COFFS HARBOUR NORTHERN BREAKWATER – NOT YOUR AVERAGE UPGRADE

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Abstract

Muttonbird Island and the Coffs Harbour Northern Breakwater attracts over 100,000 visitors each year and is considered one of Coffs Harbour's most popular and important attractions for tourists and the local community alike. The Northern Breakwater also provides shelter for important assets, services and industries including a Marina and Slipway, Water Police and other Government Vessel berths, Fishermen's Coop, Moorings and Unloading Facilities, as well as restaurants and retail outlets.

This year the harbour precinct will play host to the Australian Offshore Superboats, the World Rally Championship and a number of other significant events - Coffs Harbour is considered to have some of NSW's most critical coastal assets.

In addition to these important social and economic considerations, the breakwater is also situated immediately adjacent to the Solitary Islands Marine Park. Both the breakwater and Marine Park are home to critically endangered species.

As the value of the coastal zone is increasingly recognised and the level of community interest in coastal management solutions continues to grow, the design and implementation of major upgrades of coastal infrastructure will increasingly require innovative solutions to achieve balanced technical, social, environmental and economic outcomes.

In particular, these sometimes opposing drivers will necessitate not only innovative technical design solutions but also innovative and transparent approaches to engaging the community, local industry and other stakeholders.

The upgrade of the Northern Breakwater has built upon the wealth of experience offered by coastal science and technology as a whole and now serves as an excellent case study for addressing similar challenges which will no doubt be presented during the implementation of future coastal management solutions.

This paper provides a summary of the challenges encountered during the development of the Northern Breakwater Upgrade Project as well as the innovative design and consultation solutions employed to deliver successful project outcomes.

Introduction and background

The Coffs Harbour Northern Breakwater was built in 1924 and provides pedestrian access to Muttonbird Island as well as to the Coffs Harbour Marina and the Coffs Harbour South Eastern Moorings. The structure is a major tourist destination for the region attracting over 100,000 visitors every year. The structure was built to protect and provide safe moorings for vessels and numerous built assets including the Coffs Harbour Marina, retail and food outlets, land owned and leased by Crown Lands and local industries such as the fisherman's co-operative.

The northern breakwater is subject to wave overtopping by relatively small waves from the north-east and by large waves from any direction. The highest rates of overtopping occur along the eastern half of the breakwater between Coffs Reef and Muttonbird Island (Figure 1). Current rates of wave overtopping are a risk to human life; have potential to cause damage to vessels and infrastructure and damage to the existing breakwater necessitating ongoing maintenance.

Department of Industry 'Lands' worked together with GHD to complete a Feasibility Study with the following objectives:

- identify options to effectively reduce the impacts and frequency of wave overtopping;
- improve the level of public safety to those using the breakwater; and
- minimise damage to the breakwater and maritime infrastructure behind the breakwater and in the marina in a cost effective manner.

Following completion of the Feasibility Study, GHD worked with Lands to develop a detailed design package. Construction activities commenced in May 2016 and are expected to be completed in mid- 2017 subject to favourable weather conditions.

The purpose of this paper is to provide a summary of the challenges encountered during the development of the Northern Breakwater Upgrade Project as well as the innovative design and consultation solutions employed to deliver successful project outcomes.

