Step 7 Baseline Monitoring Biophysical measurements of pre-installation condition.	Not applicable.
Step 8 Construction and Installation Inspection and observation of biophysical environment during and after installation.	Inspection, testing and directed modification of facility components during installation (Section 10.1).
Step 9 Performance Monitoring Biophysical measurements of condition, post-installation and during operation.	Inspection and maintenance procedures to replace or repair facility components during operation (Sections 10.2, 10.3).

10.1 Installation and salvage

Installation of a new pontoon and associated facilities, upgrade of an existing facility, or removal of the facility from the Marine Park must be undertaken in accordance with the project designs and environmental management provisions established as part of the *Feasibility Design* (Step 4) and *Detailed Design* (Step 6). For installation this relates to such things as transport to the site, ease of installation, adequate mooring system strength, coral protection, and minimal disturbance to the seafloor and reef flat. Salvage proposals must provide for ease of removal, safety, environmental protection and rehabilitation etc.

The likely scope of activities involved in pontoon installation itself is presented in Box 10.3. Prior to installation commencing, a considerable amount of information will already be available, and the proponent and designer will have taken significant decisions and actions. Careful pre-installation planning and scheduling of activities is essential if the desired objectives are to be achieved, particularly if adverse environmental impacts are to be avoided. The pontoon site will have been chosen; detailed site investigations and surveys undertaken; the layout and configuration of the pontoon structure and associated facilities prepared; designs, drawings and specifications for the installation prepared; and procedures for installation established (Steps 1 to 6; Chapters 4 to 6). The pontoon structure, moorings and the other components for new or upgraded facilities will have been fabricated off site, in readiness for transport to site (Chapters 7 to 9).

Box 10.3 Activities involved in pontoon installation

- transport pontoon, mooring system and other components from port to the site
- set site out using survey control points
- relocate or remove designated corals
- clear unwanted obstructions from the site
- place or install anchors (block, screw, embedment, etc) at designated locations
- test anchors to ensure design strength is achieved
- connect mooring lines to anchors
- lay out mooring lines in controlled manner along pre-surveyed route
- position intermediate mooring blocks and connect to mooring lines
- position pontoon and connect to mooring lines
- pre-tension mooring lines according to design requirements, where stipulated
- relocate or remove excess mooring line, blocks or other components
- adjust and finalise pontoon and mooring positions
- remove all construction equipment from sea bed
- clean sediments off corals and bommies after structural works complete
- transport all construction equipment from the site to port

This section outlines the requirements for installation, modification and salvage of a pontoon facility, leading from site preparation, through installation procedures, monitoring and testing, and contract and site supervision requirements, to licences and approvals.

Site preparation

Site preparation is the first step in the installation of the facility, and must be carefully undertaken to ensure success of the project. Whereas the operator will have an inherent interest in protecting the site to ensure successful operation of the facility, contractors may not have the same interest. All parties must understand the critical elements of the site, and the special provisions made for installation during planning and design.

The work zone for site installation must first be delineated using buoys. This area is sometimes defined by several disparate factors, usually physical features, such as the coral reef or bommies that are encompassed or affected by the installation. The work area may also be determined by the boundaries of management zoning or other restrictions imposed by the permit requirements, and in some cases by property ownership or natural or cultural features that might have special significance for the site. The location of the pontoon, mooring lines, anchors, and other components of the facility are set out from the design drawings, using survey control points established during earlier site surveys and investigations. Markers should be placed to indicate their position.

Vessels, equipment and personnel

For a new facility, the pontoon is usually towed to the site. Other components for a new or upgraded facility, such as the anchors, anchor chains and other mooring system elements, are usually transported to the site by landing barge. The barge, or an alternative work vessel used for the on-site activities, is usually equipped with a winch, a lifting device such as an A-frame, and other equipment for material movements. The barge is commonly winched to and from the work vessel on site in order to lay out mooring chain etc. Dinghies, compressors, airbags and air lines, and other miscellaneous equipment are often used for the installation. In some cases, such as the installation of screw anchors, specialist equipment may be required. Vessels, equipment and personnel must comply with operational requirements outlined in Box 10.4.

Box 10.4 Operational requirements for vessels, equipment and personnel	
• vessels must be under marine survey and in a seaworthy condition • vessels must carry the required insurance • vessels must be equipped with first aid kits • running lights must be provided for the pontoon when under tow • dive vessel, work crew and dive team dive equipment must comply with Australian Standard 2299, <i>Commercial Diving Standard</i> • liquid waste from vessels must be emptied at least 500 m seaward of the reef edge where vessels are fitted with holding tanks • litter, oil or other materials must not be washed off the deck at the site and introduced from scuppers into the sea • plans for fuel spill minimisation and containment should be developed in the event of a fuel spill from the work vessels, including provision of absorbent pads and granules on board	

Installation procedure

Once the site set out is done, and the pontoon and associated moorings and equipment are transferred to the site, installation of a new pontoon will typically follow the procedure outlined in Box 10.5. A complex installation may take several weeks to complete.

Box 10.5 Site installation procedure for new pontoon <i>refer Step 8 of 10-Step Project Planning, Design and Implementation Procedure (Chapter 3)</i>	
Task	Description and comment
Mark location for mooring lines and anchors.	The line is normally marked with buoys. Comply with design tolerances for horizontal and vertical location and dimensions.
Relocate corals and clear the site of unwanted obstructions.	Identify and relocate corals, only as approved. Most coral is transplanted by hand by marine biologists.
Place deadweight anchor blocks.	Anchor blocks may be placed directly in position using the crane on the work vessel. Anchors fitted with airlift bags may be relocated small distances by man-handling, and relocated long distances by floating to the surface, towing and lowering in place. Anchors may be relocated using pulley systems attached to blocks in place. Ensure that the final installed anchor position is within the tolerances allowed on the design drawings.
Install drag embedment anchors or screw anchors (where appropriate).	Special procedures must be followed according to instructions provided by the designer or manufacturer.
Field-test anchors and mooring lines.	Test after appropriate delays, eg. for grout to gain strength. In some situations the anchors may not be tested until the mooring lines are attached.

Prepare mooring lines for placement.	Lay chains and other lines out on the barge in correct lengths, and attach airlift bags. Chains are sometimes temporarily stockpiled in an open sandy area.
Lay out mooring lines along defined routes and connect to anchors.	Connect mooring line chains to anchors and lay out from barge in a controlled manner, releasing the line under tension as the barge moves slowly forward. <i>or</i> Tow the lines forward from the stockpile using divers, dragging chains along the bottom with the help of lift bags; connect to anchors.
Position dumper blocks and connect to mooring lines.	Locate and place dumper blocks in the same manner as the deadweight anchors; connect to mooring lines.
Position pontoon and connect mooring lines, including pre-tensioning where stipulated.	Relocate pontoon from temporary moorings to design position. Winch mooring lines to the surface as required and attach to the mooring points on the pontoon. Where appropriate, apply the prescribed pre-tension to the mooring lines in an orderly manner.
Finalise pontoon installation.	Adjust and finalise pontoon and mooring positions, and mooring line tensions. Relocate or remove excess chain, blocks and other components.
Clean up site.	Remove all construction equipment from the seabed. Clean sediments off corals and bommies. Transport all construction equipment, unused facility components and refuse from the site to port.

The pontoon installation is to be undertaken in accordance with the design intent. Site conditions will not always be the same as those allowed for in the design proposals, and in such cases, on-site modifications from the design configuration may be required to suit actual conditions. For example, mooring and anchor positions may be altered slightly, and particular corals may be nominated for relocation where impact from mooring lines and disturbance during pontoon operation is likely. Variations on site must be approved by the construction superintendent and should be noted on the as-constructed drawings. Variations involving environmental matters must be approved by the QPWS environmental manager, and those involving structural matters must be confirmed with the designer prior to proceeding with any changes.

Nevertheless, discrepancies between the designed and installed mooring system should be avoided as they may adversely affect the strength and integrity of the mooring system. Seemingly small details, if designed or installed poorly, may reduce the overall integrity of the moorings and contribute to failure. For example, inadequacies in design and installation details that have caused problems in a number of pontoon installations have led to the following recommendations:

- the angle of attachment of mooring chain connections to the anchors should align with the direction of the force applied to the anchor (eg. pile caps on screw anchors)
- where dumper blocks are attached to main mooring lines, the shackle size and connecting chains must be adequate to resist the full mooring loads imposed on the block
- dumper blocks must not be covered with sand and must be able to move freely to perform their necessary function of lifting off the sea bed

Environmental impacts and mitigation measures

All installation and salvage operations should ensure that the coral and other marine ecosystems at the site are protected from physical disturbance, pollution or other impacts. Adverse impacts can

be avoided or minimised by careful planning and design, sensitive installation practices that account for environmental constraints, and adequate supervision and monitoring of installation activities. Most potential environmental impacts associated with construction will have been identified during the *Concept, Feasibility and Detailed Design* steps. Any unavoidable physical disturbance and damage must be identified and agreed upon prior to installation. Environmental aspects of the construction step are principally concerned with effective implementation of environmental safeguards already established in the *Management Plan for Installation*, which the operator should update with final design details prior to commencement of installation. Environmental monitoring and facility monitoring is undertaken during installation to ensure compliance with these plans.

The *Management Plan for Installation* shows the layout and configuration of the pontoon and mooring system, defines the zones and corridors on the sea floor where the mooring lines and anchors are to be located, and identifies the permissible movement limits for the mooring system. The management plan shows those corals that will potentially be affected by the installation, those corals that are to be relocated, and those corals that are not to be disturbed. The construction contractor, the construction superintendent, the environmental manager, and others involved in installation of the pontoon facility, should carefully identify these zones on site, and take utmost care in the identification and relocation of corals, and in the protection of those corals that are to be retained in situ. These activities will be monitored in the environmental monitoring undertaken during installation (Section 10.4).

