

Reef Breakwaters for Coastal Protection Safety Aspects and Tolerances

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Abstract

Submerged artificial reef breakwaters in the nearshore coastal zone can create the potential for a range of recreational activities as well as beach protection. As such, safety is an important issue when considering the design and construction of these types of structures. Investigations have been carried out for the proposed Palm Beach reefs and this paper provides an overview of the potential safety hazards and litigation threats presented by an artificial submerged structure to all potential users. Investigations into the safety aspects of these structures has incorporated:

- extensive monitoring of the Narrowneck artificial reef [Gold Coast, Australia]
- observations of natural reefs and beach breaks
- physical model testing of a 1:10 scale submerged reef constructed of sand-filled geotextile containers at the Deagon Hydraulics Laboratory.

The studies assessed the effect of a number of design parameters, including water depth above crest, roughness of the slope and truncation of the toe, on these safety aspects. The paper also covers the impact of achievable tolerances on the design, performance and safety of these structures and provides a number of guidelines for the design, management and maintenance of these structures in order to provide an acceptable level of risk.

1 Introduction

There has been an increased use of submerged artificial reefs in the coastal environment. Often, these structures are primarily for shoreline stabilisation and erosion protection, but increasingly they are being used to enhance the recreational and tourism value of a location, often designed specifically for a single recreation (e.g. surfing or diving). Regardless of its primary purpose, a submerged structure in the nearshore zone provides great potential for enhancing or creating favourable conditions for a wide range of recreational activities, including:

- Beach users
- Swimming
- Surfing
 - Body surfing
 - Body boarding
 - Short boarding
 - Long boarding
 - Kite surfing
 - Surf skiing / Kayaking
- Boating / Fishing
- Diving
 - Scuba Diving
 - Snorkeling
 - Spearfishing

As such, an important aspect of the design and construction of these types of structures is user

friendliness. Safety should always be a key consideration in the design of any coastal structure. Reef structures will attract surfers with varying degrees of proficiency, and the high variability in natural conditions makes it difficult for a novice surfer. The fact that the coastal zone is naturally hazardous can make risk assessment of any structure difficult. Additionally, the assessment of potential safety hazards needs to be carefully considered for all potential users [as well as the potential for increased user conflict].

2 Methodology

The guidelines for risk assessment of these types of structures, as outlined in this paper, is based on a range of data. These include:

- Observations of natural reefs and beach breaks;
- Extensive monitoring of the Narrowneck artificial reef [Gold Coast, Australia]; and
- Physical model testing of a 1:10 scale submerged reef constructed of sand-filled geotextile containers at the Deagon Hydraulics Laboratory. [results originally published by Tomlinson & Corbett, 2002]

2.1 Natural Conditions

When considering risk assessment of a recreational structure within the coastal environment, it should be considered that the

environment is subject to highly variable conditions. Natural beach breaks and rip systems present natural hazards to recreational users of the coastline, often presenting substantial risk depending on prevailing conditions. Natural rocky reefs and other submerged features can also offer substantial hazard.

Additionally, there is considerable variability in the ability of individual recreational users to deal with various conditions in a safe manner. In the case of offshore reefs, it should be considered that conditions in which it is safe to be out on a reef are often self-limiting [i.e. if conditions are severe enough, you often can't make it through the beach break to reach the reef!]

2.2 Narrowneck Reef Monitoring

The Narrowneck Reef [Gold Coast, Australia] was constructed in 1999/2000 out of over 400 sand-filled geotextile mega-containers [Figure 1]. Primarily a coastal control point, the reef had a secondary objective to "improve surfing" at the location. It was expected that the relatively shallow depths would limit the attachment of marine flora and provide little benefit in terms of fishing or diving, however rapid development of a diverse marine ecosystem has been observed [Jackson, Reichelt, Restall, Corbett, Tomlinson, & McGrath. 2004].



