COFFS HARBOUR EASTERN BREAKWATER REMEDIATION
THE CHALLENGES OF RESTORING EXISTING COASTAL INFRASTRUCTURE

G Russell[1] I Jayewardene[2] N Patterson[3]
[1] NSW Trade & Investment – Crown Lands, Newcastle NSW
[2] NSW Public Works – Manly Hydraulic laboratory, Sydney, NSW
[3] SMEC, Newcastle NSW

ABSTRACT

The Coffs Harbour Eastern Breakwater (CHEB) is one of NSW's most significant breakwater assets. Like much of NSW's coastal protection infrastructure it was designed and constructed around a century ago utilising the technology of the day. It has been repaired numerous times over its life. This latest repair with a budget of $19 million makes this the single largest project in the Government's Coastal Infrastructure Program being delivered by NSW Trade and Investment – Crown Lands.

Since CHEB was built the engineering for new coastal structures has evolved dramatically. By comparison, remediation of existing breakwaters has been largely overlooked. As the best learning tool is often previous experience, this paper aims to share the lessons learnt in the development of the remediation strategy for CHEB.

The remediation brought a variety of challenges including:

- changing service delivery and community expectations in terms of functionality and amenity
- need for a resilient design with the capacity to accommodate sea level rise and adaptable to the needs of future generations
- uncertainty as to the structural aspects of the existing structure
- ensuring the available funds will deliver works of lasting value.

Solving the problem required iterative assessments of; hydraulic performance; constructability; and cost aspects. The procurement strategy provided for 'Early Tender Involvement' to explore construction aspects of the project. Convergence on the adopted solution was achieved through Value Management (VM). The post VM design was tested and refined using a 3D physical model. The results gave confidence the solution will meet performance requirements and deliver value-for-money.

Biography

Guy Russell, Manager Assets and Climate Change, NSW Trade & Investment – Crown Lands. Guy has extensive experience in water and waste water engineering, environmental management, and waste and recycling. His involvement with Crown Lands Coastal Infrastructure Program complements his interests in the maritime activities.

Natalie Patterson, is a senior coastal engineer with over twelve years experience in Australia and the UK in the fields of investigation and design of maritime and coastal protection structures; coastal processes investigation; coastal hazard definition; coastal planning and management; project management and engineering construction supervision.

Indra Jayewardene (MSc, University of Florida) - Indra joined NSW Public Works Manly Hydraulics Laboratory in 1990 and is currently employed as a senior engineer in coastal investigations. He was the Chair of the Australian Institute of Engineers (NSW) Panel for Coastal, Ocean and Port Engineering in 2009 and 2010.

COFFS HARBOUR BREAKWATER DEVELOPMENT

Location and History

The port of Coffs Harbour located on NSW mid north coast about 540kms north of Sydney (refer Figure 1) has a history that dates back over 100 years. At this time coastal shipping was a significant factor in the regional economy facilitating export of timber and agricultural products which were the mainstay of the region. The advent of the railway and more recently modern highway transport networks has seen coastal shipping decline in importance, its place taken by commercial and recreational fishing, coastal cruising, and tourism activities such as whale watching. Coffs is the only ‘all weather’ port between Newcastle and Brisbane so it remains of strategic importance to the boating community. Further, the presence of the harbour has made the area a focal point for a range of recreational and tourist developments in the region.

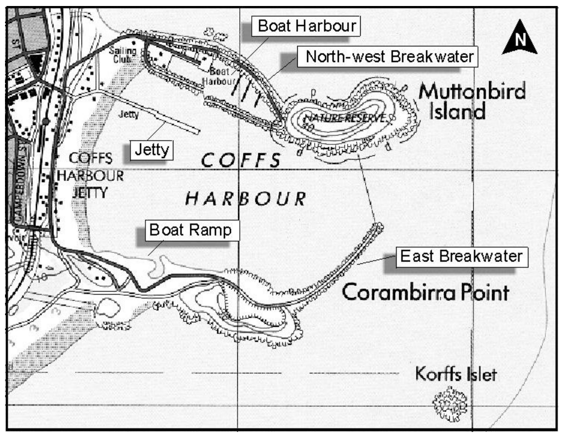

Figure 1 Port of Coffs Harbour NSW

A timber jetty was completed in 1892 and a decision was made by the government in 1912 to make an artificial harbour (Coltheart, L. 1997, cited in Jacobs et.al.). Construction of a breakwater joining Muttonbird Island to the mainland on the north was completed between 1917 and 1924 and was followed by infilling of land to South Coffs Island and the addition of the east breakwater (CHEB) enclosing the outer harbour (completed in 1939) as shown in Figures 2a and 2b. Later, development of the inner boat harbour was completed by construction of two enclosing breakwaters in 1974.