Environmental impacts from a pontoon installation may include damage to coral or substrate, physical damage to marine organisms, and other disturbance to wildlife, seabed and marine life. Potential impacts and the various mitigation measures are described in Box 10.6. The most significant potential impact is coral damage and disturbance to the seafloor and reef flat from mooring line and anchor installation. This is more likely to be a problem in areas with extensive cover of bommies, and fragile branching coral and plate coral colonies. The most appropriate mitigation measures are the adoption of installation activities that minimise coral damage during the placement of the mooring chains, blocks and anchors, and the relocation of corals where necessary. Physical damage to marine organisms, and other disturbance to wildlife, seabed and marine life from noise, vibration, craft movements and propeller wash is not usually a major problem. The overall impact of installation is minimised where adequate precautions are taken prior to and during installation of facilities, where installation contractors are appropriately instructed, and where appropriate environmental controls are supplemented with adequate site supervision.

Where coral transplanting is undertaken, the coral is most commonly relocated from within the pontoon footprint, the strip around each side of the pontoon, and the alignment and position of mooring lines and anchors. Most coral is moved by hand by marine biologists working with scuba gear. Larger pieces are lifted by airbag and shifted to a temporary site some distance away. Coral transplanting and relocation shall be strictly in accordance with the design intent and specification. Other corals not identified in the design, which may be at risk of damage or death from installation or operation of structures or moorings, may only be relocated or transplanted with the approval of the QPWS environmental manager.

Box 10.6 Environmental impacts and mitigation measures for pontoon installation <i>refer Step 8 of 10-Step Project Planning, Design and Implementation Procedure (Chapter 3)</i>	
Impact	Mitigation measure
Physical coral damage due to mooring line placement, and anchor positioning, placement and testing.	Locate mooring lines and anchor points in patches of sandy substrate away from critical coral substrate. Lay mooring line out straight to avoid lateral movement under tension. Relocate and transplant suitable corals to new location away from mooring lines and anchor blocks.
Sediment clouding due to drilling and installing screw anchors, placement of anchor blocks etc.	Clean sediments off plate corals and bommies with airjet after works complete.
Physical coral damage from support equipment, eg. barges, airlift bags, drill and test rigs.	Ensure adequate distance between equipment and critical coral substrate. Allow for movement in adverse wind, wave, tide or current conditions.
Physical damage to marine organisms due to installation activities.	Schedule work to minimise impact, and avoid direct contact between equipment/personnel and marine life.
Disturbance to wildlife, seabed and marine life from waste, noise, vibration, craft movements and turbidity.	Maintain adequate distance between equipment/personnel and sensitive marine biota. Undertake activities that comply with regulations for vessel operation and provisions for pontoon operation (see below).

Modification to existing facility

Modification of an existing facility will usually involve replacement or upgrade of the pontoon moorings and anchors, and refurbishing and strengthening some of the pontoon elements, eg. mooring lugs. New mooring lines and anchors will normally be required, and the overall scope of the operation will be similar to installing a new pontoon, including careful positioning of facilities and transplant of selected corals. The site installation procedure, and the potential environmental impacts and mitigation measures will generally follow those outlined above.

When modifications are to be undertaken in the vicinity of an existing pontoon or other tourist facility, visitor access and activities for the existing operation will commonly be retained. In order to minimise disturbance to other users at the site, access of work vessels and installation workers to the existing facilities will be restricted during normal operation, and visitor access to the installation site will be prohibited. Work vessels will not normally be allowed to moor adjacent to the existing facility when it is in use by visitors, so anything other than overnight mooring will normally be prohibited.

Monitoring and testing

Installation of the pontoon incorporates provisions for both ***environmental monitoring*** and ***facility monitoring***. The environmental monitoring, which is usually undertaken by the QPWS environmental manager, involves inspections and observations of the biophysical condition of the environment as it is affected by installation activities (Section 10.4). The facility monitoring, undertaken by the construction superintendent with auditing by the QPWS environmental manager, involves inspection of structural and other facility components to ensure that satisfactory installation procedures and outcomes are achieved. In particular, the pontoon mooring system (mooring lines, shackles, anchor blocks etc.) and other structural elements will be inspected to ensure they are constructed according to design specifications, and that on-site modifications do not conflict with permit conditions and design intentions.

Site testing will normally entail test loading of mooring lines and installed anchors in accordance with design load conditions. As well as verifying the capacity of components, test loading assists in eliminating slack in lines, mobilising capacity in drag anchors, and detecting damage to components that has occurred during installation. Care should be taken to avoid damage to the coral substrate from chain tensioning or other physical damage from the test equipment. Test loading of mooring lines and anchors shall be undertaken by progressively increasing the applied load to the maximum calculated line force or anchor force, as determined in Chapter 7. Anchor testing should be delayed until after grouted components have attained full strength, and will usually be undertaken prior to connection of mooring lines to the pontoon or other structures. Loading shall be oriented according to the direction of the maximum vector force exerted on the anchor, as indicated in Chapter 7.

The *departure angle* of the mooring line at its connection to the pontoon is to be checked and verified that it is within ± 1 degree tolerance of that specified by the designer (the specified angle may be 0°). All site-welded joints are to be subjected to full radiographic assessment to ensure they have the required capacity. Suppliers of mooring and anchor hardware must provide certification of product condition and specification (that is, factory certificates if new, and a certificate of test loading and condition if not new). Most pontoon ancillary facilities such as platforms, electrical, water and waste systems will be factory-tested prior to transport to site. Some equipment testing may be undertaken on site prior to commissioning of the facility, eg. raising and lowering of the swim and divers platform, and operation of the freshwater system.

Pontoon or mooring salvage

Salvage and removal of the pontoon structure and associated infrastructure from the Marine Park may be required where the operator withdraws from or ceases to hold a valid permit to conduct the operation, where the structures are wrecked or abandoned, or where removal is directed by GBRMPA. Salvage proposals shall be documented in the *Management Plan for Installation*, which the operator should update with final design details prior to commencement of construction, operation and maintenance. These proposals should allow for removal of anchors and mooring lines from the site, relocation of the pontoon body and associated structures from the vicinity, replacement of designated corals, and other rehabilitation activities that may be prescribed by GBRMPA as part of the salvage requirements. The proponent will indemnify GBRMPA against the cost of salvage and environmental rehabilitation that may be required as a result of damage caused by operation or removal of the facility (Chapter 3).

The salvage operation must meet all function and safety requirements, as well as minimise environmental impacts such as damage to coral or substrate, physical damage to marine organisms, and other disturbance to wildlife, seabed and marine life. In a similar manner to installation of the pontoon, adverse impacts can be avoided by careful planning of the operation, sensitive on-site practices that account for environmental constraints, and adequate supervision and monitoring of salvage activities. The contractor shall follow all legislative and regulatory provisions, and comply with the requirements for operation of vessels, equipment and personnel, as outlined above for the pontoon installation. The likely scope of salvage operations for a pontoon and mooring system is presented in Box 10.7.

Physical damage to the coral is one of the most significant impacts likely to result from removal of the pontoon, mooring lines and anchor blocks. Mooring lines and anchor blocks may be overgrown with coral in parts, and care should be taken in removing and detaching these components from the coral. The mooring lines should be cut into short lengths where they run through or under live coral, and should be pulled out manually to minimise coral breakage and facilitate regrowth over time.

Box 10.7 Activities involved in salvage of pontoon and mooring system

- disconnect mooring line chains from anchor blocks
- relocate anchor blocks into area of bare sand for use as a temporary mooring during the operation (if desired)
- disconnect mooring lines from pontoon
- relocate pontoon to temporary mooring
- carefully detach mooring lines and anchor blocks from coral where necessary
- lift mooring lines and anchor blocks to surface with a barge mounted crane, or float to the surface using airlift bags
- load anchor blocks and mooring lines onto barge
- secure pontoon superstructure and roofing materials for transit
- remove or modify elements of buried or other anchors protruding from the seabed, to the satisfaction of the environmental manager
- remove all construction equipment from sea bed
- clean sea bed and clean sediments off plate corals and bommies with airjet
- transport pontoon, anchor blocks, mooring lines, other facilities and all equipment to port

Construction contractors

Site installation and salvage are usually undertaken by contractors on behalf of the pontoon proponent/operator. Contractors should be competent to undertake the work and experienced in undertaking similar work in the marine environment. They must know relevant laws and regulations, thoroughly understand the design documents, and be familiar with the site and its biological and physical environment.

The contractor will nominate an on-site representative for contractual matters during progress of the works. Contract personnel should be instructed in the environmental objectives of the project in order to reduce supervision requirements, and minimise the likelihood of penalties and post-construction rehabilitation requirements. All contractors, agents and employees shall signify that they will comply with any restrictions or conditions imposed by the Marine Parks permit. All authorised contractors and agents must be provided with a copy of the permit, which is to be available for inspection whenever those persons or their employees are in the Marine Park.

Site supervision and management

The proponent will engage a construction superintendent to coordinate and supervise installation of the pontoon and mooring system, as well as the manufacture, construction and installation of all components of the facility. The superintendent will ensure that all activities comply with drawing and specification requirements, and that the contractors adopt and implement appropriate best management practices for the work, and comply with all technical and safety requirements. In particular, the superintendent will ensure that the pontoon mooring system (mooring lines, shackles, anchor blocks etc.) and other structural elements are constructed according to design specifications, and that on-site modifications do not conflict with permit conditions and design intentions, confirming with the designer as required. The superintendent is also required to liaise with the QPWS environmental manager on environmental matters relating to the site installation.

The QPWS environmental manager will supervise installation activities on behalf of GBRMPA. The environmental manager is responsible for ensuring the requirements of the Marine Park permit are met, that agreed installation procedures are followed, and that mitigation measures are employed to minimise the impact of the installation on the Marine Park. The environmental manager is not required to be present for all activities on site. Nevertheless, unless otherwise authorised in writing by the managing agency, significant site activities associated with the installation or relocation of the facility, such as the siting and manner of installation and

placement of the moorings, must be undertaken in the presence of the environmental manager. The operator and his/her agents must comply with any directions of the environmental manager that are reasonably necessary for the conservation, protection and preservation of the Marine Park. No installation activities may take place until the relevant procedures and techniques to be utilised have been agreed to by the environmental manager. The environmental manager is authorised to stop or suspend works that contravene permit conditions or have the potential for significant environmental impacts.