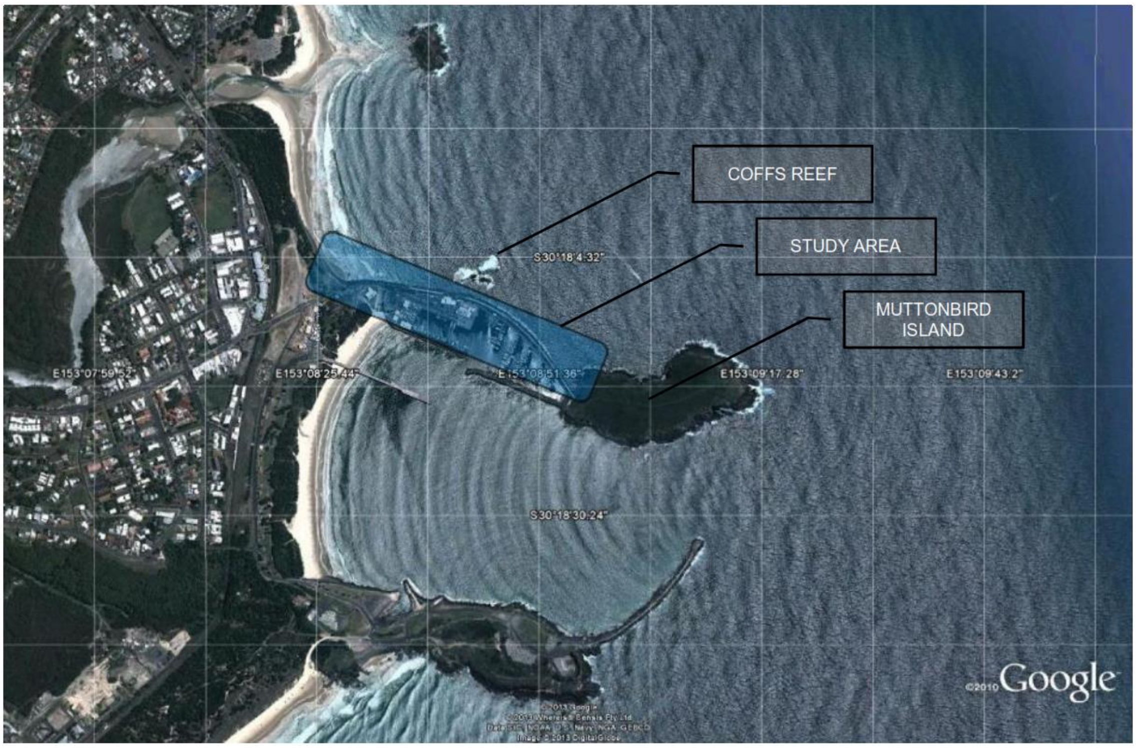

Figure 1 Study Area

Unique upgrade considerations

Coffs Harbour is considered to have some of NSW's most critical coastal assets and includes numerous social, cultural, environmental and commercial interests of regional significance.

Whilst many of these considerations are the primary drivers behind the upgrade of the breakwater, they also represent the following unique set of constraints and opportunities:

- Highest risk of marina damage due to overtopping of any breakwater in NSW
- Highest public visitation rates of any breakwater in NSW
- Regional tourist destination
- Only access to Muttonbird Island
- Public access to observe coastal migratory birdlife habitat, whale watching, dolphins, sea turtles, diving and snorkelling
- Aesthetics and preservation of views deemed critical
- Highly enthusiastic / interested community
- Unique cultural significance to the Gumbaynggirr people
- Only breakwater with a Nature Reserve at the head
- Adjoins Solitary Islands Marine Park
- Habitat for critically endangered species
- One of only six designated ports of arrival in NSW from overseas (others are Eden, Lord Howe Island, Newcastle, Port Kembla/Wollongong and Sydney)
- Supports the primary operational areas of Coffs Harbour (marina, slipway, co-op, Water Police, Customs, Fisheries, Marine Rescue)
- Immense community support for an artificial surfing reef
- Narrow existing crest width and constrained by harbour side marina
- Relatively deep water in close proximity to the structure
- Complex offshore bathymetry
- Complex and heavily modified sediment transport pathways

Design Strategies

Given the unique set of constraints and opportunities presented by the Northern Breakwater and surrounds, to achieve balanced technical, social, environmental and economic outcomes necessitated not only innovative technical design solutions but also innovative and transparent approaches to engaging the community, local industry, gaining environmental approvals and support from other stakeholders.

Presented in the subsequent sections is a summary of the innovative design and consultation solutions employed to deliver successful project outcomes.

Comprehensive Stakeholder Engagement

In response to the numerous social and aesthetic constraints and high level of community interest in the project, a comprehensive stakeholder engagement strategy was developed and implemented from project inception, throughout the design and construction phases of the project.

The aim of the stakeholder and community consultation was to present the potential upgrade options, and to identify values and concerns, as well as to seek feedback on adequacy, relevance and priorities, while achieving a high level of awareness, understanding, involvement and acceptance of the project overall. Consulting with key stakeholders and the community was considered critical in identifying and prioritising specific issues for Coffs Harbour Northern Breakwater Upgrade Options.

Consultation has been undertaken using a combination of the following methods:

- Stakeholder Engagement Workshops
- Community Information Sessions
- Community Information Sheets
- Onsite Signage and Artists Impressions
- Online Community Responses
- Monitoring email and telephone feedback
- User Group Meetings
- Community Liaison Group
- Discussion with local businesses and politicians
- Media releases, television and radio interviews

Priority issues identified through consultation included:

- Importance of aesthetics and preservation of pedestrian views
- Community desire for provision of recreational assets
- Opportunity to improve tourism prospects
- Impacts on the marine environment
- Improved community safety
- Reduced likelihood of property damage
- Emergency access during construction

In addition to the valuable information regarding the priority issues and preferred options, the initial community consultation revealed a disconnect between the project's primary objectives and the community's expectations.

From the community responses received, it was apparent that the Coffs Coast community was in favour of broadening the scope of the project to provide additional social and environmental benefits through the creation of a submerged artificial reef (as proposed in Option 4). Costing of the conceptual options however indicated that the construction of a submerged reef of this nature would require significantly more capital expenditure than alternative options, and the potential benefits in meeting project objectives were less certain.

Traditional and Alternative Design Solutions

In accordance with the original project brief the following upgrade options were considered for the Coffs Harbour Northern Breakwater:

- Option 1 – Construct a submerged berm at the toe on the ocean side of the existing breakwater;
- Option 2 – Raising the crest height of the existing breakwater;
- Option 3 – Construct a wave deflection barrier at crest level on the existing breakwater; and,
- Option 4 – Construct a submerged artificial reef in front of the existing breakwater.

Following development of the four basic upgrade options, it was agreed that consideration of additional hybrid upgrade options would lead to the development of a better tailored design solution which would offer improved technical, economic, social, political and environmental outcomes. It was also noted that refining the design solution at concept stage would minimise the risk of costly rework during the physical modelling and detailed design stages of the project.