Figure 1: Aerial photo of Narrowneck Artificial Reef

The success of the Narrowneck Artificial Reef has demonstrated the potential for safe recreational benefits from these types of structures. It is popular with swimmers and a range of surfcraft [depending on prevailing conditions] and, with the development of a complex ecosystem, it is also very attractive to fishermen and divers, both scuba and snorkel.

Safety was an important consideration during the design of the Narrowneck Reef as there was little in terms of established guidelines for construction of these types of structures.

Initial designs with a crest level essentially at low tide were considered potentially hazardous, resulting in a lowering the design crest level by some 1.5m to reduce the potential for the reef to "suck dry" and surfers to impact with the reef structure as well as reducing potentially dangerous currents around and over the structure.

Monitoring of the reef since construction has been extensive and has included observations of wave breaking behaviour, monitoring of the shoreline using ARGUS cameras, surveys, regular dive inspections and ecological surveys as well as records taken by the surf life savers regarding beach usage, conditions and number of rescues.

In terms of safety, the wider beach has improved safety for beach users and records by Surf Life Savers indicates that, while use has increased by over 20%, rescues have decreased by 60%.

2.3 Physical Modelling

Physical model testing of a simple reef cross-section [Figure 2] was undertaken using a flume tank at the Deagon Hydraulics Laboratory in 2002. Profiles were tested under monochromatic waves with nominal prototype wave heights of 0.5, 1.0, 1.5 and 2.0m and a constant period of 10s. Testing was undertaken for crest levels of 1.0m and 1.5m below still water.

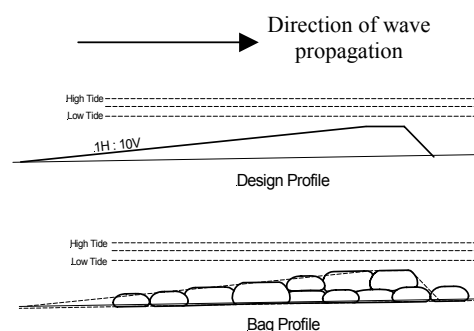


Figure 2: Physical Model Reef Cross-Section

Testing was to investigate wave breaking behaviour and associated safety issues with the structure. Testing of larger wave heights was not undertaken. Due to the fact that the 2m waves typically broke substantially seaward of the reef crest, it is considered that the risk experienced with waves over 2m are related primarily to the size of the waves rather than the presence of the reef.

Additionally, testing investigated the influence of using large geotextile containers for construction [and associated construction tolerances], the effect of truncating the toe of the slope and the potential for misplaced bags. A number of profiles were tested, including a smooth 'theoretical' profile and various profiles constructed of 1:10 scale sand-filled geotextile containers. [Figure 2]

3 Risk Assessment

Below are summarized a number of potential risks and an assessment of design and management guidelines to keep the risk to an acceptable level. These guidelines deal specifically with structures utilizing geotextile mega-containers for construction and are specifically relevant to highly dynamic coastlines similar to Australian conditions. While many of the risks will be relevant to all submerged reef-type structures, specific site conditions, likely usage of the structure and construction material should be fully considered when undertaking any risk assessment. It is the aim of this paper to provide some guidelines and general principles to those undertaking risk assessments for these types of structures. It is not an exhaustive document and further investigations should be undertaken for specific structures.

3.1 Risk: Impact with Reef when surfers dive off board

This risk of surfers impacting with the reef structure when diving off their board is primarily relevant for short boarders and long boarders. The key factor influencing safety is the depth of water above the reef in front of the breaker. Primarily, this is governed by the level of the reef crest. This is clear when you consider shallow natural reefs [e.g. Shark Island, Sydney, Australia], which are dangerous for surfers during lower tides. As shallower reefs are more effective in terms of beach protection and initiating wave breaking in a wider range of conditions, it is important that the safety aspects of crest height be fully considered.