The QPWS environmental manager will examine the significance of impacts and problems associated with the pontoon installation with respect to those predicted in the impact assessment studies undertaken in project planning and design. Possible mitigation techniques will be identified for reference in future operations. A logbook of daily activities should be maintained, including on-site observations, records of compliance with permit conditions, and records of conversations with the contractor's representative and the superintendent. Written copies of instructions and a comprehensive documentary record of the construction history should be retained in anticipation of any future dispute.

On-site meetings between the contractor's representative, the construction superintendent, the QPWS environmental manager and others should be held at key times throughout the site installation. These meetings will cover the conventional aspects of contract administration and construction management incorporated in the contract documents, and will ensure that the contractor abides by the responsibilities they hold for environmental care and environmentally sensitive construction. The contractor's representative and the environmental manager shall maintain contact at all times during the progress of the work. The contractor shall report on work that has taken place, and advise the environmental manager of the timetable of works and proposed changes to the timetable.

The pre-installation conference, normally conducted on-site, should establish a clear understanding of respective roles and responsibilities, and formally determine the frequency and mechanisms for reporting the progress of the work. The meeting should ensure that all aspects of the plans are understood by all parties, that key actions and the most sensitive areas of the site are recognised, and that the sequence and schedule of implementing control measures are agreed upon. Any changes to the design should be noted on the plan documents for future reference. Plans should be established for emergency problems that might be encountered, and agreement should be reached on a mechanism for emergency response. Additional conferences may be held during the course of the work to formalise contract matters and avoid potential misunderstandings. A post-installation inspection should be undertaken to ensure that the work has been satisfactorily completed. A list of all items requiring completion by the contractor should be prepared before scheduling this final inspection. These items should be completed and the site cleaned up prior to the final inspection.

The superintendent shall record the location, configuration and size of all components of the facility on the design drawings after installation has been completed, noting any variations from the design. This record of 'as-constructed' conditions will provide the basis for future investigations and activities associated with the operation, maintenance, monitoring and/or future modification of the pontoon facility. A photographic record of all components of the installation should be maintained by the superintendent, and a video record of each leg of the installed pontoon mooring system should be obtained.

Quality assurance and construction audit

The pontoon operator will adopt a quality assurance system to record relevant data, procedures, critical decisions, and assumptions incorporated in the manufacture, construction and installation of the facility. Contractors should adopt recognised construction standards and codes of practice, comply with established criteria and recommended procedures, and follow best practice guidelines wherever they are available.

GBRMPA, QPWS or other regulatory bodies and specialist advisors may undertake an audit of particular manufacture and construction activities such as anchor manufacture and mooring installation to ensure the contractor completes the work in accordance with the contract plans and specifications, and with other conditions of the Marine Parks permit. The QPWS supervisor, through the superintendent, may consult with the project designers for assistance on technical matters.

Licences and approvals

In addition to the Marine Park permit for the installation, pontoon installation and salvage must comply with all local, state, and federal legislation and regulatory requirements relating to installation in a marine environment. Prior to installation of the facility, the proponent, contractors, agents or employees must obtain and comply with the restrictions or conditions of all licences and approvals for the work relating to noise, marine discharges, seadumping etc. (Chapter 3). Equipment and procedures must comply with all laws in force in the state of Queensland, including the requirements of the *Queensland Workplace Health and Safety Act*. All vessels associated with the pontoon installation must comply with Queensland Department of Transport survey requirements, and all vessel activity must be conducted in accordance with Queensland Department of Transport requirements. Contractors must hold insurance cover for company, public liability, marine and hull insurance, and workers compensation insurance.

The work is to be done in accordance with the drawings and specifications (Step 6). All activities are to be carried out in accordance with installation procedures agreed with the marine management agency.

10.2 Pontoon operation

The operational phase (Phase 4) of a pontoon project must be carefully managed by the tourism operator and the marine management agency to ensure all necessary function, safety and environmental objectives are met. Pontoon operations are undertaken in accordance with the project designs and environmental management provisions established as part of the *Feasibility Design* (Step 4) and *Detailed Design* (Step 6). This encompasses day-to-day activities such as craft movements, visitor recreation and waste disposal; emergency procedures associated with fire or tropical cyclone; and environmental monitoring and facility maintenance.

All pontoon operations should ensure that the coral and other marine ecosystems at the site are protected from physical disturbance, pollution or other impacts. Environmental aspects of the operation phase are principally concerned with effective implementation of environmental safeguards already established in the *Management Plan for Operation and Maintenance*. The pontoon operator should update the MP with final design and installation details prior to commencement of operation, and prepare and submit detailed operational procedures to GBRMPA setting out each aspect of daily operations. Facility monitoring will be undertaken as part of the inspection and maintenance provisions described below in Section 10.3.

Environmental monitoring of operational activities such as snorkelling and diving, fuel use and disposal etc. will be undertaken as part of the performance monitoring (Section 10.4) to ensure compliance with the MP.

The required provisions for pontoon operation are outlined below (Box 10.8) in terms of the activities and issues to be addressed, the operating safeguards and standards to be adhered to, and the mitigation measures that should be incorporated in the planning and design of the facility. Pontoon operations will be most successful, and impacts will be minimised, through adherence to strict operational and contingency plans approved by GBRMPA and incorporated in the Marine Parks permit for the facility. All activities are to be undertaken in accordance with the permit requirements, the provisions of the relevant zoning plans, regulations in force from time to time under the GBRMP Act, and the provisions of law in force in the State of Queensland.

Box 10.8 Provisions for pontoon operation <i>refer Step 9 of 10-Step Project Planning, Design and Implementation Procedure (Chapter 3)</i>	
Activity and issue to address	Provisions and mitigation measures for successful operation
<i>General provisions for the site</i>	
General provisions for the site and operation of the facility	Limits apply to the daily number of passengers and crew allowed to visit the site. Operational limits are usually dictated by conditions affecting passenger comfort rather than safety, ie. sea state and weather capabilities of the vessel exceeding the limiting conditions for passenger comfort determine whether or not guests are taken to the reef. Pontoon activities are to be carried out in accordance with the approved operational procedures, which are to be reviewed after commencement of operations on the pontoon. The operator shall maintain appropriate public liability insurance.
Publicity of Marine Parks , tourist program advice (eg. snorkelling) and safety procedures	Interpretive programs, static information displays, documentaries, and onboard videos are to be provided on the pontoon and transit vessel to publicise the Marine Park and instruct on recreational activities. Interpreters and translator machines usually offer commentaries in various languages.
Pontoon staffing and management , guest management and supervision	Management of guests on-site and in transit is undertaken by staff of the tender vessel, sometimes assisted by full-time personnel located on the pontoon, and helicopter/seaplane staff. The pontoon operation will usually be governed by limits on staff to guest ratios, applied by the operator. Pontoon staff require extensive maritime background, a first aid certificate, and certification to operate ancillary vessels. Pontoon staff are to be trained in procedures for fire, injury, oil spills, lost diver, rescue and vessel accidents. Pontoon staff are to participate in staff training programs, emergency and safety drills from time to time.

<i>Recreational activities to be conducted in or associated with the facility</i>	
Swimming and snorkelling The concern here is for swimmer and snorkeller safety, and minimisation of damage to coral communities from poor practices or inexperienced snorkellers.	Snorkelling and swimming is to be limited to clearly defined areas, marked by ropes and buoys, away from vessel routes and other potentially hazardous areas. Snorkelling trails are commonly established on-site through consultation between the proponent, a marine biologist and the management agency representative. Access to the water for swimming and snorkelling is usually obtained from a dedicated platform on the pontoon. The operator shall monitor the impact of snorkelling and, in consultation with the management agency representative, relocate the snorkelling area if necessary to allow recovery where damage occurs. Pontoon staff shall instruct swimmers and snorkellers on acceptable behaviour in the water to minimise impacts. Qualified snorkelling supervisors and safety advisors are to be employed to control activities and to assist pontoon guests with snorkelling techniques and swim safety.
Diving The focus here is on diver safety, and minimisation of damage to coral communities from poor practices or inexperienced divers.	Diving is to be limited to clearly defined areas away from potentially hazardous areas. Diver trails are commonly established on-site through consultation between the proponent, a marine biologist and the management agency representative. The resort divers' trail should be marked by a continuous line attached to fixtures such as stakes/star pickets driven into the substrate. Access to the water for diving is usually obtained from a dedicated platform on the pontoon or diving vessel. Pontoon staff shall instruct divers on acceptable behaviour in the water to minimise impacts. Qualified diving instructors and safety advisors are to be employed to control activities and escort resort divers, and to assist pontoon guests with local conditions and diving safety. All diving and associated equipment, and all diving activities are to be conducted in accordance with the diving standard and the <i>Workplace Health and Safety Act</i> .
Fish feeding The concern here is about the effects of the wrong food on wellbeing of the fish, and the threat of attracting large aggregations of predatory fish that could cause an ecological imbalance.	Fish feeding must only be conducted by pontoon personnel in accordance with set rules and management agency guidelines. The operator shall monitor aggregations of fish relative to natural densities.
Underwater coral viewing via semi-submersible vessels, glass-bottom boats and underwater observatory	The routes for the submarines or glass-bottom boats are to be clearly defined away from vessel routes and other potentially hazardous areas. The routes and the operating regimes for the craft are to be chosen to avoid vulnerable areas and to minimise the likelihood of damage to corals from collisions with the reef. The operator may implement monitoring of vulnerable areas using still photos, tagged corals and video. Reef interpretation and commentary on underwater coral viewing is usually provided by a marine biologist.
Whale watching Opportunities are often available during the whale migration season.	The operator must have a specific permit to undertake whale watching activities. Whale watching activities shall be undertaken in accordance with the relevant legislation, Queensland Transport survey requirements, and with marine management agency guidelines.

