EVALUATION OF REPAIR METHODS FOR DAMAGED ROCK ARMOURED SLOPES

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BACKGROUND

Coastal communities are inheriting a growing list of ageing rock armoured revetments and breakwaters, many of which consist of rock armour that is undersized for current and future sea conditions. This is due to a myriad of reasons: changes in environmental conditions (beach levels or sea levels) since construction, design without sufficient data (i.e., long term wave records for extreme value analysis, or long term sea level trends), or design before current design guidance documents and laboratory investigations were published.-

When repairing a structure that consists of undersized rock armour, it is common design practice to utilise larger, more stable rock; however, a growing shortage of quarry sites and high-density development along coastal fringes (which limits site accessibility) has increased costs and difficulties sourcing and placing larger rock. Case studies by Stemm and Sorbello (2021), and Bakker (2023) demonstrate that Concrete Armour Units (CAU) can (in some cases) be preferable to rock armour, based on: cost, embodied carbon, and site constraints. However, dissimilar units (CAU, or larger rock sizes) within a repair are expected to have poor interlocking with existing rock armour and can introduce possible fault planes within a structure's armour layer matrix. This stability reduction is currently not explicitly quantified within The Rock Manual (CIRIA, 2007) or the Coastal Engineering Manual (CEM) (USACE, 2006). Both instead suggest applying design formulae such as the Van Der Meer (VdM) formula (Van der Meer, 1988) and the Hudson formula (Hudson, 1961), using engineering experience or 'common rules of thumb'.

Both the Rock Manual (CIRIA, 2007) and CEM (USACE, 2006) recommend that engineers conduct their own physical modelling to confidently quantify the stability of extensive repair options, specifically armour overlays and the use of dissimilar (larger, CAU's) units as a method to improve structure stability. However, this level of detail is often restricted by asset management budgets, especially in the case of smaller structures.

METHOD & ANALYSIS

This study aims to evaluate a range of potential repair options for an impermeable, double layer rock armoured slope and provide quantitative data to better understand the performance of typical repair options, and the effect of using differential sized and/or shaped units within each repair. Three repair options have been tested: minor (spot) repairs, moderate repairs (band infill of eroded area), and a full armour overlay (with regrade of underlying armour material). Three different armour units have been implemented in each repair method: a same sized rock armour unit, a larger rock armour unit, and a Hanbar CAU. Hanbar CAU's have been used as a repair unit alternative in this study because they have been used in multiple Australian and New Zealand breakwaters / revetments. Furthermore, they have a non-catastrophic failure (Blacka et al., 2005) that is comparable to rock armoured revetments. This allows for direct comparison of CAU's to rock units using the VdM formula, with adjustments to stability coefficients c_{pl}/c_s. Both c_{pl} and c_s are directly proportional to the stability number $H_s/\Delta D_{n50}$, and have been used to describe differences in rock armour shapes (Van Der Meer, 2021). The tested control structures and repair structures are outlined in Figure 1.

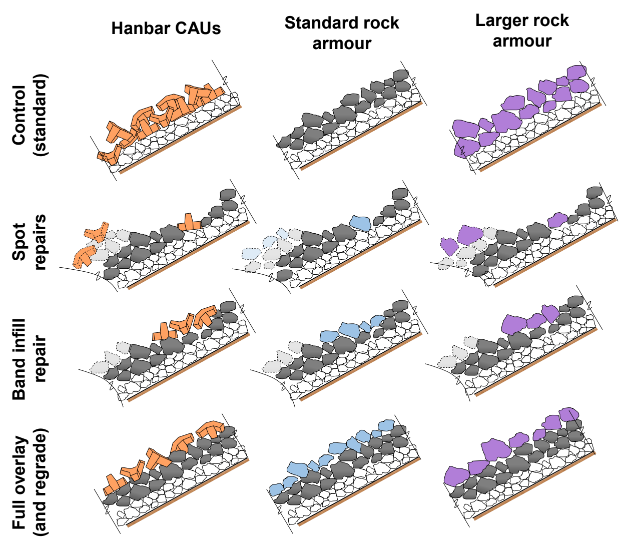

Figure 1 Tested structures within this laboratory investigation.

Model structures had slopes of 1V.1.5H, and were tested under plunging wave conditions. The study used incremental wave height loading on structures, and back-calculated non-accumulated damage by application of the cumulative damage method first discussed by Van der Meer (1985). Cumulative wave damage from different sequences of wave loading was also tested in comparison to the Van der Meer's method and the Melby (1999) formula, to ensure adequacy of this experimental approach.