There is little to govern acceptable water depths for surfing. FINA regulations suggest 1.8m is acceptable for diving in pools. Surfers have higher initial (essentially horizontal) speeds, however they also tend to fall off their boards rather than dive more vertically, reducing both the depth of the dive and the risk of serious injury (e.g. damage to the neck and spine). As such, they typically need less water for an equivalent level of risk.

Physical modeling indicated that the depth of water during backflow under the wave trough could be quite shallow depending on the level of submergence of the crest. For a crest level 1.0m below the still water level, water depths as low as 0.3m were experienced for a 1.5m wave. With the crest 1.5m below still water level, the minimum depth above crest varied between 1.2m and 0.9m. As wave conditions over 2m typically broke seaward of the reef crest for this water level, this is likely to be the minimum depth experienced on the structure.

In a three-dimensional environment, the formation of rips on the leeward side of the structure is likely to reduce flow seaward over the crest. Experience at Narrowneck [crest ~1.5m below low tide], however, indicates that the low water depths observed in the model are not only a function of the two-dimensionality of the flume. Water depths of ~1m have been observed with wave heights waves of approximately 1.5m [Figure 3]. While observations in typical conditions have not been substantially lower than this figure, reports indicate that the reef does "suck dry" [i.e. no water above crest] on rare occasions, typically associated with larger wave conditions.



Figure 3: Water Level during backflow at Narrowneck Artificial Reef (H ~1.5m)

3.2 Risk: Impact with Reef due to turbulent wave action in shallow water

Reef structures that initiate wave breaking over the structure create the potential for swimmers and surfers to impact with the structure if there is sufficient turbulent wave action. This is particularly relevant when the surfer gets caught in the break while trying to surf or when the swimmer / surfer ducks under a break where the turbulence extends to the structure itself. The risk is dependent on a number of factors, including the inception of wave breaking, the size and type of the break as well as the depth of water at the break point.

3.2.1 Inception of Wave Breaking

It is clear that the risk due to turbulent wave action is only relevant when wave conditions are such that breaking is initiated on the reef structure. As such, there is little risk during small wave conditions and for deeper reef structures as wave breaking does not occur.

Breaking on all reefs is highly dependent on tidal level [i.e. water depth over the reef]. Observations of the Narrowneck reef indicate that breaking is typically initiated at wave heights between 0.7m and 2.0m [Figure 4]. This equates to approximately 1.5 times the water depth at the crest.

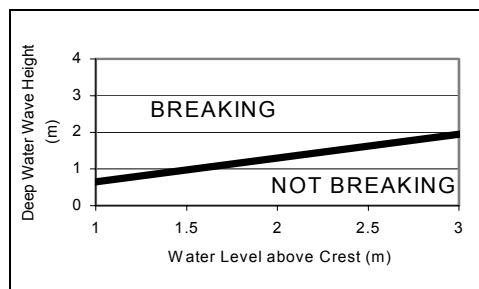


Figure 4: Inception of Breaking at Narrowneck

3.2.2 Breaking Wave Height

As is the case for natural beach breaks, higher breaking wave heights result in more powerful turbulence over a greater portion of the water column and, correspondingly, increased risk. This risk is further increased by the enhanced shoaling over the reef and the potentially close proximity of the structure in certain conditions. Breaker heights will vary substantially based on offshore conditions as well as aspects of the reef design.

3.2.3 Breaking Wave Type

Breaking wave type is also a significant factor influencing risk due to breaking-induced turbulence. It is generally considered that a more spilling wave is typically safer than a strongly plunging wave as it breaks gradually and turbulence is restricted to a relatively smaller portion of the water column. For plunging waves, higher breaking intensity contributes to increased turbulence and increased risk.

3.2.4 Depth of Water at Break Point

The depth of water at the break point is, perhaps, the most important factor when considering this risk. Shallower depths result in a greater portion of the water column becoming turbulent and increased likelihood

that turbulence will extend down to the structure itself. In this case, those caught in the break or trying to duck under it will have a much higher likelihood of impacting with the structure.