<i>Vessels or aircraft, including ancillary vessels, to be used in the operation</i>	
Ancillary vessels to be used in the program, eg. semi-submersible coral viewing craft	Areas of operation, operating hours and limiting weather conditions for the craft are to be clearly defined. Operators shall maintain Queensland Marine Board survey requirements for all vessels and comply with survey limitations on the maximum number of passengers and crew. Vessel masters shall be appropriately certified and crewmembers shall meet all regulatory obligations for operation of the vessels.
Vessel access to/egress from pontoon facility	Catamarans and other transit vessels shall follow designated routes from port to the reef pontoon site, and return. Channel markings shall be placed at the site to define normal access and egress routes through the reef to and from the pontoon. Designated routes shall be provided for ancillary vessels in order to separate them from passenger and swimming areas. Adequate berthing is to be provided alongside the pontoon for the certified tender vessel, eg. catamaran. Vessel manoeuvring and docking shall be undertaken in a manner to minimise disturbance of bottom sediments. Pontoon and vessel staff will be required to assist passengers in vessel berthing/departure, disembarking and embarking of guests, loading and unloading of supplies.
Helicopter and seaplane access and scenic flights Helicopter access may be available to a helipontoon at the site.	The operator must have a specific permit to undertake helicopter and seaplane operations, and shall comply with relevant Civil Aviation and Safety Authority standards. Aircraft or helicopters are not permitted to fly directly over the pontoons on arrival or departure. Helicopter and aircraft pilots will usually be required to advise pontoon operators in advance via radio/phone communication on passenger numbers and requirements for pontoon visits. Pontoon operators will usually be required to advise helicopter and aircraft pilots in advance on sea conditions (wind, tide etc.) for pontoon visits. Pontoon operators may be required to assist in the transfer of helicopter and seaplane passengers and aircrew to and from the pontoon via passenger transfer vessels.
<i>Facilities, equipment and procedures including overnight accommodation</i>	
Overnight guest and caretaker accommodation	Where provided, overnight guest and caretaker accommodation must comply with the facility and safety requirements of the <i>Sea Installations Act</i>. The pontoon operator shall develop detailed operational procedures for accommodation facilities, setting out each aspect of the accommodation manager's and caretaker's duties, and addressing specific health and safety aspects at times when the main passenger vessel does not attend the pontoon. The operator shall define the means of communication with the caretaker, and emergency procedures for the pontoon, including contingency plans in adverse weather conditions.
Miscellaneous pontoon facilities and equipment	Communication equipment provided on the pontoon or tender vessel may include cellular telephone, car phone, VHF radio transmitter and HF radio. Navigation aids on the pontoon shall include anchor lights during periods of darkness, and a radar reflector mounted on the highest section of the pontoon superstructure. Power will usually be supplied to the communication equipment and nav aids via battery banks and a solar cell charger.

<i>Operation and maintenance procedures for miscellaneous pontoon facilities and equipment, and for transit and ancillary vessels</i>	
Day to day management and maintenance of miscellaneous pontoon facilities and equipment, other than moorings and structures	Inspect, service and maintain all machinery daily as outlined in the daily equipment checklist prepared by the operator. Check fuel, water and sillage levels and complete daily logs, including engine room logs. Prepare and reinstate equipment and facilities (eg. furl shade sails) prior to passenger arrival and after departure. Reinstate swim and dive facilities, and clean, service and restore snorkelling and diving equipment daily. All guest areas are to be cleaned, equipped and ready for use at all times. Wash pontoons down with salt water when deemed necessary. Monitor weather conditions daily and record in log.
Transit and ancillary vessel maintenance, eg. catamaran and semi-submersible coral viewing craft	Provide vessel and mooring maintenance schedule, procedures and controls to ensure proper operation and maintenance, and to avoid environmental harm and structural and safety damage. Clean, inspect, service, refuel and maintain ancillary vessels in accordance with the daily vessel checklist prepared by the operator. Complete vessel maintenance sheets and give notification of any mechanical faults or major repair requirements. Relocate ancillary vessels daily from overnight moorings in readiness for berthing and operation alongside the pontoon.
<i>Transfer, use and disposal of fuels and other consumables, effluent and waste</i>	
Liquid waste handling and disposal The concern here is the potential impact on water quality (particularly an increase in nutrients) and the resultant impact on corals.	Public toilet facilities are provided on the main vessel but are not normally provided on the pontoon. Fresh water showers, without soaps or shampoos, and with waste discharge directly to the sea, are provided for guests to rinse off salt water. No sewage, effluent and liquid wastes except those from the freshwater showering facilities are to be discharged into the sea adjacent to the reef. Sillage from daily washdown of cooking areas and cleaning of storeroom and machinery space, and pontoon food service area sinks are to be drained to holding tanks on the pontoon. Permanent caretaker facilities (where applicable) will usually be equipped with a portable chemical toilet, shower, wash basins, sink, and washing machine. Liquid wastes will be collected in sillage tanks on the pontoon. Liquid wastes from the pontoon holding tanks will be pumped daily into the passenger vessel holding tanks, which will be discharged on the return voyage to the mainland or disposed of in onshore sewage facilities on return to port, according to the management agency requirements.
Solid waste handling and disposal The concern here is the impact of litter and the potential impacts on water quality and corals.	All solid wastes/garbage associated with the operation, maintenance or modification of the facility shall be taken on board the passenger vessel for disposal on return to port. Ensure that the sea floor in the vicinity of the facility is kept free from waste that may be lost or thrown overboard from vessels using the facility, or lost or thrown from the facility during operations or maintenance.

Pollution control The concern here is the affect of degraded water quality on corals and other organisms.	Ensure that anti-fouling preparations are not applied to the pontoon or any fixed structure at the site, as some leaching can be expected to occur over time. Anti-fouling paint may be used on the visiting vessel without experiencing pollution problems. Some effect on water quality may be expected from sunscreens and food grease from up to 500 daily visitors, although regular dispersal of pollutants should occur as a result of current flushing.
Transportation, handling, storage, use and disposal of fuels, consumables and other toxic and chemical substances	Few toxic substances are normally stored and maintained on the pontoon. Shipwash, biodegradable detergents, toxic and chemical substances for cleaning and maintenance purposes are normally carried on the catamaran. High pressure hoses should be provided on the catamaran, along with treatment agents and detergents to break up any minor fuel and oil spills. Tankage for bunkered fuel and oil tanks on the catamaran shall be separate from the main hull of the vessel. Handling, storage and use of toxic and chemical substances shall be in accordance with the manual of chemical use, Queensland Transport requirements, and the code of practice for the management of hazardous substances at work under the <i>Workplace Health and Safety Act</i>.
<i>Health and safety standards and provisions for emergencies</i>	
Safety standards and provisions for pontoon and associated vessels	Safety equipment shall be installed and maintained in accordance with Queensland Transport survey, and workplace health and safety requirements, and a schedule of equipment shall be recorded in a safety manual describing the equipment and its recommended use. Safety drills are to be conducted in accordance with clearly defined procedures. The pontoon shall be fitted with appropriate fire-fighting equipment. First aid and emergency provisions should be made, with the ability to conduct medivac to all operators in the adjacent reef area. Vessels must be operated by qualified masters. Propellor guards shall be fitted to the vessels to eliminate accidental contact with wayward swimmers, mooring lines or underwater obstructions.
Injuries to passengers and staff	In the event of injury, the extent of injury should first be determined, and the established treatment, therapy and evacuation procedures should be followed. The diving instructor must have current advanced certification in CPR and be responsible for maintaining oxygen therapy equipment, and administering if necessary. Minor accidents on board the pontoon or the catamaran will be treated by the crew, who should all be trained in first aid procedures. A procedure for search and recovery of missing and overdue swimmers and scuba divers should be adopted. Evacuation procedures for heart attack, stroke and other serious injury should be arranged in conjunction with the local ambulance, the State Emergency Service, helicopter emergency services, or the Royal Flying Doctor service, as appropriate. Injuries and other mishaps to passengers and staff shall be reported to the relevant authorities and recorded in a logbook on the pontoon.

Emergency operations and management, for equipment failure, fire, explosion, oil or fuel spill, accidental damage, grounding, collision of vessels, and other vessel incidents	All emergency, health and safety procedures for the facility shall be clearly documented. In the event of an explosion or fire, pontoon operators should assess the situation, determine the extent of damage and/or injuries, and take appropriate action. In the case of fire, shut down the remote fuel shut offs and air dampeners, use the fire extinguishers or mobilise portable fire pumps etc. In the case of an oil or fuel spill, contain and clean the spill with absorbent materials, rolls, sorbent booms etc. If an emergency situation develops at the facility as a result of a vessel collision, grounding, breakdown or other incident, evacuation to a rescue boat should be undertaken in accordance with evacuation plans prepared in conjunction with Queensland Transport and Queensland Water Police. Communicate normal maritime standard distress signals and notify the relevant authorities in the case of an emergency. Spills, fires and other safety breaches shall be reported to the relevant authorities and recorded in a logbook on the pontoon.
<i>Contingency plans for safety, communication, and evacuation for adverse weather and other emergencies, eg. tropical cyclone, fire, explosion, collision, fuel and oil spills, equipment failure</i>	
Operation in strong winds, storms and rough seas	Travel to the pontoon site should be restricted, and operations cancelled if weather conditions exceed maximum operating parameters. Refer to Chapter 5 for a discussion on limiting conditions for vessel operation and passenger comfort and safety.
Emergency procedures and contingency plans for tropical cyclones and other adverse weather	Weather conditions should be closely monitored to provide early warning of low-pressure systems and slow moving depressions, which may develop into tropical cyclones. Emergency procedures are progressively implemented as the cyclone threat increases, normally on the basis of the Bureau of Meteorology categories for cyclone watch and warning. Conduct regular evacuation drills during the cyclone season and record outcomes in the pontoon logs. Where appropriate, develop appropriate procedures for implementing the cyclone mooring, such as quick release mooring connections to facilitate relocation of the pontoon to an independent cyclone mooring.
Emergency procedures for a Stage 1 tropical cyclone alert, an initial cyclone watch that may affect the area	Check and secure all moorings, pontoons, vessels, and plant located on the reef. Arrange regular reports on sea conditions for evacuation decisions to be made at the appropriate time. Ensure stores, water and fuel are topped up prior to departure of the last vessel.
Emergency procedures for a Stage 2 tropical cyclone alert, for which the tropical cyclone is still on course to affect the area	Clear decks, attach and secure loose facilities and ancillary components. Standby for evacuation of all personnel to port. Return vessels to mainland for shelter, weather permitting.
Emergency procedures for a Stage 3 tropical cyclone alert, immediately prior to evacuation	Undertake a final check on security of all facilities. Shut down and close off all plant and equipment. Gather personal items and logbooks and abandon pontoon by helicopter or catamaran.

