UNREAL XBLOCPLUS - USE OF A MULTI-MODEL APPROACH TO ASSESS SEISMIC AND POST-SEISMIC PERFORMANCE OF A SINGLE LAYER ARMOUR REVETMENT

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INTRODUCTION

The use of single layer, pattern placed concrete armour units for coastal edge protection in place of rock is becoming increasingly common. Revetments constructed from these units can provide benefits of a reduced footprint, reduced material usage and transport costs as suitable rock becomes increasingly difficult to source, and reduced construction timeframes (Bakker et al., 2023).

These units are, however, highly reliant on interlocking with surrounding units. While performance of these revetments has been the subject of rigorous testing under wave loading, they have not, to the authors' knowledge, been investigated under seismic loading. Damage under this forcing could be initiated by a range of failure modes including direct shaking leading to individual blocks being displaced and losing interlock, sliding failure with rows of blocks riding over those below and lateral displacement and deformation of the ground profile beneath the revetment. Following such an event, a damaged revetment may remain vulnerable to the impacts of storm waves until repaired.

PROJECT BACKGROUND

The Ngā Ūranga ki Pito-One Project is a major coastal infrastructure project within Te Whanganui-a-Tara, Wellington Harbour that comprises 4.5 km of coastal edge protection which provide improved resilience to the state highway and rail corridor and a shared (pedestrian/cycling) pathway. The project is being delivered by the Te Ara Tupua Alliance.

XblocPlus® units (1m^3) with unique and project-specific cultural, ecological and architectural modifications have been adopted as the primary armouring for the project (Foster and Shand, 2023). XblocPlus® (XP) units are pattern-placed interlocking armour concrete units that remain stable at steep slope angles while providing high coastal performance (DMC, 2022). However, these units have had limited application in seismically active regions and the Wellington Fault, on the boundary between the Pacific and Australian plates is located between 100 and 600 m offshore of the project site. Therefore, the behavior of the revetment during, and following seismic activity was of key interest to the project and was assessed in detail to assess performance and enable development of a post-seismic inspection and repair strategy.

MULTI MODEL APPROACH

The response of a revetment to seismic shaking, particularly the interlocking of the individual XblocPlus® units and interaction with the ground profile below is complex and could not be determined using a single method or model. Therefore, a suite of complementary models was used to assess the behaviour of individual components and combined performance of the revetment asset under the design earthquake events (Figure 1).

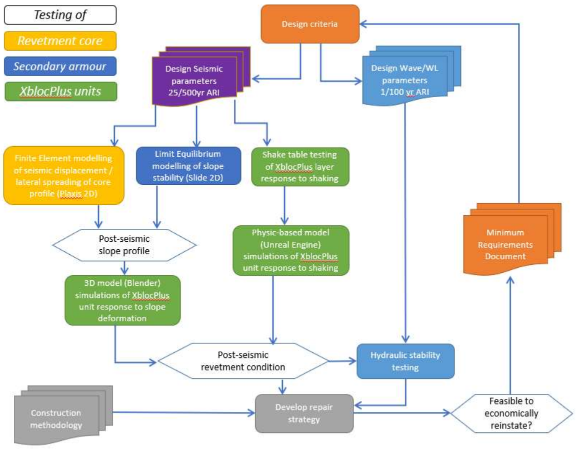

Figure 1 Approach taken to assess seismic and post-seismic hydraulic performance and to develop a repair strategy.

The physics-based model Unreal Engine (Epic Games, 2023) was calibrated against uni-directional testing on a physical shake table and run for 3D acceleration time history record for design earthquake events to assess how the individual XP units reacted to shaking. The use of gaming engine technology to study engineering problems is in it's infancy (Zhou, 2022) but offers a powerful platform to study and visualize physical processes and interactions. Results from both the physical shake table and Unreal model (Figure 2) showed XP units in the second or third row tended to ride over the lowest unit, which was more effectively restrained by the toe armour. As units rode over the lower units, they often tilted sideways, and the units above would also slightly rotate as their wings or noses lost full or partial contact with the unit below. Above the third row of units, the XP units generally remained well interlocked while moving down the slope slightly.