Construction of CHEB and similar structures up and down the coast was dictated by the technology of the day and involved tipping locally quarried rock armour from specially constructed tipping frames on rail wagons. With the tipped material falling naturally to its angle of repose, the structure, by definition, achieved a factor of safety of about 1. No doubt this was a factor in the requirement for regular and ongoing maintenance campaigns (R. Jacobs, et.al, 2013) with armour bocks tipped on the wall almost every year up until 1965 by then owner/operator – NSW Public Works.

Construction method was (and remains) a key factor in determining the approach for construction/repair.

Early last century the choice of a local quarry was simple, suitable rock close at hand. In the case of Coffs, the headland provided a suitable and convenient source of material and a dedicated railway provided the means of getting the rock to where it needed to be placed as shown in Figure 2b.

The original construction makes the area and the structure of Heritage value, as recognised in the LEP. We now know the site is also of significance to the traditional custodians, the Gumbaynggirr people. Planning controls, urban encroachment and transport corridor impacts are real constraints to be factored into contemporary repair solutions and mean the option of gouging additional rock armour from what is left of the headland is not available. Sourcing of rock from other quarries needs to have regard to product availability, quarry approvals, etc. Furthermore, approved quarries gear their operations and blast patterns to meet the main market segments, aggregates for concrete and road construction, so procurement of large size blocky rock in size range upwards of 1 tonne can be problematic regardless of the location of project. (H. Rangger – pers. comm.) To address this problem concrete armour units, hanbars, were developed and patented by NSW Government Coastal Engineers and have been used at various ports.