10.3 Pontoon maintenance

A tourist pontoon facility in the tropical marine environment is subject to severe conditions such as tropical cyclone and storm loadings, marine organism attack, abrasion and corrosion. A maintenance program is therefore essential to monitor performance and inspect and replace, repair or adjust deficient components of the pontoon, mooring and other facilities, and repair damage that occurs to, or is caused by, the facility. Pontoon maintenance is aimed at meeting serviceability, function and structural integrity objectives, at avoiding threats to visitor or crew safety, and at protecting environmental and amenity values that may be affected by deterioration or failure of the pontoon, mooring system or other facilities. Neglecting maintenance may lead to deterioration of the facility and ultimately its failure to perform its desired purpose. Regular inspection and maintenance is required for the reasons outlined in Box 10.9.

Box 10.9 Reasons for regular inspection and maintenance

- establish the condition of facility components and the extent of deterioration
- confirm recommended acceptance/discard criteria for components
- evaluate performance of the facility against the agreed criteria
- ensure the safe and reliable long term performance of components in accordance with agreed criteria
- provide early detection of environmental impacts, functional problems or structural damage and to investigate their causes
- identify maintenance requirements and confirm whether modifications should be made to the facility
- minimise the chance of failures due to maintenance deficiencies
- reduce overall maintenance costs and avoid extensive problems
- build knowledge of this facility and provide information to assist practitioners in design modifications that may be required for future projects

Maintenance is carried out in Phase 4: *Operation, Monitoring and Review*, after installation is complete and operation commences. Maintenance must be undertaken in accordance with the project designs and environmental management provisions established as part of the *Feasibility Design* (Step 4) and *Detailed Design* (Step 6). The maintenance program incorporates monitoring and inspection activities that form part of the overall facility monitoring requirements outlined in the following subsections.

All pontoon maintenance activities should ensure that the coral and other marine ecosystems at the site are protected from physical disturbance, pollution or other impacts. Most potential environmental impacts associated with maintenance will have been identified during the feasibility design. Environmental aspects of the operation and maintenance phase are principally concerned with effective implementation of environmental safeguards already established in the *Management Plan for Operation and Maintenance*. The pontoon operator should update the MP with final design and installation details prior to commencement of operation, and prepare and submit detailed maintenance procedures to GBRMPA prior to maintenance commencing. Environmental monitoring is undertaken during operation to ensure compliance with these plans.

Provisions for maintenance are incorporated in the Marine Parks permit for the facility issued by GBRMPA, and the operator should ensure that all maintenance activities comply with the approved schedule and procedures, and are limited in their nature, scale and extent to those approved in the permit. The operator shall provide GBRMPA with a copy of reports of designated mooring inspections for the facility within a statutory period after these inspections, and notify GBRMPA within a statutory period of the occurrence of a significant event that may require maintenance inspection or activity. The operator shall then give prior notification to GBRMPA of significant maintenance activities that are proposed, including maintenance involving the use of chemicals, replacement of section(s) of the facility, and maintenance

activities that may cause environmental damage. The operator shall comply with any reasonable conditions given in writing by GBRMPA for conduct of this maintenance, and shall undertake other modifications to the facility that may be directed by GBRMPA with the object of mitigating impact(s) on public health, safety, user amenity or other matters. All maintenance activities are to be undertaken in accordance with the provisions of the relevant regulations in force from time to time under the GBRMP Act, and the provisions of law in force in the State of Queensland, including the *Workplace Health and Safety Act*. Some maintenance actions will require permits, and these requirements should be identified well in advance to avoid permitting delays.

Inspection and maintenance programs

Pontoon maintenance and associated inspection programs, undertaken as part of the overall facility monitoring requirements, are usually classified into three categories as outlined below. In all cases, where facility components or facility operations do not meet specified requirements or have failed structurally, the operator should upgrade operations, and/or replace the components with properly functioning components that meet the specifications.

Scheduled maintenance	This is part of regularly scheduled upkeep performed at intervals that are pre-established during the design phase or are based on project-specific needs. Maintenance activities (eg. cleaning marine growth from the pontoon hull) can be anticipated, scheduled, and funded well in advance.
Routine or remedial maintenance	This encompasses repairs to facility components that are triggered by the results of a regular (eg. annual) inspection. These maintenance activities (eg. replacement of chain where links are thinned by abrasion) are unlikely to be addressed during normal scheduled maintenance, but are not emergencies.
Event-driven or emergency maintenance	This involves maintenance or repair following storm events or emergencies that require immediate mobilisation to repair or prevent damage. Maintenance activities (eg. repair broken shackle or chain) may arise on an emergency basis in addition to scheduled or routine maintenance. The operator shall undertake a full inspection of the facility immediately following such events or emergencies.

Scheduled maintenance for the pontoon includes regular activities such as facility clean-ups and equipment servicing. These can be considered part of pontoon operations (Section 10.2).

Emergency maintenance requirements will be specific to the facility and to the event causing the problem or damage, and will be developed according to the actual situation. Scheduled maintenance and emergency maintenance, and maintenance of facility components and service vessels other than the mooring system are not discussed further here. Marine regulations require that vessels be subjected to regular survey to ensure they are maintained in a seaworthy and safe condition. The following subsections deal with routine or ***remedial maintenance*** for the pontoon mooring system.

Routine maintenance provisions for pontoon mooring system

Routine or remedial maintenance of the pontoon mooring system is triggered by routine inspections of the physical condition of the moorings, commencing at the time of installation and continuing as part of facility monitoring. The biophysical aspects of the facility performance are part of environmental monitoring (Section 10.4). The maintenance schedule incorporates a program of regular inspections, combining visual assessment, measurement and testing.

In situ visual inspections provide a general overview of condition, and the other inspection methods are based on defined criteria that specify the minimum condition, size or percentage wear before replacement. The maintenance schedule allows the operator to predict and budget for replacement, and the frequency of inspections may be able to be reduced if the performance history and expected rate of deterioration of the component warrants it. Guidance on appropriate inspection programs for mooring lines and connections is provided in BS 6349 Part 6 (19??) and API (1987).

The maintenance schedule normally incorporates an initial inspection immediately after installation, a visual inspection at monthly intervals, a detailed inspection at least every 3 months and after periods of bad weather, and an annual photographic and underwater video record. The features that are normally examined in the monthly and other routine inspections of the pontoon mooring system are outlined in Box 10.10. The monthly inspection involves a visual check of every component of the mooring system, and looks for initial signs of deterioration and movement in mooring chains, shackles, plates, mooring lugs, clump blocks and anchors. The other regular detailed inspections should be scheduled according to loading condition, service experience and design criteria. Some areas may require more frequent inspection because of severe loading, concern for corrosion and short fatigue life. The operator should pay particular attention to maintenance inspections for facility components that are not commonly used, such as the cyclone mooring systems (where applicable).

Mooring inspection requirements should be documented in the maintenance schedule according to reference number, component description, inspection type, and frequency. Inspections and maintenance activities are usually undertaken by a contractor on behalf of the pontoon operator, and audited by the marine management agency. Qualified diving personnel should undertake the underwater work, whilst above water mooring components can be inspected by others. Inspections should be conducted on a calm day with minimal platform or vessel movement. Results are recorded on standard maintenance report sheets, preferably adopting a separate record sheet for each mooring. Inspectors will record all findings and defects, and recommend maintenance and repair actions to the pontoon operator. On completion, the contractor provides proof of inspection to the marine management agency and notifies other agencies (eg. Queensland Transport) of modifications such as repair or additions to the mooring system. The contractor must seek approval from the operator and from the designer before undertaking any alterations to the mooring system, other than replacement of existing components.

Box 10.10 Provisions for pontoon routine inspection and maintenance <i>refer Step 9 of 10-Step Project Planning, Design and Implementation Procedure (Chapter 3)</i>	
Mooring system component	Provisions and mitigation measures for successful maintenance
Multi-leg pontoon mooring	Undertake inspections for each pontoon mooring leg, with acceptance criteria recommended by the designer and supplier. Inspect anchors, chains, anodes, shackles, dumper, pelican hook, lug, flexi chain, blocks, swivel, floats, and bridle. Record degree to which anchors or dumper blocks are buried, wear or distortion of components, mooring line tension, slackness of chains, and movement of components from the design position.
Issues of concern for wire rope sections	Look for broken wires or 'bird caging' of the strands. Examine the condition of rope strands at the entry into the socket boots used to terminate the wire ropes. Inspect sockets for corrosion, distortion and wear.

Chain sections	Look for chain link wear, corrosion, fatigue cracking, missing or displaced studs. Note the importance of the dip section of chain that is close to tangential to the seabed and which may be subjected to wear or abrasion due to contact with the seabed.
Sheathed or jacketed mooring lines	It is not possible to determine the condition of the material beneath the jacket. The purpose of the inspection is to verify the integrity of the jacket to ensure it is not cracked, torn or subject to serious chafing.
Connecting hardware consisting of fabricated plate connectors, tri plates or connecting links	Undertake a visual inspection for signs of corrosion, wear or distortion of the plate, link or pins.
Submersible buoys (not recommended for pontoon moorings lines)	Observe the weldments of the seam joints, the buoy segments and padeye connections.
Mooring and anchor maintenance	It is sometimes necessary to relocate dumper blocks and modify connections on mooring lines to provide a straight alignment or to fix locations to provide the best dampening effect. Periodically clean substrate material from dumper blocks and anchors. Apart from anchor point fixtures, ensure free unrestrained movement of the mooring lines is retained in accordance with the design intention.

10.4 Environmental monitoring

Monitoring of the development and operation of a tourist pontoon facility is undertaken in order to ensure satisfactory performance, and to determine development impacts of the structure and associated activities. A monitoring program documents the chronological aspects of a project, explains the reason for changes that occur, informs decision-makers, and provides for considered management responses. These activities help build a long-term picture of development impacts, which is useful in future decisions, and in other projects.

