Physical modelling of novel upgrade strategies for the Maroochy River geotextile groyne field

Ian R. Coghlan[1], Dan Howe[1], James T. Carley[1], Gildas Colleter[2],
Dan Rodger[2], Georgia Keeshan[3], and Denis Shaw[3]
[1] Water Research Laboratory, School of Civil and Environmental Engineering,
UNSW Sydney, Manly Vale, Australia.
email: i.coghlan@wrl.unsw.edu.au
[2] Jeremy Benn Pacific, Spring Hill, Australia.
[3] Sunshine Coast Council, Maroochydore, Australia.

Abstract

This paper discusses physical modelling of geotextile sand container (GSC) groynes at Maroochydore, Queensland. The existing field of four groynes was one of the earliest GSC groyne fields constructed on the open coast in Australia, having been in place for up to 20 years. As with many GSC structures, the field was constructed as an interim trial, and utilised the largest readily available GSC units, namely 2.5 m^3. Little engineering guidance regarding their hydraulic stability was available at the time of initial construction. The groynes in their present condition suffer storm damage, requiring more maintenance than is desirable. This is likely to be a limitation for standard GSC groynes constructed from 2.5 m^3 containers on many open coasts.

One of the existing groynes was first modelled in its existing condition, with the model correctly reproducing GSC groyne damage observations from the site. Three different potential upgrade strategies (to be built on the bottom two layers of the existing structure) to improve the stability of the groyne were then tested. These included 2.5 m^3 GSCs in the standard stretcher bond arrangement, 2.5 m^3 GSCs in a herringbone pattern and larger 5.0 m^3 GSCs placed in stretcher bond. It was found that the herringbone pattern was more stable than standard stretcher bond placement, but that large 5.0 m^3 GSCs would provide the greatest improvement in stability and the greatest certainty, making lower maintenance GSC groynes feasible on the open coast.

This paper also compares the results of these tests with previous generic GSC groyne physical model tests conducted by WRL in 2008 and the performance of an existing GSC groyne Cardwell in Queensland during TC Yasi in 2011. Preliminary design guidelines have been updated which are broadly applicable for planning other GSC groyne structures elsewhere on the eastern Australian coast.

Keywords: groyne (groin), sandbag, geocontainer, geotextile sand containers, coastal structure.

1. Introduction

The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney completed physical modelling of the Maroochy River Groyne Field on behalf of Jeremy Benn Pacific (JBP) and the Sunshine Coast Council (SCC) for the renewal of the existing geotextile sand container (GSC) groynes at Maroochydore Beach near the mouth of the Maroochy River (Figure 1). The groynes in their present condition suffer storm damage, requiring more maintenance than is desirable. The objective of the physical modelling was to test the stability of 3 distinct upgrade options.

2. Model design

2.1 Test facility

Modelling was completed using WRL's 3 m wave flume, which is 32.5 m long, 3 m wide & 1.3 m deep.

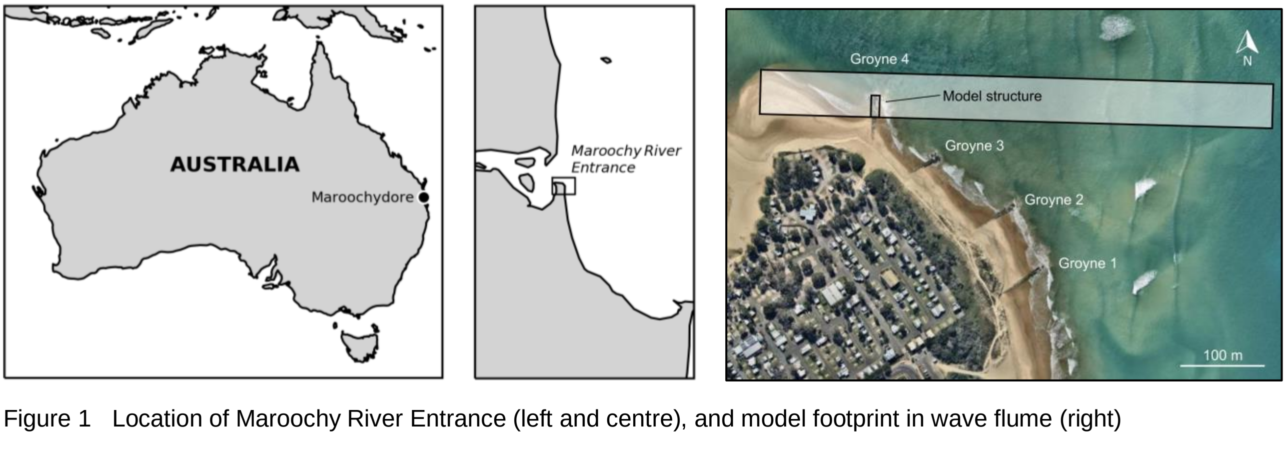

Figure 1 Location of Maroochy River Entrance (left and centre), and model footprint in wave flume (right)

