UPGRADING BREAKWATERS IN RESPONSE TO SEA LEVEL RISE: PRACTICAL INSIGHTS FROM PHYSICAL MODELLING

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INTRODUCTION

Coastal structures in many parts of the world are typically designed for depth-limited breaking wave conditions. With a projected sea level rise of up to 90 cm by 2100 (Church et al., 2013), the design wave height for these structures is expected to increase. Many of these structures will require significant armour upgrades to accommodate these new design conditions (for example, a 25% increase in wave height will require the mass of similar density armour to be doubled).

Many breakwaters and seawalls on the east coast of Australia are armoured with quarry rock, but these structures are difficult to upgrade because of the low availability of large rock material (it is not economic to supply quarry rock larger than approximately 8 t).

Concrete armour unit (CAU) structures do not have the same size limitations as quarry rock, but their stability depends on interlocking between units.

Much of the literature on seawall and breakwater adaptation is focussed on the economics of upgrades (e.g. Headland et al., 2011; Burcharth et al., 2014). Practical design guidance for retrofitting existing coastal structures with rock or concrete armour units is limited.

Upgrading of either rock or CAU structures by adding layer(s) of larger rock or different-sized CAUs may not achieve theoretical improved stability with climate change due to the creation of planes of weakness.

PHYSICAL MODELLING

This study followed on from preliminary work at the Water Research Laboratory (WRL) by Li and Cox (2013) and Harrison and Cox (2015), and was designed to investigate the effectiveness of retrofitting existing rock and concrete-armoured coastal structures with additional (and more stable) primary armour (Figures 1 and 2). Physical modelling was used to enhance our understanding of unconventional designs that may arise when coastal structures are upgraded in response to sea level rise and increased design wave conditions. Placing larger rock or CAUs over existing rock or CAU armour can be undertaken but stability is dependent upon achieving sufficiently high placement densities during construction - model testing is essential

The results of two retrofitting strategies are discussed in more detail :

1. Concrete armour above existing rock armour; and
2. High-density concrete armour

CONCRETE ARMOUR ON ROCK

Physical model testing was undertaken to examine the effectiveness of a single and double layer Hanbar CAU upgrade of a typical existing rock structure (Hanbar CAUs are commonly used in NSW). The Hanbars were found to perform very poorly when placed in a single layer upgrade - consistent with the high level of damage to the single-layer Hanbar upgrade on the Forster breakwater shown in Figure 3 after June 2016 storm. Hanbar CAUs were found to interlock very poorly with primary rock armour, and only performed well when placed in two layers.

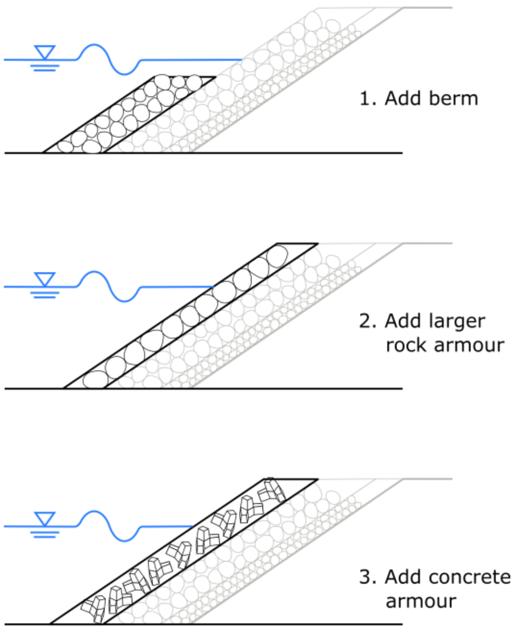

Figure 1 - Potential upgrade options for rock armour

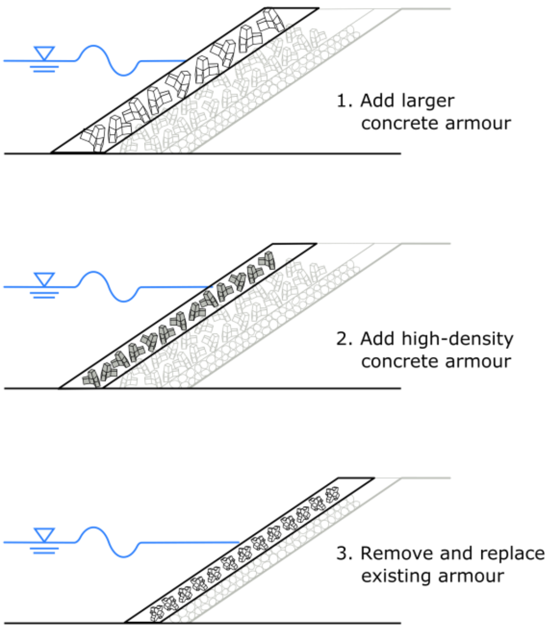

Figure 2 - Potential upgrade options for concrete armour.

Figure 3 – Forster breakwater head before (left) and after (right) June 2016 storm event (source: NSW Crown Lands).

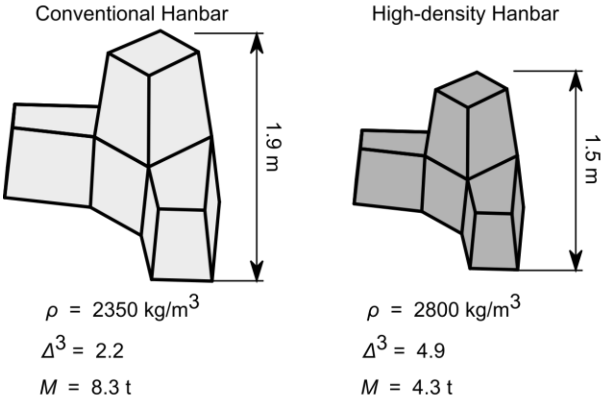

Figure 4 – Hanbar armour units with equivalent stability.

HIGH-DENSITY CONCRETE ARMOUR

To significantly increase relative submerged density and primary armour stability, the density of conventional concrete can be increased by replacing gravel aggregate (SG = 2.6) with steel furnace slag (SG = 3.0). The concrete product is however prone to cracking because of chemical reactions between Portland cement and the steel furnace slag. Recent advances in concrete technology have enabled the development of new products where Portland cement can be entirely replaced with geopolymer cement that does not react with steel furnace slag, making it suitable for use in high-density concrete (Khan et al., 2016).

Physical modelling was used to compare the stability of high-density (SG=2.8) and conventional concrete (SG=2.35) Hanbar units. The different units tested (Figure 4) had similar stability, confirming the breakwater design equations of Hudson (1959) and van der Meer (1987) which state that armour stability is inversely proportional to the armour submerged relative density, Δ, raised to the third power.

A single layer of high-density Hanbar CAUs has been shown in model testing to provide effective upgrading for existing two-layer CAU Hanbar structures, providing stability while retaining the same dimensions (ensuring good interlocking with existing armour units). This important result provides a potential upgrade pathway for all concrete armour unit structures in response to sea level rise. Prototype installation of 20 t high-density CAU Hanbars in a trial repair to a major coastal port in NSW Australia is planned for April 2018.

CONCLUSION

Physical modelling was used to enhance our understanding of unconventional designs that may arise when coastal structures are upgraded in response to sea level rise.

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