A monitoring program for the pontoon and associated facilities should be developed to reflect the desired objectives embodied in planning and design of the project. Short-term reactive monitoring provides an opportunity for early detection of damaging impacts in time to allow mitigation before the environment is degraded. Long-term monitoring is used to monitor natural changes and human-induced changes attributable to the facility, to trigger management actions that will minimise adverse effects, and to evaluate the continued operation and success of the facility. An environmental monitoring program may provide any of the following outcomes:

Modification of the facility	Significant changes in parts of the facility, such as addition or removal of components, or design changes to individual elements, might be needed.
Maintenance of the facility	Parts of the facility may require replacement or repair to avoid further damage.
Rehabilitation of the site	Bio-physical damage to the site caused by the facility may require rehabilitation.
No action	This is appropriate if the facility is generally performing as expected and is likely to continue to meet performance objectives.

Environmental monitoring and **facility monitoring** are undertaken in conjunction with installation, operation, removal or relocation of the facility in the *Implementation* (Phase 3), and *Operation, monitoring and review* phases (Phase 4). **Environmental monitoring**, which is described in this section, relates to the biophysical environment affected by the pontoon, and involves biophysical measurements of the pre-installation condition as part of *Baseline monitoring* (Step 7), inspections and observations during *Installation* (Step 8), and biophysical measurements during *Performance monitoring* (Step 9). **Facility monitoring** requirements, relating to function, safety and structural integrity aspects are outlined in Sections 10.1 to 10.3.

Purpose and scope of environmental monitoring

The intention of environmental monitoring is to undertake periodic surveys that will pick up changes to the environment. Although general, qualitative characterisation of integrity and quality might be sufficient in some areas, it is normal to estimate the extent of changes rather than merely demonstrate that changes have occurred. The extent of monitoring required depends on the goals and performance criteria for the installation as well as on the type of ecological system. A monitoring plan does not need to be complex and expensive to be effective, but it should be flexible enough to allow modifications where necessary to suit a change in conditions or new information that becomes available. A clear, meaningful monitoring plan with simple and unambiguous goals and objectives should be developed, and predetermined criteria and checklists determined for the key variables that are to be measured.

Monitoring may include inventories, measurements, condition assessments, technical analyses of data, and evaluations of habitat or populations. Monitoring methods and documented protocols are required for sampling design, sampling, and sample handling and processing in order to efficiently provide accurate and replicable data. Useful and accessible monitoring information should be made available to all interested parties.

An environmental monitoring and evaluation program should have the following features:

- pre-construction baseline survey and report on pre-construction conditions
- regular (eg. annual) inspections, plus inspections during (if possible) and after critical events
- a consistent set of observations using a consistent and repeatable methodology (eg. photographs and observation from known points, topographic survey on known transects, ecological sampling using consistent methods and intensity)
- a reporting and recording program that ensures monitoring and evaluation data are available for present and future use
- a mechanism for initiating rehabilitation or maintenance if required
- a mechanism for periodic feedback to practitioners

Monitoring plan design and monitoring report

The objective for environmental monitoring is development of a plan that clearly identifies information needs, the size of effect that is acceptable or unacceptable for particular activities and their impacts, and the expected reaction to perceived impacts. The minimum requirement for monitoring studies is to use multiple control sites and to sample before and after the development proceeds (modified BACI designs).

Control surveys at reference sites form an important part of baseline monitoring. The level of success of pre- and post-implementation comparisons of the system can only be judged relative to reference systems, as evaluation of the amount of change attributed to the installation must be based on established reference conditions. In the case of tourist pontoon installations, the control

sites are usually coral bommies located away from the influence of pontoon and people, selected to represent typical reef locations similar to the pontoon site. Multiple control sites are usually chosen because coral reefs and associated fish assemblages are naturally highly variable spatially.

Designing a monitoring program to evaluate the performance of an installation requires careful planning to ensure that sufficient information is collected. This requires choice of sampling locations, the measurements to be made, the techniques to be used, and how the results will be analyzed. The results of the environmental monitoring program should be presented in a report describing the general objectives and scope of the monitoring program, the methods used and the results obtained. The standards for the various environmental parameters, against which changes to the environment can be assessed, should be presented. The monitoring report should outline the monitoring methods and the timing and reporting schedule. The proposed management responses where the standards are not being met, should be described. The document is meant to serve as an interpretative report, synthesizing the field and laboratory data analysis results. Technical analyses in a monitoring report should reflect the objectives for the facility and identify and discuss options to address deficiencies, such as modification of mooring lines if impacts exceed a particular level.

Environmental monitoring program for tourist pontoons

Environmental monitoring is mandatory for all major structures in the GBRMP. The monitoring protocol for tourist pontoons now advocated by GBRMPA has been scaled down from previous monitoring programs, which had a largely exploratory purpose. Repeated monitoring of things such as the effect of shading on corals has already been undertaken extensively at various sites. These and other pontoon monitoring studies indicate that well-run pontoon operations do not cause major impacts on hard corals in the short to medium term. Nevertheless, it is necessary to continue monitoring pontoon operations because reef managers do not know about long term impacts (10 years and over), and not all pontoon operations are necessarily well run. It is essential to have some form of monitoring data to detect unforeseen natural or human induced impacts on the reef, and to make sure all pontoon operations are being run in an ecologically sustainable way.

GBRMPA requires that the proponent develops and implements an environmental monitoring plan for construction and operation of the pontoon facility, incorporating the designs for *Baseline monitoring* (Step 7) and ongoing short-term and long-term *Performance monitoring* (Step 9). The monitoring plan will usually be specific to the pontoon site but may form part of a general monitoring program for the adjacent area. Environmental monitoring incorporated in the plan will be based on terms of reference prepared by GBRMPA, will be subject to independent review prior to adoption, will be funded by the proponent, and will be undertaken by a consultant contracted to GBRMPA. The environmental monitoring plan forms part of an overall ***Environmental Management Plan*** for the facility, and should be updated with final design and installation details prior to commencement of *Baseline Monitoring* and again prior to *Performance Monitoring*.

A range of matters would typically be assessed in the baseline and performance monitoring, although not all matters will be covered for each pontoon project. Monitoring of the physical and biological environment will concentrate on the direct impacts of the pontoon on benthic assemblages (mostly corals), fishes and water quality. Subject to compliance with the current GBRMPA protocol for tourist pontoons, the monitoring program for any particular site should focus on the areas identified in Box 10.11. Much of the information that follows in this section is based on the GBRMPA monitoring protocol (GBRMPA 1998).

Box 10.11 Environmental monitoring provisions for tourist pontoons <i>Source: GBRMPA monitoring protocol (1998)</i>	
Focus area	Monitoring provisions
Abrasion and disturbance by anchors and chains	Monitor impacts from movements of the mooring chains, dumper blocks and anchors. Determine the effect on the boulders and coral bommies situated in the vicinity of the mooring lines under and adjacent to the pontoon.
Resort diving area	Monitor the effects of diving activities. Determine if resort divers are damaging prominent corals through physical contact. Monitor the edge of colonies on dive routes, near points of interest.
Snorkelling areas	Consider the impacts of snorkelling activities on the surrounding reef.
Pontoon footprint (area immediately under pontoon)	This is aimed at detecting the gross effects of the pontoon on corals. Document change in coral assemblages and benthos cover under the pontoon. Assume shading will be the main cause of impacts on coral cover.
Large aggregating fish	Undertake a fish survey to document changes in fish aggregation at the pontoon site and quantify the effects of the pontoon operation on the abundance of small benthic fish.
Water quality	Examine the effects of anti-fouling paint. Monitor changes in water quality associated with fish aggregations and large numbers of people.

Baseline monitoring (Step 7 of 10-Step Planning, Design and Implementation Procedure)

Baseline monitoring, undertaken prior to installation and operation of the facility, provides a quantitative background description of the physical and biological environment at the site, against which environmental impacts and changes to the facility can be measured and performances evaluated. This provides information about natural spatial and temporal variations for the site, and represents a baseline for short-term or long-term performance monitoring that may extend throughout and beyond the life of the project. The environmental performance of the facility is determined from this baseline of pre-existing conditions, and from subsequent comparisons during construction and operation.

The baseline (pre-installation) monitoring usually has to be in place for at least three months before pontoon installation commences or modifications are made to existing facilities. It is normally conducted after *GBRMPA Detailed Assessment* and approval of the Marine Parks permit application (Step 5), but may be done earlier in the project as part of the *Feasibility Design* (Step 4). Baseline monitoring activities should be closely integrated with, and use appropriate information from, the site bathymetric, substrate and ecological surveys undertaken as part of site investigations and condition assessment in the concept and feasibility phases (Chapter 4).

The baseline survey should encompass areas of the reef adjoining the pontoon that will be used for intensive snorkelling and diving activities, as well as at least two control locations away from the influence of pontoon-based activities. In normal circumstances, no special attention needs to be given to the footprint of the pontoon (the shaded area beneath the pontoon body). Significant coral colonies likely to be affected by pontoon shading should have been identified for relocation as part of earlier studies, and it is safe to assume that the majority, if not all, hard corals directly shaded by the pontoon will die after installation. By positioning pontoons over sand as much as possible, the effect of shading will be minimised, and it will normally not be necessary to devote resources to monitoring associated coral decline.

The baseline survey will include a brief description of the existing physical and biological environment that may affect, or be affected by, the proposal. The survey should establish the percent cover of sessile benthic organisms, and specific details of corals, including species, size and location of coral outcrops shall be recorded. Identification of hard corals must be at least to genus and life form, if not species level. The breakage levels of hard corals and the physical dimensions of selected hard coral colonies should be noted, along with the levels of coral stress and disease indicators, such as bleaching and white and black banding. The density of fish species typically associated with pontoons (eg. Spangled Emperor and Red Bass) should also be noted.

Installation monitoring (Step 8 of 10-Step Planning, Design and Implementation Procedure)

Environmental monitoring of the biophysical environment at the pontoon site will be undertaken in conjunction with facility monitoring of the pontoon structure and mooring system during and after pontoon *Installation* or modification of an existing pontoon facility (Step 8). Installation monitoring is undertaken by the QPWS environmental manager, who is responsible for ensuring that the requirements of the Marine Park permit are met, that agreed installation procedures are followed during installation and site testing, and that mitigation measures are employed to minimise the impact of the installation on the Marine Park.