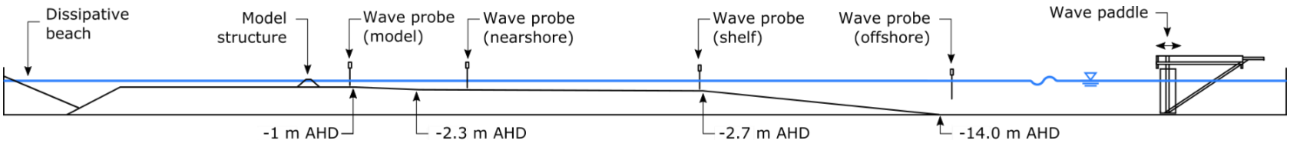

Figure 2 Model bathymetry and wave probe locations

2.2 Scaling

Model scaling was based on geometric similarity between model and prototype, using an undistorted Froude scale of 19. Selection of the length ratio was primarily based on fitting a suitable length of bathymetry within the length of the flume. All quantities are reported in prototype scale, unless otherwise noted. The scale ratios (prototype divided by model) derived for the study are summarised in Table 1 and followed the same methodology for scaling GSCs as [3]. Brief notes on GSC scaling considerations are included later in Section 2.4 (refer to Appendices A, B and C in [4] for a more detailed discussion on these matters).

Table 1 Froude scaling factors

Quantity	**Froude relation**	**Scaling factor**
Length (m)	λ	19
Mass (kg)	λ^3	6,859
Geotextile (ideal) tensile strength (N/m)	λ^2	361
Geotextile (ideal) hydraulic conductivity (L/m^2/s) & Time (s)	$\lambda^{1/2}$	4.36
Filler sand (ideal) grain diameter (m)	$\lambda^{1/4}$	2.09

The wave flume was filled with fresh (~1,000 kg/m^3) rather than salt water (~1,025 kg/m^3) to avoid corrosion of the hardware and to ensure responsible disposal of drained water. This is standard practice for almost all coastal hydraulic laboratories in the world [5]. Ideally, the density of the water and the sand in the geotextile containers would be the same in both the model and the real world. While the fresh water in the wave flume was 2.5% less dense than would be ideal, this potentially unconservative component was balanced by other conservative components, such as geotextile stiffness (tensile strength) and model bathymetry.

2.3 Bathymetry

The model was quasi three-dimensional (Q3D) in that it examined 3D effects of waves interacting with the groyne, but the bathymetry in the flume was two dimensional (2D). Bathymetric transects were extracted from a LIDAR survey by the Queensland Government on 20 April 2012 seaward of each of the four groynes in the field. The physical model bathymetry (Figure 2) was based on Groyne 4 (the northernmost groyne) but transects from the remaining three groynes were also considered, to ensure the tests were conservative and that results could be applied to the other three groynes, which will also be upgraded. A false floor with the following characteristics was adopted:

- Intersected structure at -1.0 m AHD (flat for 23 m seaward of the groyne centreline);
- 1V:23H slope from -1.0 to -2.3 m AHD;
- 1V:400H slope from -2.3 to -2.7 m AHD; and;
- Seaward of -2.7 m AHD the false floor sloped at 1V:10H until it intersected the permanent flume floor at -14.0 m AHD.

The model bathymetry extended a distance of 190 m (2.7 to 7.1 wavelengths depending on water level) seaward of the groyne structure centreline to the top of the 1V:10H transition slope. A 2D bathymetric profile was constructed in the 3 m flume as a false floor using blue metal gravel overlain with concrete capping. A recess was left in the concrete below the footprint of the model groyne structure.

The model groyne structure was built perpendicular to the walls of the 3 m wave flume. That is, wave attack was directly perpendicular to the long axis of the structure.

The model structure was built down to -2.0 m AHD (the design toe level at the head) and the recessed area was filled with fine grained sand up to the finished level of -1.0 m AHD (Figure 3). The adopted sand level of -1.0 m AHD in the model was based on a March 2017 groyne survey but should not be considered the lower limit for expected scour at the head. This burying of the structure toe avoided having an artificial hard boundary between the flume floor and the course of GSCs at the scour level. The sand around the model structure acted as a moveable bed, but no quantitative measurements of erosion or accretion of this material were completed as the moveable bed was qualitative only. The recessed area was refilled and levelled after reconstruction of each new model.