Where the water depth is greater than that required to initiate breaking, there is little risk. In larger conditions, waves tend to break seaward of the crest, resulting in a gradual deepening of the water at the break point. As these larger waves break in deeper water, the resulting risk of impact with the structure due to turbulence is reduced. The point of minimum depth generally corresponds to the largest wave to break on or very near the crest of the structure. Appropriate crest levels and associated water depths are discussed above.

3.3 Risk: Trapped underwater due to gaps in the reef

Where a reef structure is comprised of a number of individual components, there is the potential for a swimmer or surfer to become trapped between two units under the water. It is important that units are inspected to ensure that any gaps do not present a threat.

Specifically for geotextile mega-containers, observations at Narrowneck indicate that sand-filled containers of this size and shape [Figure 5] do not generally form gaps that would present a threat to swimmers and surfers and, as a result, the risk is relatively minor. This may not be the case with other construction materials.



Figure 5: Photo of Mega-Containers in Place

3.4 Risk: Drowning due to rips

Submerged artificial reefs have flow of water over the structure which results in rip cells in much the same way as sand bars, although they are also dependent on the interaction between the reef and adjacent sand banks. These rips present a risk to swimmers in the lee of the structure just as natural rips do.

Natural rip systems are highly variable in response to changing sand bar formations. In many conditions they present substantial risk. Rip currents surrounding submerged reefs, while still variable, are typically more stable than completely natural rip systems.

Observations at Narrowneck indicate that the patrolled areas are often directly shoreward of the structure, indicating that conditions in the lee of the reef are typically safer than the adjacent beach breaks. The decrease in recorded rescues since reef construction also confirms the improved safety conditions.

To ensure rip currents are acceptable, submerged structures should have relatively low crest levels, be located sufficiently far offshore and not be excessively long.

3.5 Risk: Dangerous marine organisms

In terms of dangerous marine organisms, the risk to users is typically comparable to that experienced at natural reef sites. Swimmers, surfers and divers should exercise the same caution at the reef site as they do in other locations.

At Narrowneck, a number of potentially dangerous marine organisms have been observed, including sharks and stingrays. The shark species in residence, however, are not the more aggressive varieties – typically Wobbegong [Figure 6], Port Jackson, Shovelnose & Lemon Shark. It should be considered, however, that species inhabiting artificial reefs will vary widely depending on location and construction material.

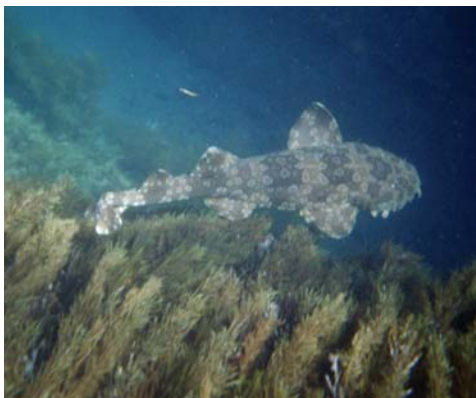


Figure 6: Photo of a Wobbegong on Narrowneck Artificial Reef

3.6 Risk: Vessel overturning due to sudden shoaling over reef

Artificial reefs that are popular for fishing will encourage vessels to anchor on the structure.

In addition to the potential damage to the structure by anchors, depending on the construction material, the anchored vessels are also vulnerable to the passage of larger waves that are substantially increased in height over a small distance due to shoaling over the reef, capsizing the vessel.

At Narrowneck, this has been addressed in a management framework after construction as the extent of marine growth and resulting popularity was largely unanticipated. A Notice to Mariners was issued and the reef itself has been declared a “no anchoring” zone, with three buoys placed to mark the reef [Figure 7].