Environmental monitoring during installation is primarily concerned with compliance with, and implementation of, environmental safeguards already established in the *Management Plan for Installation*. This may relate to damage to coral or substrate, physical damage to marine organisms, and other disturbance to wildlife, seabed and marine life that may occur as a result of relocation of corals, mooring and anchor installation, site testing, or other on-site activities. By referring to the baseline conditions established from the baseline surveys, the environmental manager will note any impacts due to the installation, and determine the appropriate management response.

Performance monitoring (Step 9 of 10-Step Planning, Design and Implementation Procedure)

Performance monitoring, undertaken during operation of the pontoon in the *Operation, Monitoring and Review* phase, forms part of the environmental monitoring plan developed in the *Feasibility* phase. Performance monitoring describes the physical and biological environment at the site, examines environmental impacts and changes to the facility, and provides a basis for developing mitigation strategies to minimise further impact. This may involve short-term or long-term performance monitoring that extends throughout and beyond the life of the project. Environmental performance of the facility is determined by comparison with baseline or pre-existing conditions established in the *Baseline Monitoring* (Step 7).

Performance monitoring is primarily concerned with compliance with, and implementation of, environmental safeguards already established in the *Management Plan for Operation and Maintenance*. This may relate to damage to coral or substrate, physical damage to marine organisms, and other disturbance to wildlife, seabed and marine life that may occur as a result of day-to-day activities such as craft movements, visitor recreation and waste disposal. Performance monitoring examines the impact of movement of mooring chains and anchor blocks on coral, the effect of pontoon shading etc. on the coral substrate, and the effect of snorkellers and divers on the coral.

Performance monitoring will be conducted immediately post-installation and during operation of the facility. In a similar manner to the baseline survey, the detailed monitoring surveys will be undertaken by a monitoring contractor, employed by GBRMPA and funded by the proponent. It

is preferable to use the same contractor for all detailed surveys wherever possible to maximise comparability between surveys. Detailed surveys and site inspections should be carried out in the same season each year to minimise the variation from seasonal change in algal biomass.

Post-construction monitoring and audit is usually undertaken immediately after installation to check the validity of environmental predictions and to ensure environmental protection measures are well founded and are being properly implemented. The marine management agency should conduct a site inspection as soon as practical after installation, and concentrate on signs of impact from the pontoon installation procedure, not on impact from day to day operation of pontoon. After the post-installation inspection, the marine management agency should conduct a site inspection once per year. This monitoring will concentrate on coral breakage levels and indicators of coral stress and disease for comparison with the baseline survey. The percentage cover of sessile benthic organisms does not need to be measured directly, but can be described using a pre-defined set of categories. A brief report should be prepared for distribution within the marine management agency and to the operator.

No further immediate action is necessary if annual inspections reveal nothing of concern. GBRMPA will commission a more detailed survey if the results of the inspection indicate significant human-induced changes may have occurred since the baseline survey. The detailed survey will follow the design of the baseline survey, and will be conducted for the marine management agency by the designated environmental contractor. Further action by GBRMPA will depend on the results of the detailed survey. Assuming no detailed surveys are triggered as a result of the annual inspections, further detailed surveys following the design of the baseline survey will be commissioned according to a schedule to be developed by GBRMPA. These surveys should be conducted at approximately five year intervals, with the actual timing dependant on the term of the Marine Parks permit, such that the final survey occurs 6 to 12 months before the permit is due for renewal. Further action by GBRMPA will depend on the results of the detailed survey, which will be used to determine whether or not the permit should be renewed, or if conditions should be changed if the permit is renewed.

10.5 Recommended reading

- American Petroleum Institute. 1987. *API RP 2P-87 Recommended practice for analysis of spread mooring systems for floating drilling units, ANSI/API RP 2P-87.*
- British Standard 19??, *BS 6349 Part 6.*
- Bureau of Meteorology. *Categories for cyclone watch and warning.*
- GBRMPA 1998. *Protocol for Environmental Monitoring for Tourist Pontoons.*
- Nelson VM, Mapstone BD. 1998. *A review of environmental impact monitoring of pontoon installations in the Great Barrier Reef Marine Park, CRC Reef Research Centre Technical Report No 13.* Townsville, CRC Reef Research Centre, 85 pp.
- Sweatman HPA. 1996. *Impact of tourist pontoons on fish assemblages on the Great Barrier Reef, CRC Reef Research Centre Technical Report No 5.* Townsville, CRC Reef Research Centre, 54 pp.

APPENDIX A MARINE PARK LEGISLATION AND MANAGEMENT

Box A1 Legislation relevant to tourist pontoons on the Great Barrier Reef		
Legislation	Where it applies	Relevance to pontoon installations in GBRMP
Commonwealth Acts		
<i>Australian Heritage Commission Act 1975</i>	Great Barrier Reef Region, incorporating the GBRWHA minus Queensland islands and internal waters	Protects items of cultural and natural heritage listed on the National Estate; requires consideration of feasible and prudent alternatives before taking action or making decisions which may adversely affect National Estate Property
<i>Environment Protection and Biodiversity Conservation Act 1999</i>	Great Barrier Reef World Heritage Area and adjoining properties	Requires environmental assessment of actions in or adjacent to a World Heritage Area which have, will have, or are likely to have a significant impact through loss, degradation, or diminution of integrity or authenticity of one or more world heritage values
<i>Environment Protection (Impact of Proposals) Act 1974¹</i>	Australian lands and waters	Ensures that matters significantly affecting the environment are fully taken into account by or on behalf of the Australian Government
<i>Environmental Protection (Sea Dumping) Act 1981</i>	Seaward from the 3NM Territorial Sea (3NM from the mainland or Qld islands)	Prohibits dumping of waste or other matter at sea unless a permit has been issued, and regulates disposal of dredge spoil and construction of artificial reefs
<i>Great Barrier Reef Marine Park Act 1975</i>	Great Barrier Reef Marine Park	Provides for administration of the Marine Park, conservation of the Reef and regulation of activities that use or exploit the Reef
<i>Native Title Act 1993</i>	Australian lands and waters	Provides for recognition and protection of native title and a mechanism for determining claims to native title that may affect planning and management of installations
<i>Sea Installations Act 1987</i>	Seaward from the 3NM Territorial Sea	Ensures activities relating to sea installations will not interfere with navigation, fishing or conservation of resources of the sea or seabed; reduces the threat and rectifies the damage caused by a sea installation threatening safety adversely affecting the environment; requires removal of unauthorised fixed structures and making good of damage caused by the installation
<i>World Heritage Properties Conservation Act 1983¹</i>	Great Barrier Reef World Heritage Area	Provides for protection of natural and cultural properties in the World Heritage Area
Note	1	After July 2000 these acts are replaced by the <i>Environment Protection and Biodiversity Conservation Act 1999</i>
Queensland Acts		
<i>Environmental Protection Act 1994</i>	State of Queensland	Provides for protection of Queensland's environment through an integrated management program that is consistent with ecologically sustainable development
<i>Fisheries Act 1994</i>	Queensland waters within the 3NM territorial sea	Provides for protection and management of fisheries resources in Queensland; possibly relevant to coastal developments, as it requires a permit for the removal of marine plants

<i>Integrated Planning Act 1997</i>	State of Queensland	Coordinates and integrates planning at the local, regional and state levels and manages the process by which development occurs
<i>Marine Parks Act 1982</i>	Declared areas of State Marine Park	Provides for conservation of marine areas and declaration of zoned marine parks for their sustained use and protection; may require preparation of an impact assessment study
<i>Nature Conservation Act 1992</i>	State of Queensland	Provides for nature conservation and species management through an integrated conservation strategy for Queensland
<i>Harbours Act 1955-1987</i>	Below high water	Requires approval under s86 for works on tidal land or waters

Box A2 Zones of the GBRMP and their objectives	
Zone	Objective
General Use A Zone	To provide opportunities for reasonable general use consistent with the conservation of the GBRMP; this is the least restrictive of the zones, providing for all reasonable uses including shipping and trawling; prohibited activities are mining, oil drilling, commercial spearfishing and spearfishing with underwater breathing apparatus
General Use B Zone	To provide for the conservation of the GBRMP while providing for opportunities for reasonable general use in areas that are free from trawling and generally free from shipping; this zone provides for reasonable use, including most commercial and recreational activities; trawling and general shipping are prohibited as well as those activities not allowed in General Use 'A' Zone
General Use Zone	Provides areas of Marine Parks for a diverse range of recreational and commercial activities, consistent with the region's long term conservation
Marine National Park A Zone	To provide for the protection of areas of the GBRMP while allowing opportunities for their appreciation and enjoyment by the public, including the limited removal of natural resources; provides for appreciation and recreational use, including limited line fishing; spearfishing and collecting are prohibited, as well as those activities not allowed in General Use 'B' Zone
Marine National Park B Zone	To provide for the protection of areas of the GBRMP while allowing opportunities for their appreciation and enjoyment by the public, free from activities that remove natural resources; this is a 'look but don't take' zone; fishing and all other activities which remove natural resources are prohibited
Marine National Park Buffer Zone	To provide for the protection of natural resources on some reefs while allowing the public to appreciate and enjoy those reefs while enabling trolling for pelagic species and to provide for areas through which ships may pass
Habitat Protection Zone	Provides areas of Marine Parks free from the effects of trawling, while allowing for a diverse range of recreational and commercial activities
Estuarine Conservation Zone	Provides for estuarine areas free from loss of vegetation and disturbance and from changes to the natural tidal flushing regime, while maintaining opportunities for commercial and recreational activities
Conservation Park Zone	Provides areas of Marine Parks which allow opportunities for their appreciation and enjoyment including limited recreational fishing
Scientific Research Zone	To provide for the protection of the GBRMP while allowing opportunities for authorised research to be carried out free from disturbance from other human activities; set aside exclusively for scientific research; entry and use for other reasons is prohibited

