ARMOURSTONE PARAMETERIC DESIGN AND PATTERN PLACEMENT

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INTRODUCTION
Rock armouring is an efficient and economical method of stabilising coastal structures. The hydraulic stability under wave actions of graded rock armour in two or more layers has been the subject of model studies, field analysis, and design formulas that can estimate the quantity of damage on the armour for given wave action. Engineering principles[1] typically consider random placement, distributed armour graded, permeability constraints, and controlled stone interlocking. These four conflicting parameters interact in various ways. Design formula and practical experience in the laboratory and the field show that random amourstones are not entirely stable: some proportions of rocks are likely to be displaced over time.

ROCK ARMOUR GEOMETRY
The geometry or random armourstone structures is amorphous. Displacement occurs not only during or beyond the design storm conditions. The initial bedding of the structure, weathering and small wave action generate distortions. Many (if not most) randomly placed rock protection works form voids and cavities and evidence rock displacement. The shape of the armour changes with the appearance of voids in the primary armour, with a bulge at the water line, infill of secondary armour and a reduction of void ratio below the waterline.

On the opposite side of the spectrum[2], it is possible to design geometrically stable gravity-based blocs placed in a fully interlocked pattern. The relevance of placement of individual armour rock is not only a matter of wave stability but also long-term safety and appearance[3].

PARAMETRIC DESIGN
We investigated the pattern placement of rock armour has using parametric design principles. The parametric investigation process analysed random and semi-deterministic placement of armourstone on a slope, using Grasshopper®. A model layout of the rock quarry is shown on Figure 1.

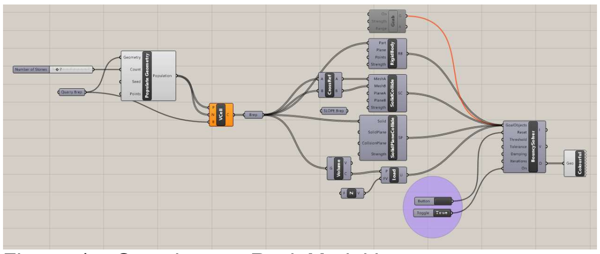

Figure 1 - Grasshopper Rock Model Layout

ROCK ARMOUR PATTERN PLACEMENT
The model was used to compute the armour void ratio, degree of interlocking and texture of the following placement pattern:

- "Hito" - Turtle shell with a finished surface that is both smooth and tight where the stones principal dimension placed perpendicular to the slope, avoiding straight lines
- Staggered with herringbone patterns and vertical placement
- Controlled with long dimension perpendicular to wave - this pattern may increase wave stability[4]
- Block modularisation - where the design use modularisation to deliver a structure with defined safety, environmental and aesthetic outcomes

RECOMMDED ARMOUR PLACEMENT PATTERNS
Construction is commonly carried out with excavator grabs for armourstones ranging 500kg to 5 ton. Excavator grab can be used to rotate stone and place stone into the armourstone matrix in a deliberate manner rather than in a full random pattern

A simple set of instructions were generated to assist to charaterise the quality of interlocking. The analysis of armourstone property and rock placement indicates that the following 3 principle increase amourstone stability:

Principle 1: Armourstone long dimension, or "principal dimension" should be orientated facing the wave direction for maximum stability
Principle 2: The largest flat face on armourstone surface is also the closest to the armourstone centre of mass. This "flat surface" should be interlocked in the armour system and not apparent on the finished surface
Principle 3: The armorstone "flat surface" should be in contact with other flat surface whenerver possible to reduce overturning moment and increase stability.

Figure 2 provides a sample to generate of site instruction a "turtle shell" type of placement where stones are placed in a partically controlled pattern.

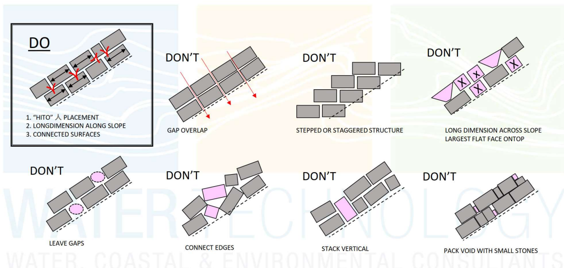

Figure 2 - Recommended primary armourstone placement patterns - Turle shell finish.

APPLICATION
The rock armouring renewal at Bridgewater Bay was carried out using parametric design principles.

The design process analysed random and semi-deterministic placement of armourstones. The final design used modularisation to meet performance to design loads and to deliver a structural aesthetics compatible with the site natural textures.

The seawall rock armour used a “turtle shell” placement while the viewing and sitting platforms used a palette of natural material to extend the texture of the reef, shared path and neighbouring cliffs in and out of the beach. The modularisation of armour works was fundamental to achieving a high-quality structure.

Figure 3 - Seawall texture and block placement - Tuttle shell, random block placement and blocks

Figure 4 provides typical contractor instruction provided to guide the placement of rocks in a simple set of “do and don’t” instructions. a “turtle shell” type of placement where stones are placed in a partically controlled pattern.

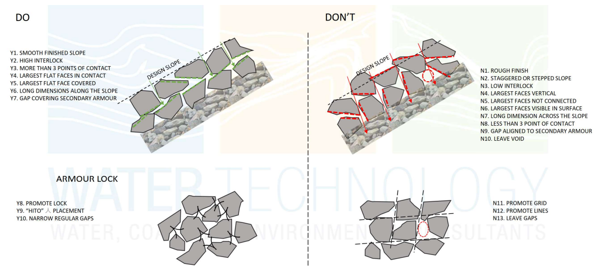

Figure 4 - Contractor instructions - Do and Don’t

FIELD VERIFICATION
The engineering verification has been carried out using an Iphone 12 Lidar Sensor with an accuracy of approximately 100mm[5]. The use of Lidar allows to calculate armourstone length, width, volume and void ratio as well as geometrical compliances including slope measurement and crest deviations.

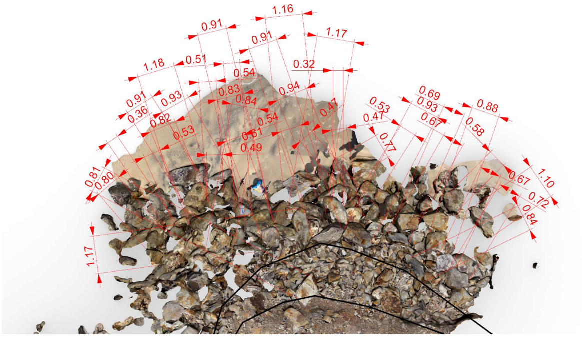

Figure 5 - LiDAR Scan used to calculate armourstone principal dimension.

Portable LiDAR was found to be extremely valuable during field inspections as it allows to consider the granular nature of the rock revetment.

REFERENCES
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