Final damage measurements relied primarily on manual counting of unit displacement, as this study demonstrates that repair units with different sizes, shape, or density require careful separation from underlying armour units when applying stability formulae. Additional methods for damage measurement were also explored, with specific focus on the collection and processing of 3D model data from: high resolution 3D scanning, LiDAR enabled iPad scans, and photogrammetric models. The application of laboratory measurement methods is discussed in the context of present day data collection in the field.

RESULTS & CONCLUSIONS

Figures 2 (a to d) outlines the laboratory results for the different repair methods, highlighting variations of VdM's plunging stability coefficient, c_{pl} and notional permeability P for each structure. Each structure also had Hudson's K_D coefficient calibrated.

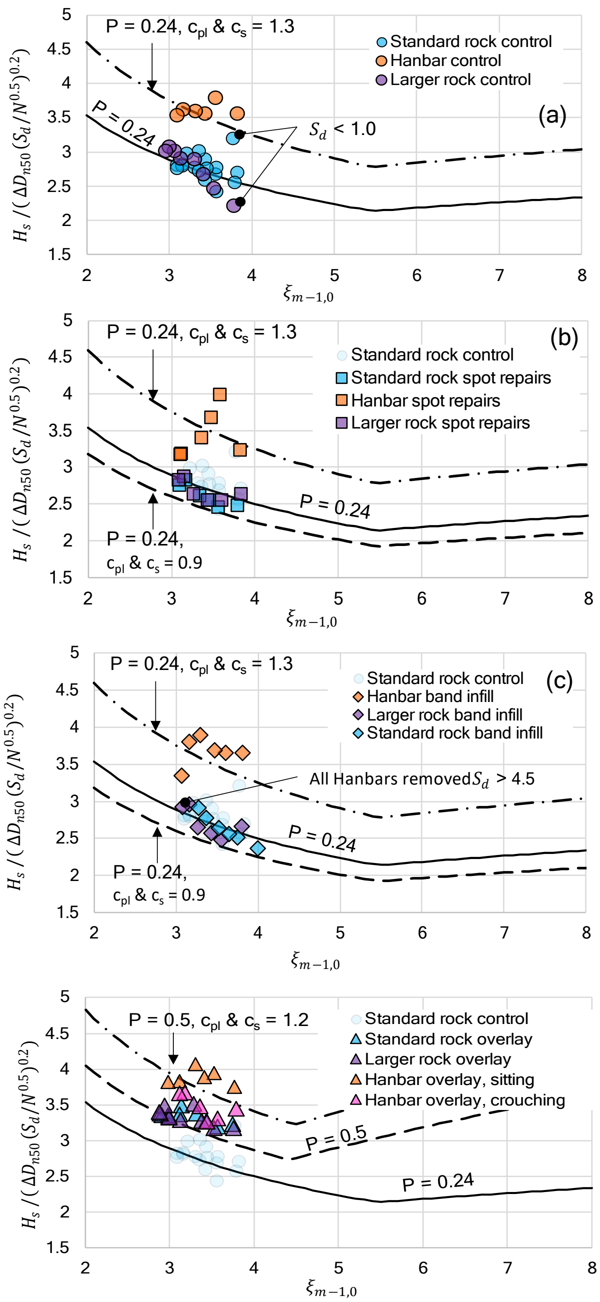

Figure 2 Performance of control revetments (a), spot repairs (b), band infills (c), and armour overlays (d).

Results show that the spot repairs have reduced stability coefficients compared to a new structure, because of decreased interlocking within the armour layer matrix. This is not immediately apparent in Figure 2(b), because the data points are presented for the structure as a whole (i.e., base armour + repairs). For example, the structure using larger rock spot repairs has an overall c_{pl} of 0.96; but isolating the repair method, based on proportional damage, results in a c_{pl} of 0.9.

Bank infill repairs show slightly improved stability compared to a new structure, likely due to the settlement and compaction of the structure during initial damage event. This could also be attributed to the formation of a slight berm from initial damage units that both provided a platform to found the repair on and helped dissipate wave energy. Laboratory experiments on armour overlays confirm findings by Eldrup et al. (2019): overlays created a triple layer of armour units, which both increased the tolerable damage of a structure and improved the stability of armour units through an increased structure permeability (P values raised from 0.24 to 0.55).

This study explores key questions such as: How do we measure damage of repairs, and incorporate repairs within stability formula? How does storm sequencing influence the stability of repairs? Does early intervention improve overall structural health and resilience? In answering these questions, this study will provide preliminary design guidance and supporting laboratory data for the repair and damage parameterisation of rock armoured slopes in the context of an uncertain future.

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