Buffer Zone	Provides protected areas of Marine Parks and allows opportunities for their appreciation and enjoyment; Buffer Zones allow mackerel trolling in areas adjacent to reefs zoned as National Park
Preservation Zone	To provide for the preservation of areas of the GBRMP in their natural state undisturbed by human activities; all entry is prohibited, except in an emergency, with the exception of permitted scientific research, which cannot be conducted elsewhere

Box A3 Permit Assessment Criteria under GBRMP Regulation 18AC(4)		
Consideration	Reg	Assessment criteria
Location	(a)	The objectives of the zone
Existing use and future options for an area	(e)	The nature and scale of the proposed use in relation to the existing use and amenity, and the future or desirable use and amenity of the relevant area and of nearby areas
	(c)	The likely effect of granting permission on future options for the Marine Park
Aboriginal and Torres Strait Islander interests	(b)	The need to protect the cultural and heritage values held in relation to the Marine Park by traditional inhabitants and other people
Environmental impacts	(d)	The conservation of the natural resources of the Marine Park
	(f)	The likely effects of any proposed use on adjoining and adjacent areas and any possible effects of the proposed use on the environment
Liability of the GBRMPA	(h)	In relation to any structure, landing area, farming facility, vessel or work to which the proposed use relates: (i) the health and safety aspects involved including the adequacy of construction, (ii) the arrangements for removal upon expiration of the permission for the structure, landing area, farming facility, vessel or any other thing that is built, assembled, constructed or fixed in position as a result of that use
	(i)	The arrangements for making good any damage caused to the Marine Park as a result of the proposed activity
	(l)	The capacity of the applicant to satisfactorily develop the project
Other considerations	(g)	The means of transport for entry into, use within or departure from the zone or designated area and the adequacy of provision for aircraft and vessel mooring, landing, taking off, parking, loading and unloading
	(j)	Any other requirements for ensuring the orderly and proper management of the Marine Park
	(k)	Any charge payable by the applicant in relation to a chargeable permission (whether or not in force) that is overdue for payment

APPENDIX B TECHNICAL DATA SUBMITTED TO GBRMPA FOR ASSESSMENT

Box B1 Information to submit to GBRMPA for preliminary assessment - Steps 2 and 3 (refer to 10-Step planning and design procedure and description of individual tasks for further detail)	
<i>Note: list applies to new projects; omit information, as appropriate for upgraded projects</i>	
Data	Description
Project identification	Project title Name and contact details of proponent(s) Company name and registered address (ACN #) Brief description of proposal including location, objectives and background
Zoning and conditions	Location in Great Barrier Reef Marine Park Tenure and zoning of marine and land areas proposed for use, eg. General Use 'B' zone, Mackay/Capricorn section Previous and existing marine park permits
Market potential	Relationship of proposal to other operations in the area Usage of the reef by proponent, other operators, general public Include type and location of any other existing facility or tourist operation Other potential uses of the proposed site that would be foregone or affected if the proposal proceeds
Site location	Preferred location for pontoon facility Listing, in order of preference, of any alternative locations suitable for the proposal Details of the site including any other facilities operated in the area within a radius of 5km of the preferred site Site constraints, particularly those that may affect the pontoon design, anchoring system and subsequent operation of the facility
Facility operations	Activities to be conducted in or associated with the facilities, eg. Swimming, snorkelling, scuba diving, semi submersible Details of vessels or aircraft to be used for transportation in the marine park Equipment including ancillary vessels to be used in the operation (indicate - locations on site plan) Any accommodation on the structure(s) Number of persons per day expected to use the facilities Expected average and maximum numbers of persons using the facility (seasonal variation) Expected frequency and duration of use Details of existing uses of area where operation is planned Proposed future development or expansion Foreseeable location and likely extent of expansion
Facility description	Describe surface and underwater facilities such as boat moorings, snorkelling, diving, viewing chambers Identify shelters, toilets, accommodation, swimming platforms, vessel anchoring points and waste treatment/storage
Layout and configuration	Aerial photographs showing site and surrounding coral formations Map of location showing natural features, existing structures and proposed facilities Sketch or artist impression of facilities Preliminary layout of pontoon and mooring relative to reef Mooring configuration for cyclone conditions, including alterations to mooring arrangements where appropriate
Design details	Mooring design information (Chapter 7) Anchor design information (Chapter 8)
Site characteristics	Site plan showing degree of exposure, currents and tides Cyclone characteristics for the proposed site Preliminary estimates of design winds and design waves Preliminary geotechnical information for the site

Environmental impact	Likely environmental impact of operation including effects on other users Effects of operation on use of general public Preliminary assessment of likely impact Methods of mitigating and monitoring environmental impacts Alternative sites or configurations
Implementation timetable	Proposed date for installation of facilities Proposed timetable for installation and necessary site activities Timing and relevant information on staged development if appropriate Proposed date for commencement of operations Construction and installation schedules

Box B2 Information to submit to GBRMPA for detailed assessment - Steps 4 and 5 [information additional to or at variance with information listed in Box B1 for preliminary assessment] (refer to 10-Step planning and design procedure and description of individual tasks for further detail) <i>Note: list applies to new projects; omit information, as appropriate for upgraded projects</i>	
Data	Description
Facility operations	Activities to be conducted in or associated with the facilities Equipment to be used (indicate locations on site plan) Any accommodation on the structure(s) Number of persons per day expected to use the facilities
Alternatives	Describe any prudent and feasible alternatives that were considered Describe any alternative locations or designs considered for the proposal Outline reasons for rejection of alternatives in favour of the preferred site and/or design
Facility description	Describe surface and underwater facilities such as boat moorings, snorkelling, diving, viewing chambers, flotation chambers, windows Identify awnings, shelters, toilets, accommodation, swimming platforms, vessel anchoring points, anti-bird devices and waste treatment/storage
Layout and configuration	Aerial photographs showing site and surrounding coral formations Map of locations showing natural features, existing structures and proposed facilities Sketch or artist impression of facilities Layout of pontoon and mooring relative to reef Mooring configuration for cyclone conditions, including alterations to mooring arrangements where appropriate Arrangements for mooring of ancillary equipment
Site characteristics	Provide bathymetric plan of the site Provide ecological information for the site Describe corals and other substrate - % coral cover under pontoon shadow Provide plans and diagrams showing ecological characteristics Provide geotechnical subsurface information for the site Provide plans and diagrams showing geotechnical characteristics
Hydrodynamic design studies	Define design wind, wave, water level and current parameters for prevailing and severe conditions in various directions Provide basis for hydrodynamic calculations Provide maps, drawings and diagrams showing hydrodynamic characteristics and conditions for the site

Design details	Naval architect drawings of pontoon and superstructure Layout and description of mooring and anchor components Pontoon and mooring design calculations Maximum movement of moorings and anchors across the seabed Likely disturbance to substrate Mooring design information (Chapter 7) Anchor design information (Chapter 8) Pontoon body design information (Chapter 9)
Design report	Describe the project requirements, design concept, data used, assumptions made, and procedures and outcomes Provide a basis for review of acceptability by stakeholders Provide a basis for peer review of specialist designs where required
Certification of designs and operations	Written approval of relevant marine survey authority and classification society for safety, passenger/crew numbers, and other aspects of vessel operations Adequacy of design and structural soundness of the pontoon and its anchoring system Confirm operations conducted in accordance with prescribed government regulations
Installation and salvage	Submit the following in the <i>Management plan for installation</i> (Chapter 10): Details of on site construction and site constraints Installation methodology, plant to be used, and steps proposed to minimise coral damage Estimated salvage cost for removal of pontoon or mooring units from site if in good condition, or if totally wrecked and either stranded or sunk Demonstration that units can be removed from the marine park and disposed of (ie. auctioned, scrapped, dumped as landfill, etc) Description of recovery methods that are to have a minimal destructive effect on the natural resources of the marine park
Public information	Restrictions that might apply to the public Means of access to facilities Employment opportunities, numbers to be employed, skills required Method of publicising GBRMP in operations and encouraging support for the protection of the reef
Interaction with other operators	Details of services to be provided by other operators to users of the facilities Arrangements with other operators for sharing of facilities or services (fishing charter vessels, aircraft etc) Purpose and use of facilities by other operators, including number of persons involved
Accommodation and guests	Proposals for accommodation facilities, including number of persons and permanent or temporary basis Guest management and supervision including guest numbers and staff to guest ratio Identify passenger programs, management, controls, schedule of operations, numbers involved and activities undertaken (eg. Educational/ interpretation)
Facility operation	Submit the following in the <i>Management plan for operation and maintenance</i> (Chapter 10): Operational limitations on vessels and aircraft such as sea state/weather capabilities Practice and procedures for day-to-day operation of facilities and equipment (eg. Vessels, tenders, pontoons) Methods for use of toxic chemicals or paints (eg. Antifouling) and transfer of fuel and other consumables Procedure for disposal and removal of effluent or waste resulting from activities

Daily operation	Submit the following in the <i>Management plan for operation and maintenance</i> (Chapter 10): Program for typical day's operation Snorkelling and diving, fishing, glass bottom boat and dingy trips, use of small sailing craft, fishfeeding (locations, timing etc) Describe staff qualifications, skills, training and supervision
Emergency and safety arrangements	Submit the following in the <i>Management plan for operation and maintenance</i> (Chapter 10): Contingency plans for evacuation for adverse weather conditions and other emergency operation Means and limitations on access to and egress from facilities Warning times and evacuation procedures for staff in case of cyclone Procedure for injury to personnel (safeguards, lifesaving, first-aid, evacuation) Procedure for accidents to vessels and tenders (eg. Grounding, collision, fire, explosion, breakdown etc) Procedure for oil and fuel spills Roles and responsibilities of staff during emergencies Safety standards and equipment including measures to prevent accidents involving vessels Proposed nav aids, radar reflectors, lighting including night lighting Communication arrangements in event of accident or emergency
Maintenance and monitoring	Identify servicing and maintenance schedules and procedures for the pontoon and moorings Define surveys, inspections and personnel responsible for maintenance Outline the proposed environmental monitoring program
Bonds and insurance	Bond or bank guarantee and insurance provisions for pontoon operation Provide sufficient resources in the event that the permittee either defaults or is unable to remove the facility or clean up the site from damage caused by the operation