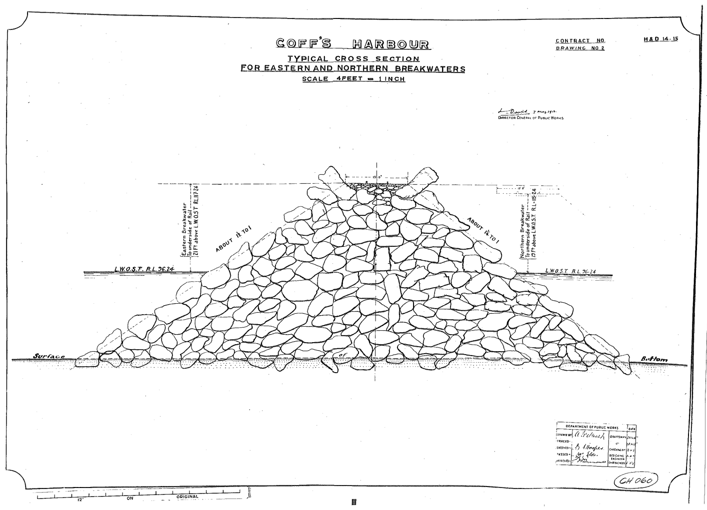

Figure 2a - Original construction drawings for the Coffs Harbour breakwaters

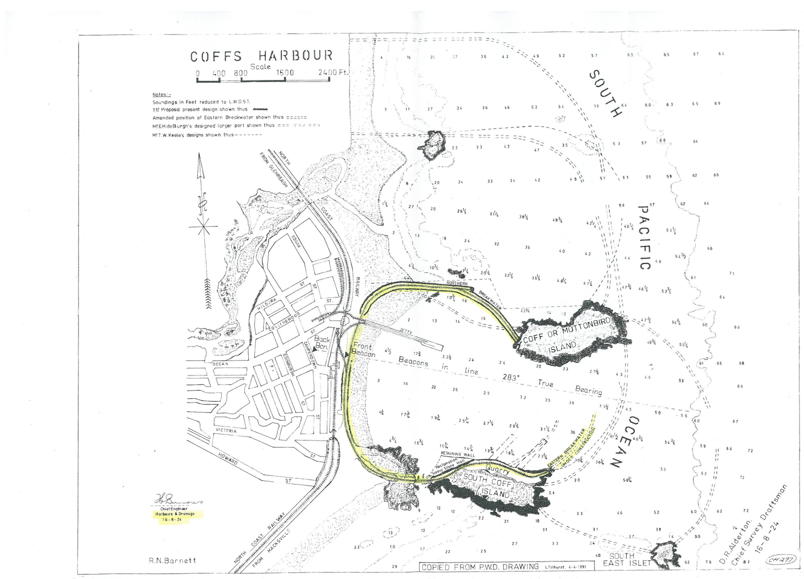

Figure2b - Coffs Harbour Northern and Eastern Breakwater General Arrangement

The Case for Repairs (The never ending Challenge of Budget and Funds)
Various condition assessments and repairs have been carried out on CHEB since 1965 dictated by the availability of funds and the urgency of repairs. Major repairs were carried out in 2001 to 2002 following damage by a storm in May 1997 which moved 12 x 40t blocks from the head and 20 in all along the structure. The repairs involved placing 55 x 28t hanbar units on the head and 98 x 28t units along the trunk together with some 7,000 tonnes of rock armour. The 2001/02 repairs adopted widening of the breakwater crest to a nominal 3m to enable use of 250T mobile crane working at the head on a specially constructed reinforced concrete platform.

Crown Lands income from its ports is limited and significantly less than the level of expenditure required when compared to what contemporary maintenance regimes suggest as reasonable when measured in proportion to asset value. For example other port authorities (NSW Roads and Maritime, Port of Newcastle) maintenance spend is around 1% to 2% of asset value compared to Crown Lands spend of some 0.2% prior to implementation of the Coastal Infrastructure Program. Because Crown Lands does not have an income stream dedicated to maintenance of its ports maintenance funds are through bids to NSW Treasury.

A Total Asset Management System (TAMS) is a fundamental requirement for success of any bid for NSW Treasury funds. Crown Lands TAMS system was a key factor in preparing a business case for repair and renewal of its coastal assets and subsequently winning the incoming O'Farrell Government's support for this infrastructure renewal as part of a 4 year $50 Million Coastal Infrastructure Program funded in the 2011 budget. The business case to NSW Treasury clearly showed the importance of the Coffs Eastern Breakwater with some $150 million of assets at risk for the 'do nothing' option. The various condition assessments meant that the decision to repair was a "no-brainer" its substantial $19M estimated cost notwithstanding.

PROCUREMENT STRATEGY

Flush with Treasury funds Crown Lands set out to procure the necessary repairs, and mindful of the vagaries of future funding, drafted an ambitious design brief. In conjunction with this and consistent with NSW procurement requirements, a workshop facilitated by NSW Public Works was held to identify project risks and develop a procurement strategy. The workshop participants included experienced coastal engineering consultants and the Government's experts from Manly Hydraulics Laboratory (MHL). The workshop identified a conceptual solution based upon hanbar armour on the ocean side of the wall. A ball-park cost estimate indicated the repairs could be achieved within the available budget.

Following from the workshop NSW Public Works (Coffs Harbour) were engaged to provide project management for delivery of the works. NSW Public Works is an accredited Project Manager for NSW Government works over $1 Million and were ideally located geographically with available expertise to manage delivery of the works.

The project plan provided for early tender involvement (ETI) of contractors selected through calling Expressions of Interest (EOI). The idea being that the experience of contractors could be factored into the design and construction methodology to advantage in terms of project delivery and cost. Other risks identified were procurement of suitable rock armour, up to date condition assessment, and reliability of survey data. The EOI process was scheduled to finish in conjunction with the draft design so that the tender could incorporate any innovations that emerged.

Design
With regard to Design Criteria Crown Lands brief was:

> *Prepare Design Criteria for the proposed modifications or improvements along the total length of the breakwater. The Design Criteria should take into account the required service life from the upgrade*

(50 years), climate change and the acceptable level of damage that may be sustained to the breakwater during this period. Factors such as the level of overtopping permitted, required raising of the crest and public risk should also be assessed.

The two main drivers behind Crown Lands' Design Criteria were:

- Need to minimise future maintenance, and
- Overtopping events should be no worse.

Consistent with Government Procurement Policy, a designer was selected through competitive tender and the contract awarded to SMEC. Their tasks also included condition assessment; review of available hard rock armour from various local quarries; preparation of a design and technical specification. Constructability was significant factor.

Condition Assessment

The first step in the design of the remedial works for the breakwater involved establishing the existing condition of the structure. This involved a review of previous investigations, bathymetric surveys and dive surveys, and a walkover inspection by coastal and geotechnical engineers. New bathymetric surveys and detailed photogrammetric surveys of the above water portion of the structure were also undertaken. The findings were that most of the existing 40t concrete armour units were defective, there was a lack of secondary armour, the core was effectively impermeable, and the oceanside slope was excessively steep. All of these factors contributed to create a highly reflective structure with reflected wave energy increasing the instability of the armour.