The hybrid design options were developed with a focus on reducing rates of overtopping within the most exposed portion of the breakwater, whilst offering cost effective improvements in the lower risk zones. This approach focused available funds within the zones of highest risk to public safety and infrastructure.

The following three hybrid options were developed in consultation with Lands:

- Option 5 – Construct a submerged eastern toe berm and low-crested offshore breakwater at the western extent of the proposed works.
- Option 6 – Construct a submerged berm at the toe of the ocean side of the existing breakwater with slope upgrades along the most exposed section of the structure.
- Option 7 – Construct an armoured berm upgrade on the seaward face of the existing structure.

A technical peer review workshop was held involving industry recognised experts experienced in the design and construction of coastal structures. A key outcome of the workshop was to develop an additional option as follows.

- Option 8 – Construct a composite armoured berm consisting of a mid height rock berm combined with an upper armour layer constructed from Hanbars.

It is also important to note that prior to selecting the intial four options, Lands considered other potential solutions, in recognition of the ongoing sedimentation of the harbour and the ongoing need for dredging. One of these options included the use of the dredged material from the harbour to construct a sand berm on the seaward side of the northern breakwater to reduce the rate of overtopping.

Whilst Coffs Harbour City Council and members of the community indicated their support for a sand bypassing option, Crown Lands identified a number of significant drawbacks which excluded this option from consideration as part of this study. These included the cost benefit of this solution to specifically reduce the frequency of wave overtopping of the northern breakwater.

Overview of Preferred Upgrade Solution

The preferred Option 8 – a composite armoured berm upgrade – gernerally consists of a layer of concrete Hanbar armouring which will be constructed on top of a newly constructed rock berm extending from the seaward side of the existing structure at mean sea level. The crest of the breakwater will be widened and raised along the eastern portion of the structure.

Pedestrian views to the ocean will be retained with Hanbar heights ranging from 0.5 m to 1.5 m above the crest.

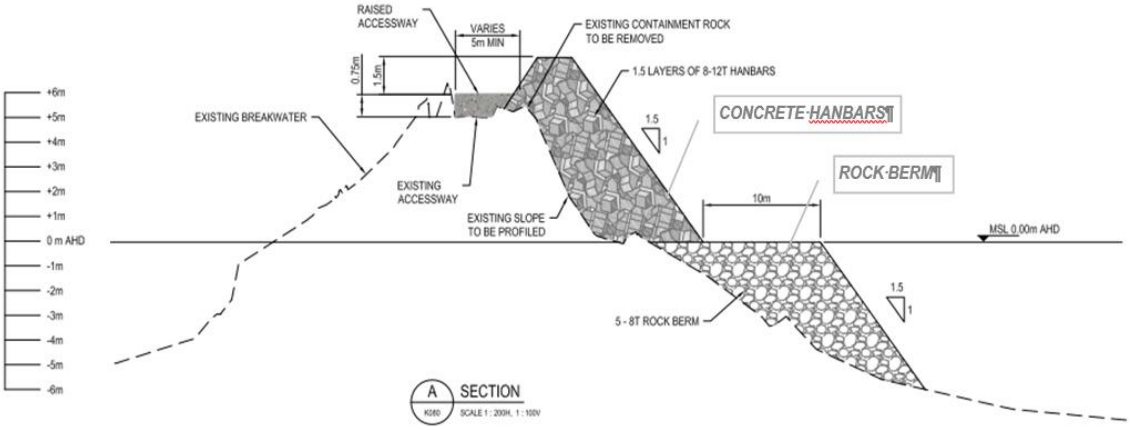

Figure 2 Typical Section of Proposed Upgrade (Option 8)

The rock berm will force waves to break seaward of the existing structure, whilst the concrete Hanbar armouring will increase the structure's freeboard above sea level and the absorption of wave energy, thereby minimising the amount of wave energy reaching the top of the structure. This will result in reduced frequency and magnitude of overtopping at the crest of the breakwater, and improved safety for those accessing Muttonbird Island and the Coffs Harbour Marina.

To construct this option, trucks will transport and tip the rock armouring for the berm into place from the existing crest structure before a long reach excavator would undertake rough profiling of the berm. Depending on the plant/equipment available, an alternative methodology would involve construction of an interim access berm at approximately +2 m AHD, from which the rock for the berm would be placed and profiled. The Hanbar armour units will be stockpiled at the existing casting yard located on the southern foreshore of Coffs Harbour, with the Hanbars transported to the northern breakwater via road. Trucks will then reverse along the crest of the breakwater where the Hanbars will be unloaded prior to their placement on the face and crest of the breakwater by an awaiting crane.

Along the western section of the breakwater, the existing natural reef to the north provides reasonably effective coastal protection for the breakwater, and the breakwater therefore does not require major upgrade works to improve energy dissipation or reduce wave overtopping rates. However, recent condition assessments have identified that upgrade works are required to maintain the structure into the future.

In addition, crest widening works are required to improve public safety and improve access along the breakwater and to Muttonbird Island.