Figure 7: Photo of buoy marking Narrowneck Artificial Reef

3.7 Risk: Conflict between recreational users

With so many users, there is always the potential for conflict between the many activities. For the most part, these conflicts are minimised by the observation that vessels and divers prefer calmer conditions when waves are not breaking while surfers prefer conditions in which waves are breaking. This leaves only the potential for conflict between vessels and divers [particularly skin divers and spear fishermen].

It is always recommended that divers exercise caution and swim with dive flags and buoys and vessels should also exercise additional caution when divers are present. In situations where this risk remains unacceptably high, however, vessel exclusion zones on the reef should be considered.

3.8 Risk: Fishing / Surf Rage

With natural locations suitable for surfing and fishing becoming overcrowded, there is an increasing presence of fishing and surf ‘rage’. By increasing the number of locations suitable for these activities, the pressure on natural sites and resultant ‘rage’ is, overall, reduced.

4 Other Design Aspects

4.1 Construction Tolerances

Construction using geotextile mega-containers similar to those utilised at Narrowneck has many advantages, however the sheer size of the containers limits achievable construction tolerances. As a result, physical model testing involved comparisons between a smooth 'theoretical' profile and an achievable 'constructed' profile of mega-containers.

As expected, the smooth profile had slightly larger breaking wave heights, as less energy is lost through friction and turbulence prior to breaking. The breaker on the smooth profile was also typically slightly further landward, although there was little difference between observed breaking types.

Similarly, transmitted wave heights were consistently larger on the smooth profile, with transmission up to some 15% higher for 0.5m waves and approximately 5% higher for waves over 1m. Thus, for structures that are primarily for shore protection, the 'constructed' profile of mega-containers achieves better dissipation and is actually superior to a smooth 'theoretical' profile.

In terms of safety, the lower breaking and transmitted wave heights indicate that the actual 'constructed' profile is typically safer.

4.2 The Effect of Truncation

The inherent value of the deeper sections of a reef profile and the potential for the profile to be truncated was investigated. This is particularly relevant when it is considered that mega-containers cannot fully replicate the very tip of a design profile as it merges with the seabed and the profile is essentially truncated to create a constructible profile.

In terms of the testing, the truncation was relatively mild and involved the removal of progressively 1 and then 2 containers from the seaward side of the profile. The containers removed were located at a prototype depth of ~5m below the still water level.

The truncated profiles typically initiated breaking further seaward and in a more spilling manner with marginally higher breaker heights, although these differences were slight. Differences in transmitted wave height were marginal at best, indicating that there is very little difference in terms of energy reflection and dissipation between the profiles.

It should be noted that more excessive truncation or truncation in shallower depths will have more of an impact on the

performance of the structure. Additionally, the effect of these deeper regions on transmission is likely to increase with larger wave heights, which were not tested. As such, they may affect the performance of primarily shore protection structures in these conditions.

In terms of safety, the slightly larger breaker heights are offset by the more spilling [and therefore safer] nature of the break and it is considered that truncation of the toe of the reef has little overall effect on safety.

4.3 The Effect of Misplaced Containers

In terms of testing, one container was misplaced by the equivalent of 1m, effectively 'roughening' up the slope. This was based on placement accuracies achieved at the Narrowneck Reef, which were typically sub-metre.

While there was no recorded difference in breaking wave height, the irregularities in the profile tended to initiate breaking slightly further seaward and with a more spilling breaker characteristic. In terms of transmission, the profile with the 'misplaced' container provided substantially increased dissipation, with transmission reduced by up to 15% [for a 1.5m wave height] in comparison to the smooth 'theoretical' profile. Thus, physical modeling indicates that the roughened slope due to misplaced bags actually improves the effectiveness of the structure in terms of energy dissipation.

In terms of safety, the slightly more spilling nature of the break indicates that 'misplaced' containers actually improve the safety of the structure and, with the lower transmitted wave height, safety shoreward of the reef is also improved. There is a potential, however, for misplaced bags to create gaps that could possibly trap swimmers or surfers underwater, although this risk is considered to be relatively low.

5 References

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