Potential failure mechanisms for the structure included loss of armour via overtopping or reflective energy, exposure and loss of core, toe scour, crest edge failure or break down of the aging 40t armour blocks to undersized units that could be readily displaced by wave action. The geotechnical assessment concluded that if the structure was not remediated through major reconstruction works, deterioration of the primary armour would continue to expose the core and would likely cause a major failure of the structure in due course.

Quarry Review

The review of local quarries and available material was not encouraging. Crown Lands own quarry at Karangi was briefly considered but rejected on the grounds that re-opening would require new development approval via an EIS. Cost, timeframe and likely impacts on adjoining residential areas were all factors in this decision.

Commercial quarries were not ruled out. However, major highway works north of Coffs Harbour placed significant demands on their production capacity and sourcing suitable rock armour from these was not encouraging.

Design Criteria

At some point the interpretation of *"... acceptable level of damage"* over the 50 year design life specified in Crown Lands brief lead to the adoption of <u>zero damage</u> over a 50 year service life. As there would theoretically be no need for maintenance over the 50 year service life a further specification for the design was that the breakwater crest covered in armour units, a driver for this being mitigation of risks to the public going on to this (at least at times) inherently dangerous structure by making this activity virtually impossible.

The designer advised that these were very stringent criteria which would be difficult to achieve practically and economically, and some relaxation of the damage criteria would be appropriate. Further, they questioned whether covering the breakwater crest with armour units was a viable option.

In exploring the design criteria conundrum the consultant considered damage and risk of design events occurring within the period of the design storm Average Recurrence Interval (ARI).

In the first iteration an acceptable risk of occurrence of the design event of 10% over the 50 year service life was adopted. A 10% risk of occurrence over 50 years equates to a 500 year ARI design storm event. This, like the 'zero damage' starting point was considered to be difficult to achieve and cost prohibitive and lead to a further iteration with the adoption of the design criteria based on 15-20% damage over 50 years design life and to 3-4% damage in any 10 years period - i.e. a design service life of 10 years with some minor maintenance. This equates to a 100 year ARI design event (refer Figure 3).

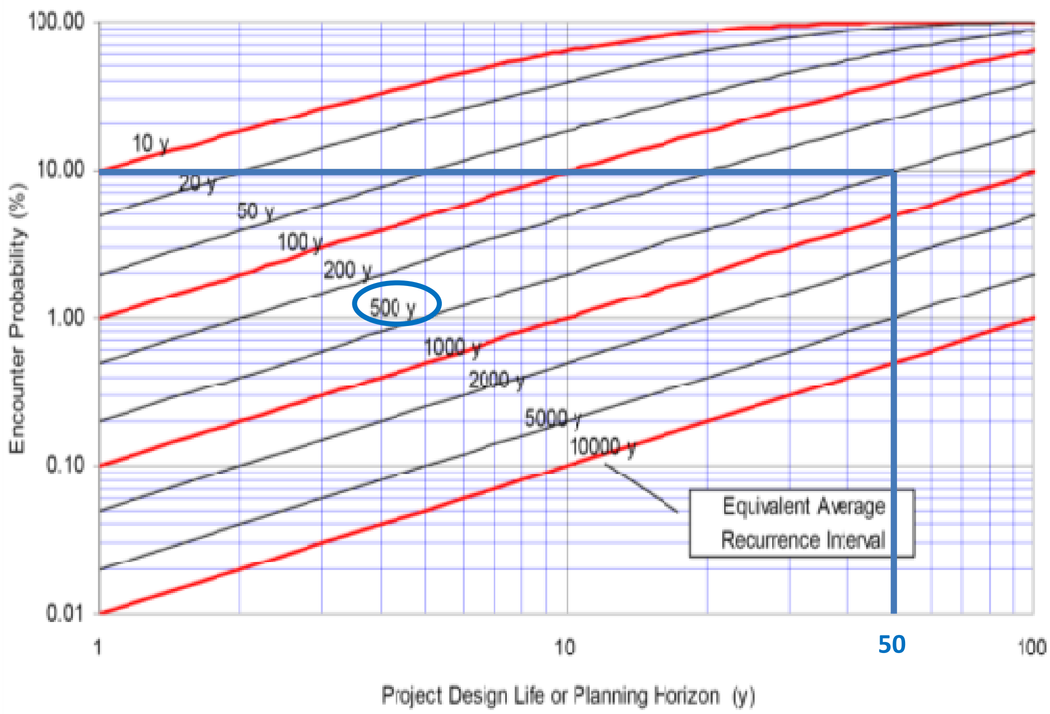

Figure 3 - Relationship between encounter probability, average recurrence interval (ARI) and project design life

The design criteria also specified overtopping was not to increase beyond existing levels over the 50 year design service life including predicted sea level rise. Sea level rise of 0.5m over the 50 year service life was adopted, this being planning policy at the time, and resulted in a design water level of 1.9m AHD for the 100 year ARI storm event.