Specifically, widening of the existing breakwater is required to provide access for large cranes and excavators to facilitate the works on the northern and south-eastern sections of the breakwater. This will also ensure access for NPWS to Muttonbird Island. In addition, widening of the existing armour layer adjacent to Park Beach will allow the installation of a pedestrian footpath and associated guardrail along the northern side of Marina Drive. Currently, many pedestrians access the breakwater via the narrow strip between the existing armour rocks and the northern edge of Marina Drive or risk crossing Marina Drive against the traffic.

Multi Criteria Analysis of Potential Options

In order provide confidence in the selection of the preferred option, an evaluation was undertaken for each of the short-listed options, involving assessment of the merits and constraints of each option. The evaluation was undertaken on the basis of the social, environmental, economic and project criteria that were developed in consultation with Lands and agreed to be the most important to differentiate between options.

An overview of the evaluation process undertaken is shown in Figure 3 below and described in detail in the following sections.

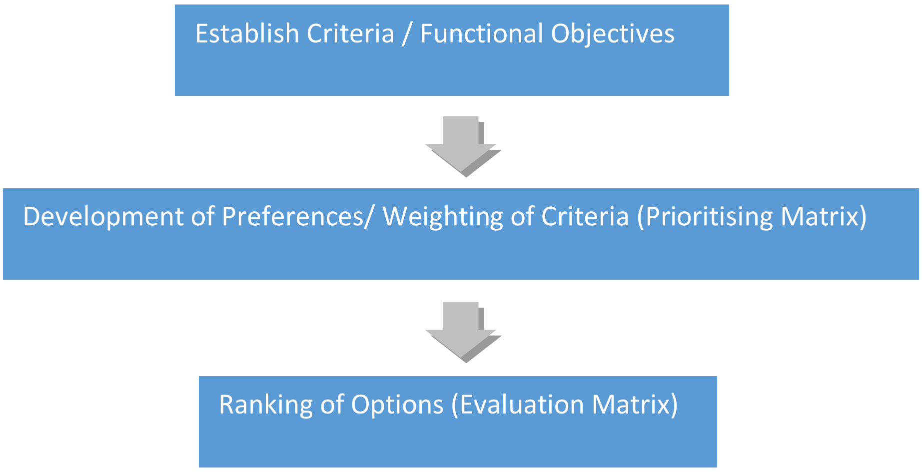

Figure 3 Option Evaluation Process

In undertaking an assessment of the merits of each of the options, a number of assessment criteria were identified and applied. The criteria were as follows:

- Overtopping Performance
- Recreational Impacts
- Aesthetic Impacts
- Environmental Impacts and Approvals
- Coastal Process Impacts
- Impacts during construction
- Ongoing Maintenance Requirements
- Future Adaptability
- Constructability
- Program and
- Cost

The next stage in comparing the different options was rating the criteria in order of importance.

The relative importance of each of the above criteria was individually compared to each of the other criteria. The extent of preference is based on the following points system:

- 3 High
- 2 Medium
- 1 Low (i.e., the two criteria are regarded as being of close importance)

For example, criterion A (Overtopping Performance) was rated as more important than J (Programme) and was given 3 points. In contrast, B (Recreational Impacts) was rated only slightly more important than C (Aesthetic Impacts) so 1 point was allocated for B.

The resulting matrix is shown in Figure 4 below.

PRIORITISING MATRIX

	B	C	D	E	F	G	H	I	J	K
A	2A	2A	2A	2A	2A	1A	2A	1A	3A	2K
	B	1B	1D	1E	2B	1B	1B	1I	3B	2K
		C	1C	1E	2C	1C	1C	1I	3C	2K
			D	1D	2D	1G	1H	1I	3D	2K
				E	2E	1G	1H	1I	2E	2K
					F	2G	2H	2I	1F	3K
						G	1G	2G	2G	2K
							H	2I	2H	2K
								I	1I	3K
									J	3K

		A	B	C	D	E	F	G	H	I	J	K
	17	15										2
	12		8			1				1		2
	12			8		1				1		2
	12				7			1	1	1		2
	9					4		1	1	1		2
	10						1	2	2	2		3
	6							4				2
									2			
	4									1		3
	3											3
Total	85	15	8	8	7	6	1	8	6	7	0	21
	87											

CRITERIA

A	Overtopping Performance
B	Recreational Impacts
C	Aesthetic Impacts
D	Environmental Impacts and Approvals
E	Long Term Coastal Process Impacts
F	Impacts during Construction
G	Ongoing Maintenance Requirements
H	Future Adaptability
I	Constructability
J	Programme
K	Cost

Figure 4 MCA Prioritising Matrix

From the prioritised matrix the scores for each criterion were subsequently added to determine the score for each. Weighting of the criteria was then calculated on the following basis:

$$\text{Weighted Score} = \frac{\text{(Criterion Score)} \times 10}{\text{(Total Score)}}$$

The weighting of the criteria / functional objectives is shown in Table 1.