Limit equilibrium and time history finite element modelling were used to understand how the ground profile supporting the revetment might perform with the profile found to displace preferentially above the toe armour which acts as a partial restraint. These results were then used in the 3D physics-based model in Blender to determine the unit response to slope deformation with units on the third row and above pushed over the lower units with slight rotation, similar to the Unreal engine results. The response to both shaking and slope deformation was combined to create a post-seismic revetment which was then re-created and tested within a 2D wave flume at the UNSW Water Research Laboratory (Figure 3) to assess performance under moderate storm conditions before repairs could be enacted.

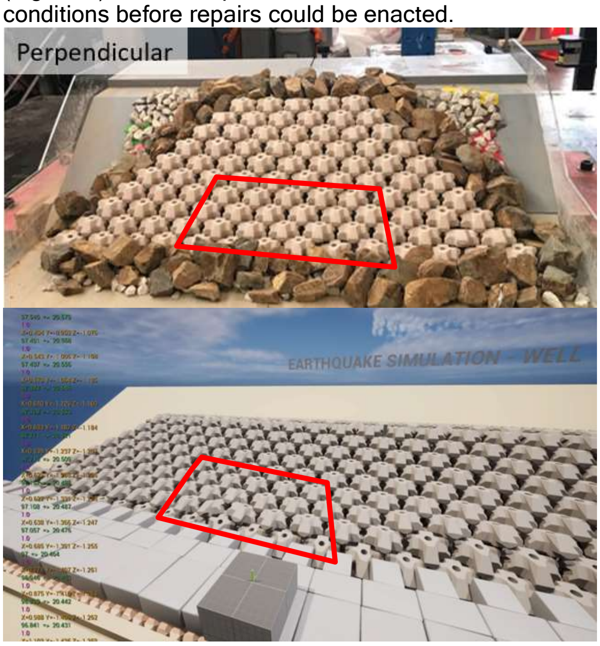

Figure 2 Example of the XblocPlus Revetment following a design seismic event using a shake table (1D - upper) and Unreal Engine (3D - lower).

For the typical conditions (less than 1 year return period), unit movement was very limited (<50 mm prototype). For larger (~1 year) events, units which has been displaced due to the seismic shaking (3rd row and above) shifted seaward up to 150 mm (prototype scale), causing overlying units (within a central wedge) to also move forward. However, these units generally retained their interlocked form and therefore were deemed to have performed acceptably. It is noted that on this project the units are over-sized ($1m^3$) for the design wave height (Hs = 2.74m) which likely improved performance of the damaged revetment.

Figure 3 Post seismic event profile constructed in the laboratory with the secondary armour and 3rd row of XblocPlus displaced forward with their noses and wings not interlocked.

REPAIR STRATEGY

The assessment results provided confidence that the revetment could maintain function following seismic and storm events allowing repairs to be enacted. A post-event inspection and repair strategy was developed including initial inspection, detailed above- and below-water survey, unpicking failed sections of units diagonally above the lowest units showing displacement, inspection and replacement of structurally damaged units (not assessed here), reinstatement of the profile and underlayers and replacement of the XP units.

CONCLUSION

Single-layer, pattern placed concrete armour units offer significant advantages over traditional double layer units or rock. They are, however, highly reliant on interlocking between individual units and their performance under seismic loading had not, to date, been thoroughly investigated. The processes that such a revetment is subject to during a seismic event are complex and no single modelling solution is currently available. A multi-model approach including use of a physics-based gaming engine was employed to understand the potential behaviors of a revetment slope and individual units to shaking, it's hydraulic performance following the seismic event, and to develop a repair strategy. While this study focused on a specific site, the methods employed would be generally applicable.

Flexible, physics-based simulators such as Unreal Engine are becoming increasingly powerful as they leverage advances in the gaming industry and GPU hardware and offer potential to investigate complex real-world engineering problems. Careful calibration and comparison with traditional models and engineering judgement remains a key requirement.

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