Wave Climate

The design wave height for the structure was determined using numerical wave modelling. MHL have operated a waverider buoy offshore of Coffs Harbour for several decades, however it is only recently that wave direction has been added to height and period data. This data provided the input conditions for the numerical wave modelling.

Typically the design wave height for near shore structures is less than the offshore wave due to shoaling. In the case of CHEB the offshore features e.g. Korff's Islet and potential wave superpositioning and focussing behind these features needed to be explored.

Broad scale wave transformation of offshore waves to the nearshore was undertaken using a SWAN model with boundary conditions determined with regard to the MHL offshore wave data. A

BOUSS 2D model was then used to model the complex wave patterns resulting from the offshore features. Output from the model is shown in Figure 4 below.

Output from the model provide the basis for the design wave height on the structure for the design of the hydraulic design of the primary armour. The numerical wave modelling also sought to determine if there were any opportunities to reduce the design wave climate (and thus the required armour size) for the landward portion of the structure.

A key finding of the modelling was that there was no significant spatial difference in wave climate along the outer 400m of the structure though there was significant complexity evident in the wave patterns occurring within the first 100m of the landward end of the structure. For a six hour storm duration the 100 year ARI significant wave height was 7.4m (based on a water level of 1.9m AHD). This wave could be breaking on the structure anywhere along the outer 400m of the breakwater.

This finding and discussions on handling the complexity in wave climate as a consequence of the Korffs Islet proved to be a fertile area for discussion at the VM. It was quite different to that found in prior and subsequent physical (3D) modelling and shows coastal process are inherently complex and modelling, be it numerical of physical, is at best an approximation and thus the results should be interpreted with caution and by experienced coastal engineers.

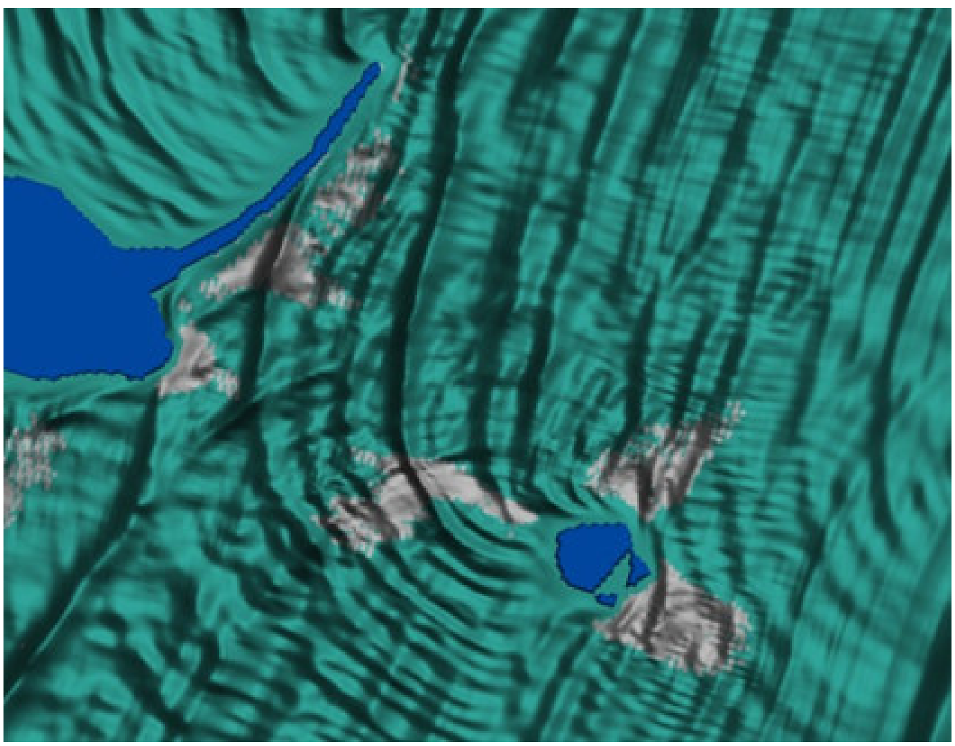

Figure 4: BOUSS 2D wave modelling results for ESE direction showing breaking waves along the structure and wave super-positioning and focussing behind Korff's Islet.