Table 1 MCA Criteria Weightings

Scores and Weighting of Criteria

Functional Objectives			Score	Weighted Score	Rank
A	Overtopping Performance		15	1.72	2
B	Recreational Impacts		8	0.92	3
C	Aesthetic Impacts		8	0.92	3
D	Environmental Impacts and Approvals		7	0.80	6
E	Long Term Coastal Process Impacts		6	0.69	8
F	Impacts during Construction		1	0.11	10
G	Ongoing Maintenance Requirements		8	0.92	3
H	Future Adaptability		6	0.69	8
I	Constructability		7	0.80	6
J	Programme		0	0.00	11
K	Cost		21	2.41	1
TOTAL			**87**	**10.00**	

The final stage in the evaluation involved assessment of how each option was perceived to meet each of the criteria. The option was rated as excellent, very good, good, fair, or poor. A value system of 5 points for excellent, through to 1 point for poor performance was assigned.

This value was then multiplied to the weighted score for each criterion. The scores for each option were subsequently added to achieve a total point rating as shown in Table 2.

Table 2 Scoring of Options

Option		Criteria											
		A	B	C	D	E	F	G	H	I	J	K	
		Overtopping Performance	Recreational Impacts	Aesthetic Impacts	Environmental Impacts and Approvals	Long Term Coastal Process Impacts	Impacts during Construction	Ongoing Maintenance Requirements	Future Adaptability	Constructability	Programme	Cost	
		1.72	0.92	0.92	0.80	0.69	0.11	0.92	0.69	0.80	0.00	2.41	
	Rating												**TOTAL**
1 Toe Berm	*Excellent*			5									
	Very good					4			4			4	**Rank**
	Good		3		3						3		**6**
	Fair	2					2	2					
	Poor									1			
	Sub Total	3.45	2.76	4.60	2.41	2.76	0.23	1.84	2.76	0.80	0.00	9.66	**31.26**
2 Raised Crest	*Excellent*							5					
	Very good					4							**Rank**
	Good	3	3	3	3				3			3	**5**
	Fair						2			2	2		
	Poor												
	Sub Total	5.17	2.76	2.76	2.41	2.76	0.23	4.60	2.07	1.61	0.00	7.24	**31.61**
3 Wave Barrier	*Excellent*					5						5	
	Very good				4						4		**Rank**
	Good		3	3						3			**8**
	Fair						2		2				
	Poor	1						1					
	Sub Total	1.72	2.76	2.76	3.22	3.45	0.23	0.92	1.38	2.41	0.00	12.07	**30.92**
4 Submerged Reef	*Excellent*	5		5	5		5						
	Very good		4										**Rank**
	Good							3	3				**7**
	Fair					2							
	Poor									1	1	1	
	Sub Total	8.62	3.68	4.60	4.02	1.38	0.57	2.76	2.07	0.80	0.00	2.41	**30.92**
5 Low-Crested Offshore Breakwater & Toe Berm	*Excellent*												
	Very good	4	4	4	4								**Rank**
	Good							3	3			3	**3**
	Fair					2	2			2	2		
	Poor												
	Sub Total	6.90	3.68	3.68	3.22	1.38	0.23	2.76	2.07	1.61	0.00	7.24	**32.76**
6 Slope Upgrade & Toe Berm	*Excellent*												
	Very good	4				4		4					**Rank**
	Good		3	3	3				3			3	**4**
	Fair						2			2	2		
	Poor												
	Sub Total	6.90	2.76	2.76	2.41	2.76	0.23	3.68	2.07	1.61	0.00	7.24	**32.41**
7 Armoured Berm	*Excellent*	5						5		5			
	Very good					4	4		4				**Rank**
	Good		3	3	3						3		**2**
	Fair											2	
	Poor												
	Sub Total	8.62	2.76	2.76	2.41	2.76	0.46	4.60	2.76	4.02	0.00	4.83	**35.98**
8 Composite Armoured Berm	*Excellent*							5		5			
	Very good	4				4	4		4				**Rank**
	Good		3	3	3						3	3	**1**
	Fair												
	Poor												
	Sub Total	6.90	2.76	2.76	2.41	2.76	0.46	4.60	2.76	4.02	0.00	7.24	**36.67**

Technical Review Workshop

Based on the success of previous technical review workshops for similar projects managed by Lands, it was agreed that the most effective method of securing peer review input was through a workshop with industry recognised experts experienced in the design and construction of coastal structures.

The workshop was held following the preliminary evaluation of the options and prior to commencement of the 3D physical modelling activities. The aim of the workshop was to facilitate discussion to determine the best option(s) to proceed to 3D physical modelling works. Evaluation criteria included suitability of assumptions, adequacy of available data / information gaps, technical design and constructability.

Invitations to attend the peer review workshop were extended to the following parties:

- Crown Lands (client)
- GHD (primary consultant)
- Water Research Laboratory (3D Modelling sub-contractor)
- NSW Public Works (project manager)
- Manly Hydraulics Laboratory (technical adviser and modelling peer reviewer)
- The JDS Group (construction company)
- Coffs Harbour City Council (CHCC)
- Coffs Harbour Boardriders Club (community)
- Marine Parks Authority (state government)

The technical review workshop was considered highly successful. Key outcomes of the workshop included:

- Review and discussion of design assumptions
- Refinement of Design Criteria
- Recommendation for comparison of numerical results to historical evidence
- Inclusion of additional Evaluation Criteria
- Changes to scoring of Options 1 to 7
- Contractor feedback regarding constructability and rock availability
- Development of Option 8 (preferred option)

Physical Modelling

Having undertaken a comprehensive options development and evaluation exercise, Lands was able to proceed directly to physical modelling with confidence that the preferred option represented the solution that offerred the best value for money.