The design of the remedial works required parallel investigations down several paths concurrently looking at: hydraulic stability of armour; crane/construction methodology; program/sequence, and cost. Each of these components are interrelated and an iterative process of assessing each of the components was then undertaken in order to converge on the optimum solution.

The hydraulic stability was assessed using the empirically derived Hudson's Equation to determine armour slope and size requirements. The damage coefficient Kd is critical to this equation as it accounts for all of the variables other than structure slope, wave height and specific gravity of water. Kd values are empirically derived and all previous modelling using Hanbars was reviewed to select a range of Kd values to be adopted for the design. Kd values ranged from 6 to 11.4 for the 0-5% damage level. The consultant's professional judgement was to adopt a Kd of 6 (subject to validation by physical modelling).

For the adopted Kd of 6 and a design breaking wave height of 7.4m the primary armour selected was 22 tonnes at a 1:2 slope.

Constructability

Selection of crane type and construction sequence options were investigated to determine how the ocean side design profile could be constructed. The size of crane (footprint) needed to lift, reach and place the primary armour on the ocean side dictated the crest width dimension and thus the harbour side profile as well since this had to match the working surface for the crane. A crawler crane was selected over a mobile crane due to savings identified in both hire costs and the cost of the crest strengthening to accommodate the significant crane outrigger loads of these 250t machines.

A construction sequence followed to determine the likely duration of the construction works and resourcing requirements giving due consideration to site constraints.

As noted above, quarry investigations were undertaken to identify suitable rock sources. The investigation revealed that local supply of large armour rock (approx. 5t) in significant quantities (some 17,000 tonnes to armour the harbour side) could be problematic. This was because of the significant highway construction works in progress with their demand for concrete aggregates and roadbase. DTI made the decision at this point that rock armour was not to be considered for the harbour side and that Hanbar units were to be utilised throughout.

This initial design was tested using 2D physical modelling at the UNSW Water Research Laboratory (WRL). Through iterative testing the cross sectional design was refined to achieve the design criteria for damage and overtopping. The resulting initial design appears in Figure 5 below.

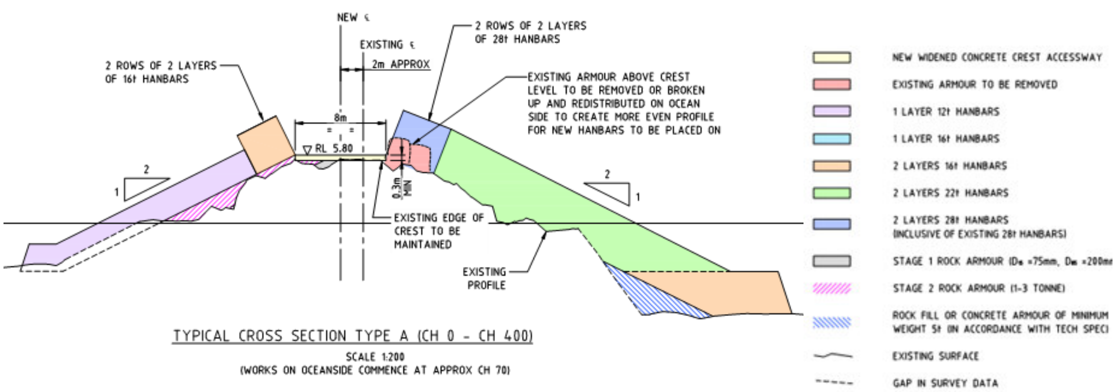

Figure 5: Initial typical design cross section.

Photos from the WRL 2D model are shown in Figure 6. With the model as built (Figure 6a) and following a 100 year storm and sea level rise test (Figure 6b). It shows some minor damage to the hanbar units.

As Built

After 100 Year (+ SLR) Test

Figure 6: 2D physical modelling in the wave flume at WRL

The remediation of the breakwater head was also added to the scope of works at this stage due to damage incurred during the June 2012 storms. Quasi 3D modelling was also undertaken at WRL in a 3m wide flume to test the transitional zones and the head armour design.