Physical modelling was undertaken by UNSW's Water Research Laboratory (WRL). Key objectives were as follows:

- Assessing nearshore wave breaking, shoaling and refraction processes
- Assessing 3D aspects of the upgraded breakwater stability
- Analysing the 3D aspects of overtopping of the existing and upgraded breakwaters

The SWAN and Boussinesq numerical models performed well at predicting the wave climate as waves approach the structure from deep water and provided accuracy appropriate for the concept design stage of the upgrade. In order to inform the detailed design stage, the 3D physical model provided a more accurate simulation of wave processes in the nearshore area where there is significant wave diffraction, refraction and other interaction with bathymetric features. The model also verified the results from the Neural Network tool for assessment of overtopping.

The physical model was validated by assessing the breakwater overtopping in areas where there is known to be a major hazard (e.g. adjacent to the marina). This validation was based on qualitative visual comparison of historical data, videos and photos of specific storm events at the existing breakwater, and observation of the physical model under the same scaled conditions. This included verifying the location and intensity of the overtopping in the model in comparison to the photographic records.

Figure 5 Physical Modelling of the Preferred Primary Upgrade Option

The stability of the primary armour, crest specific armour and rock berm armour was investigated and assessed under 10 year ARI (HAT) and 100 year ARI (HAT + SLR) wave conditions. In general, both design iterations were considered stable and suffered very low overall damage[1] (less than 1%). The rock berm was observed to exhibit some slight reshaping behaviour but with overall negligible damage. It was observed that the reduced 5m width rock berm resulted in slightly higher damage to the Hanbars and rock berm when compared to the 10m berm width investigated.

Quantitative overtopping assessment was performed for the same wave conditions over the critical 400 m of crest length for the upgraded breakwater, i.e. Ch 400 to 800 m. The

[1] 'damage' is measured by movement of primary breakwater armour units (Hanbars) by more than one Equivalent Cube Diameter. Thus one Hanbar in 100 displaced by that distance equates to 1% damage. This definition does not refer to rock armour within the berm which is expected to initially reshape but subsequently become statically stable

proposed upgrade was observed to significantly lower the average overtopping rates compared with the existing structure. Overtopping rates were reduced to below 3 L/s/m for the 10 year ARI HAT event, and to below 10 L/s/m for the 100 year ARI (HAT + SLR) wave conditions confirming that the proposed upgrade would reduce the risk of damage to vessels within the marina and limit the hazard to a pedestrian risk only.

The findings of the physical modelling exercise were used to develop the detailed design and included a number of refinements during testing. In particular, the size, positioning and placement of containment Hanbar units was refined to include a more efficient pattern placement of interlocking reduced height 20 tonne Hanbars. This modification ensured that the pedestrian views from the crest of the breakwater will be maintained whilst preserving the stability of the units against wave attack.

In addition, due to the encouraging stability and overtopping performance of the modelled Option, a refined design with a reduced rock berm width of 5m was put forth for physical model testing. This refinement significantly reduced the quantity of rock armour required and subsequently became necessary to reduce the upgrade footprint to avoid environmentally sensitive areas as described below.

Designing for Positive Environmental Outcomes

The Review of Environmental Factors (REF) (GHD, 2015), considered the available information provided by Lands and held by the Department of Primary Industries regarding the Critically Endangered Marine Brown Alga (*Nereia lophocladia*). Seen below is an excerpt from the REF outlining the existing known extent of consideration of the Marine Brown Alga:

> *N. lophocladia* is currently known only from one small population growing at the base of vertical rock faces between 3 - 8 m depths on the northern side of Muttonbird Island, Coffs Harbour, NSW. It is a location that is prone to sand build--up due to the blocking effect by the marina breakwater on natural sand movement. The species has been observed at Muttonbird Island on four separate occasions over a 22 - year period, first in 1980 with subsequent records confirmed in 1986, 1990 and most recently in 2002. On all occasions the species has been found in late winter (August) to early spring (September). Surveys to locate the species in 2004 and 2006 were unsuccessful, at which times it was observed that deep sand deposits had covered the substratum in its known distribution range (Elgin, 2015).
>
> Targeted surveys conducted in April 2015 (Elgin, 2015) also failed to locate *N. lophocladia* growing on the northern breakwater, or on sub--tidal reefs located within the species known range of distribution on the northern side of Muttonbird Island.

Since the targeted surveys conducted in April 2015, further targeted surveys were undertaken by Elgin Associates in September and October of the same year. These surveys indicated that there were a significant number of the species present on, and in the vicinity of, the existing structure as seen in Figure 6 below.

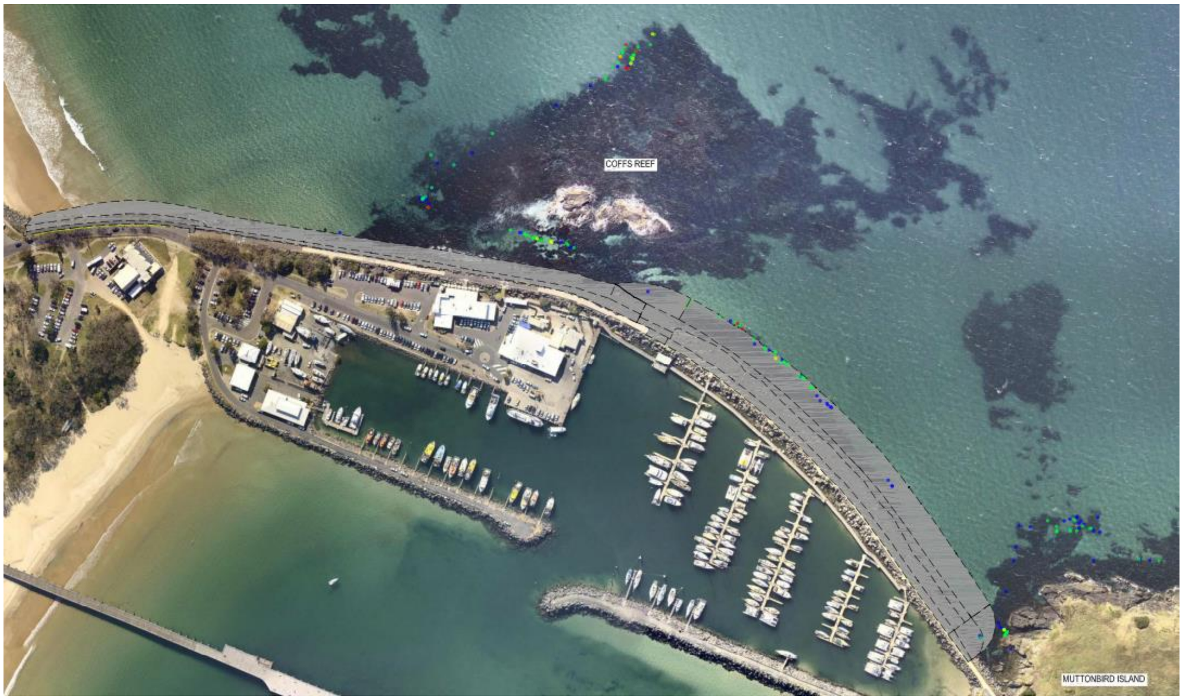

Figure 6 Extent of Initial Design and Relative Location of *N. lophocladia*

With identification of the *N. lophocladia* seen in Figure 6, a revised breakwater upgrade design was developed to minimise the impacts of the upgrade works on the *N. lophocladia* through reduction of the upgrade footprint. A plan view of the final breakwater design can be seen in Figure 7.

Figure 7 Extent of Final Design and Relative Location of *N. lophocladia*

The greatest estimated number of individuals of *N. lophocladia* at risk of being directly impacted by the upgrade works are located at the toe of the central portion of the existing structure. To eliminate the direct impact of the upgrade works on the alga in this region, the upgrade design was altered, narrowing the 5-8 tonne rock berm at MSL to 5 m and bolstering the design with the placement of 1.5 layers of 12 tonne Hanbars atop this berm. This design constrained the upgrade within the footprint of the existing structure in the vicinity of the N. lophocladia and allowed for a buffer between the approximate locations of the alga and the proposed works. Consideration of the location of the existing N. lophocladia as well as of the coastal engineering advantages and disadvantages of the final design, led to the final design being proposed. Figure 8 below shows a typical section for the Final Design in the vicinity of the greatest estimated number of individuals of *N. lophocladia*.

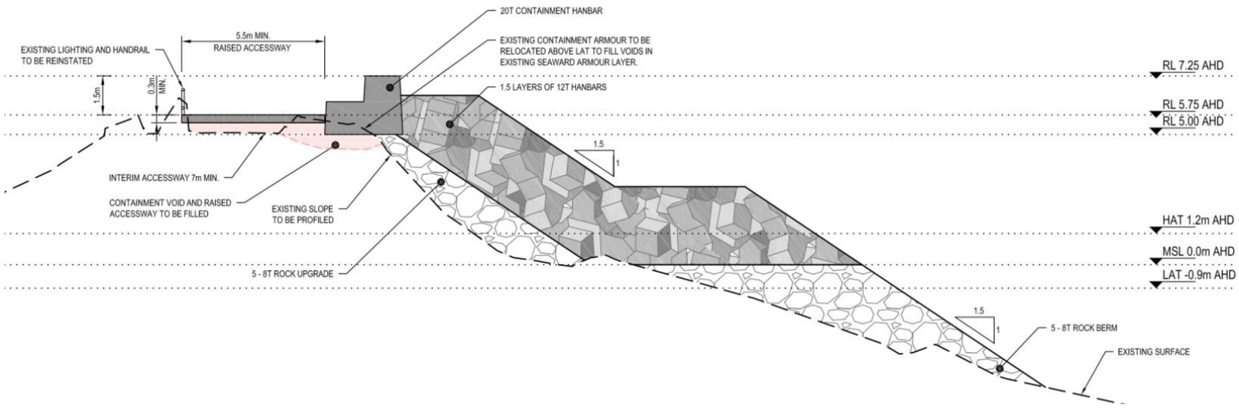

Figure 8 Typical Cross Section for Final Design

In addition to the reduced width of the rock berm, a number of mitigation and offsetting strategies were developed through consultation with DPI Fisheries and Elgin Associates in order to better replicate the conditions under which the *Nereia lophocladia* showed the greatest colonisation outcomes.