Having established a design solution and feasible construction methodology for the remedial works, a cost estimate was prepared. Perhaps not surprisingly, the ‘fully optioned’ initial design solution (including repairs to the head and harbour side hanbar armour) came in more than twice the initial budget estimate with a price tag of some $40 million. With such a massive disparity between the preliminary design cost and the budget allocation this was a prime case for the application of Value Management (Value Engineering).

Further, at this point design delays threatened to have serious impacts on Project Delivery.

VALUE MANAGEMENT

NSW Public Works had been engaged to project manage delivery the works, and based on the outcomes of the procurement workshop mentioned above, had initiated an Expressions of Interest Process (EOI) in parallel with design activities.

The intent of the EOI was that short listed contractors might be invited to participate in Early Tender Involvement (ETI) a process used to advantage when difficult construction or complex projects are to be delivered. This is because it allows an arguably experienced contractor (i.e. those best placed to comment) to contribute on work methods and management of construction risks.

Surprisingly, the EOI process was disappointing notwithstanding that this was at a time following the GFC when there was a downturn in the construction sector and thus a high level of interest in the project might have been expected. Only three contractors lodged submissions. Two were assessed as adequate and invited to participate in a Value Management (VM).

Value Management is a structured, systematic and analytical process to understand and consider all stakeholder's objectives and requirements, develop or review options to address these objectives, and optimise a solution having regard to service standards, cost, and value for money.

In addition to the key members of SMEC's design team, VM participants included: government experts in coastal processes and engineering from MHL; other highly experienced coastal engineering consultants; experienced coastal engineers from within Crown Lands; the Project Manager (NSW Public Works); and crane operators. No doubt the process was somewhat daunting for the designers who presented their solution and the reasons for its adoption in the light of their brief. However, these concerns were quickly allayed and the facilitator and all participants made genuine contributions over the two days of the workshop with all focussed on delivering the best result for the available budget.

Perhaps not surprisingly the various experts held somewhat different views on the wave modelling, though all agreed the effects of Korffs Islet were a critical factor to be considered.

A key observation made was that the structure as built (and repaired) had provided good service for some 100 years, so contemporary theory on design and actual occasional damage in storms notwithstanding, the overall geometry and armour were "about right" – most of the time. This suggested that the ocean side slope cold be steepened if the primary armour was adequate. Contributions from the contractor representatives allayed concerns with respect to rock supplies thus effectively eliminating the expensive hanbar armour on the harbour side in favour of rock. Other lower priority areas were identified and eliminated or modified to bring the estimated cost down to meet the available budget. For example the head works were excluded.

Post VM activity by the consultant saw a re-work of the design and estimate and what, on paper, appeared to be a viable, affordable solution. Key members of the VM team re-convened and discussed the revised design. A key feature of the design was a steepening of the slope of the ocean side. Some issues were identified relating to the performance of the head and transition zone to the harbour.

To address these concerns a further final round of physical modelling was considered to be worthwhile. In this case, a 3D physical model orientated to simulate the most severe design storms tested the design for hydraulic stability and overtopping performance. Further, the model was to be calibrated with a simulation of a known event thus improving confidence in its reliability. Care was taken to ensure the bathymetry offshore of the breakwater was accurate and that the wave conditions were matched with storm conditions from the earlier numerical modelling. This required good cooperation between the designer and the physical modeller. The work was carried out within a demanding timeframe over December/January 2012/13.

A series of runs with different water depths and wave heights were completed and the results assessed (MHL 2013). This additional modelling confirmed the VM design was adequate though some areas where minor tweaking was needed in the transition zone inside the head that resulted in some hanbar armour from chainage 460 to the head.

The concept that evolved is shown in Figure 7 below. The ocean side profile changed to a composite slope more closely following the existing profile and thus reducing the required number of Hanbar armour units. Its steepened lower slope and a flatter upper slope are a good fit with the occurrence of design wave events with elevated water levels where more stability high on the structure is required. A further saving was achieved by eliminating the 16t toe berm from the landward half of the breakwater where the shallower depths (and therefore reduced lifting radius) allowed the larger 22t Hanbars to be placed all the way down to the seabed.