- Sections of the proposed toe design were modified to create a complex toe profile which will promote formation of sand scour holes and provide increased habitat opportunities for *N. lophocladia*. This was achieved by including 5-8T rocks on the seaward side of the toe at 5 metre intervals along the breakwater.

- A 500 mm thick scree of greywacke cobble (sizes 100 – 250 mm and ~10% ~400 mm) was included in order to maximise the creation of the sand/rock edge habitat considered suitable for *Nereia lophocladia* in areas where the species has not been recorded. The scree was designed to cover the seabed extending between 2 m and 5 m from the toe of the structure.

Designing for Positive Social Outcomes

Community consultation undertaken at the outset of the project revealed that the preservation of views from the crest of the breakwater was a critical issue to the community. Preserving these views required careful design of crest containment armour to ensure that views were maintained whilst still meeting the upgrade performance requirements.

Containment unit placement and specification is critical for breakwater design. Containment units determine the crest freeboard of the breakwater as well as influencing the views seen from the crest of the breakwater and providing a barrier between breakwater users and the adjacent armour units. For these reasons, the sizing, placement and aesthetics of the containment armour units were given specific consideration along the length of the breakwater.

Through the western section of the breakwater, the containment was designed to be a single layer of armour rock that will be placed after construction of the eastern section of the breakwater.

Through the eastern section, to maximise coastal protection and the stability of the structure, whilst minimising the impact to views for pedestrians using the breakwater crest, customised 20 tonne Hanbars were determined to be the most appropriate unit for crest containment. These Hanbar units were customised to ensure that pedestrian views from the crest of the breakwater are maintained. The Hanbars are of the same dimension as a standard 22 tonne Hanbar unit, with the exception of the chimney, which was shortened to reduce the containment impact on pedestrian views. The 20 tonne containment Hanbars will be pattern placed on top of a level footing composed of gabion sized rock and supported by the lower level Hanbar units. This level footing will ensure the following:

- the shortened chimneys are placed upright to minimise containment disrupting pedestrian views
- the Hanbars provide an organised and consistent aesthetic and informal seating arrangement for users of the breakwater
- effective interlocking of units can be achieved to enhance stability

The pattern placement of these units will be in a similar fashion to that undertaken for the physical modelling, shown in Figure 9 below.

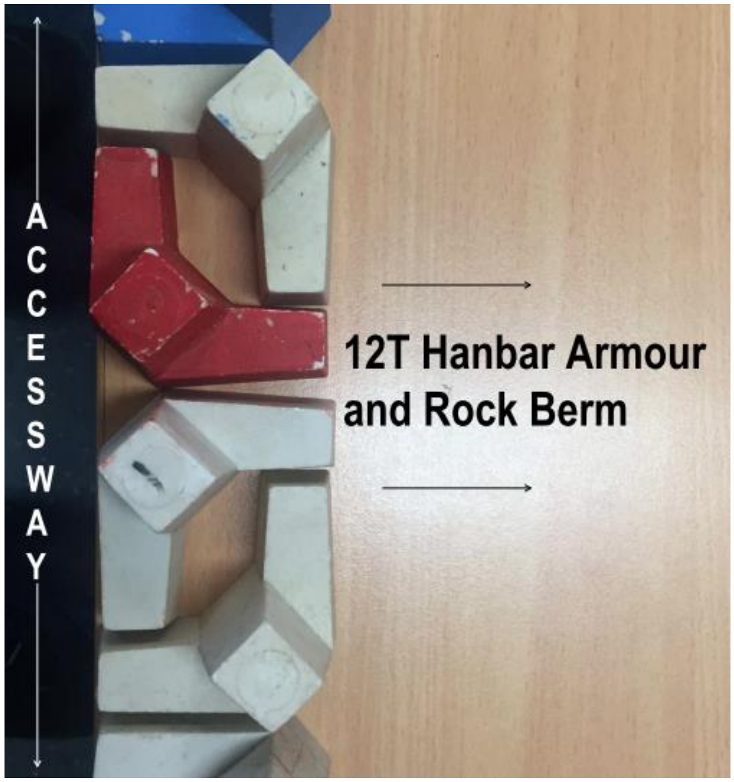

Figure 9 Pattern Placement for 20T Containment Hanbars

Summary

Coffs Harbour is considered to have some of NSW's most critical coastal assets and includes numerous social, cultural, environmental and commercial interests of regional significance. Whilst many of these considerations are the primary drivers behind the upgrade of the breakwater, they also represent a unique set of constraints and opportunities.

By adopting innovative technical design solutions and a comprehensive and transparent approach to stakeholder engagement, the project team has developed a design solution that effectively addresses these challenging and sometimes opposing drivers.

The upgrade of the Northern Breakwater now serves as an excellent case study for addressing coastal engineering challenges within a high value marine environment such that the project achieves balanced technical, social, environmental and economic outcomes.