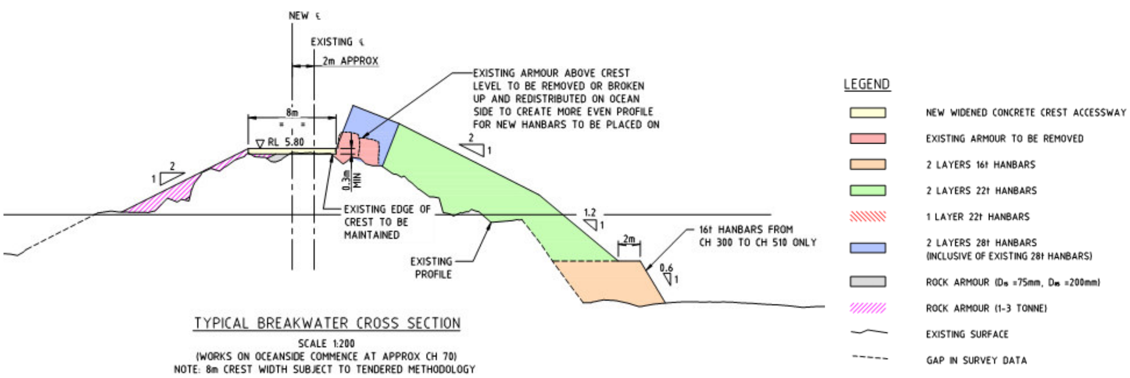

Figure 7: Final revised design following VM workshop and further 3D physical modelling

The series of runs carried out was concluded with a 'test to destruction' which was not achieved.

One of the reasons for this was waves approaching the design wave height of 7.4m were found to break off-shore dissipating significant energy in the process. Cranking the wave paddle to 'max' simply made more, larger waves break offshore. This occurred because the full 3D physical model was only partially effective in creating the complex wave effect of Korff's Islet. These were simulated using a reflective wall as the pool was not large enough to accommodate the islet and bathymetry between the modelled structure and the wave paddles. Whilst larger more complex waves were generated and seen to break on the structure, it is not clear if these achieved the wave height predicted by the numerical model.

A further limitation of the physical modelling is that the pool floor is hard concrete and thus the effects of scour at the toe of the structure do not occur. However, the modelling provided confidence that the final design is robust and was particularly helpful in addressing the complex interactions around the head and along the harbourside transition.

CONSTRUCTION

As noted above, the initial EOI process for contractors was disappointing. In order to ensure competitive bids a further EOI to identify short listed tenders took place. This generated much better interest and lead to short listing of four companies to Tender the works.

At the outset of the project the need for a substantial number of hanbars was identified and a decision taken to let a casting contract (Part 1) so as to smooth out the cash flow. The contract was structured to provide a Part 2 option for the balance of the works at the discression of the Principal.

The VM workshop identified potential for substantial contract risks with two discrete contracts, one for manufacture of the hanbars and one for placement. These could result in claims from either of the contractors, the placement contractor could be delayed through insufficient stock, or the casting contractor could be delayed due to bad weather impacting on the placement contractor being able to work and thus clear the casting yard to make space for more units.

There was also some uncertainty as to whether the tender prices would be within the budget. To address these options the tender was structured in three parts to provide flexibility. Part A covered placement of hanbars and rock armour; Part B covered the concrete crest pavement; and Part C covered casting the balance of the hanbars.

A single contract was awarded to the JDS Group and work commenced on site in July. The program is contingent upon favourable weather conditions. The contract period is for completion in 78 weeks. The contractors optimistic program is for a finish before this date.

DISCUSSION

Not surprisingly, the design focus was the hydraulic and structural performance of the wall with a view to minimising repairs and maintenance for a design life of 50 years. With this planning horizon sea level rise is a real consideration and provision was made based on policy framework then in place. The design is such that further increase in crest height and placement of additional armour is facilitated by the wide crest, a marked contrast to the initial concept that contemplated armour along the crest to preclude access.

During the design and procurement process Crown Lands completed repairs to other breakwaters, notably Ballina to the north, and Camden Haven and Narooma to the south. These too used hanbar units and were designed with a focus on structural performance. Local communities were quick to point out service and aesthetic aspects of the repairs to be considered in future designs, these were: the hanbars lack the natural look of rock, and when placed along the crest of the structure block views; and crest treatment needs to be pedestrian and wheelchair friendly. The later service requirement can be problematic since wave energy can literally blow the crest off the underlying rubble structure leaving a potentially hazardous uneven surface with an ongoing maintenance requirement. The lesson learned for CHEB was consider the crest treatment and build something that provides viewing opportunities and reasonable public access.

Other lessons were: get the brief right; share information with the consultant; test the solution as it evolves with an understanding of the sensitivities to the various cost inputs.

REFERENCES

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