2.4 GSC fabrication

For construction of the model GSCs, in addition to the obvious geometric scaling, it was also necessary to consider other important properties of both the geotextile material and the filler sand. The model GSCs were fabricated from RELN GLS150 non-woven geotextile (typical thickness = 1.3 mm) to achieve geometrical properties that resembled full scale containers as closely as possible. The model geotextile containers were filled with fine-grained marine sand (d_{50} of 0.22 mm) sourced from Anna Bay on the NSW mid-north coast.

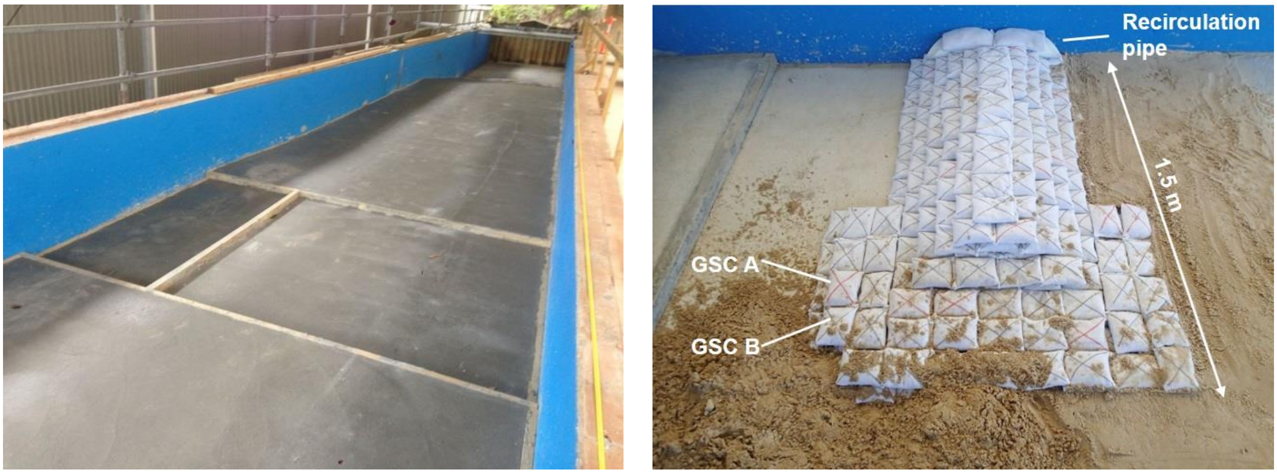

Figure 3 Recessed area (left) and backfilling sand around model structure (right)

With reference to the ideal Froude scaling factors for model GSCs (Table 1), the following properties were realised with the selected geotextile material and filler sand:

- the tensile strength of the geotextile was approximately two (2) orders of magnitude higher than ideal, however, the shape of the model GSCs was observed to be similar to the prototype installations justifying the model geotextile choice;
- the hydraulic conductivity of the geotextile was more conductive than the ideal material by a factor of approximately 25-50 (due to the relatively small thickness of the geotextile to the much wider extent of the filler sand, no significant scaling errors are likely because the selected geotextile has a higher hydraulic conductivity than the ideal material, as preferred); and
- the grain diameter of the filler sand was higher than ideal by a factor of approximately 1.5-2.2, however, no significant scaling errors are likely because the selected filler sand has a lower hydraulic conductivity than the selected geotextile material, as preferred.

Note that scaling factors achieved in the model GSCs have been presented as ranges because the prototype geotextile material and filler sand to be used in construction were not confirmed when the model design was undertaken.

Geotextile fabric to fabric friction may also be important for replicating the load required to dislodge GSCs from the armour layer, however analysis of this mechanical property was not possible because friction data was not available for the model geotextile material or any of the prototype materials being considered. Note that the model geotextile material and the likely prototype geotextile materials are all non-woven fabrics.

Prior to mass production of the model GSCs, several fabric shapes were initially trialled to investigate the resulting container shape that was produced when full. Once the required shape was achieved, cutting and stitching of the model containers was undertaken by a contracted upholsterer.

Model GSCs were constructed from a single rectangle of geotextile material folded in half and stitched on the two long sides to leave an opening at one of the short sides. The GSCs were filled with sand using electronic scales until they were within ±2 g (model scale) of their target mass, then the opening was folded and sealed with staples.

Three different types of GSC were constructed (Table 2). GSC A was based on an in-situ condition assessment and weighing which concluded that many of the GSCs (at the time of the assessment) contained less sand than their design capacity [6]. The GSC A units were filled to varying levels, based on an asymmetric gaussian distribution from the in-situ observations (Figure 4).

Table 2 Comparison of GSCs used in modelling

ID	Description	Nominal volume (m^3)	Wet mass (t)
A	Current condition	2.5	2.0 – 5.0
B	Initial specification	2.5	4.6
C	Double-size	5.0	9.4

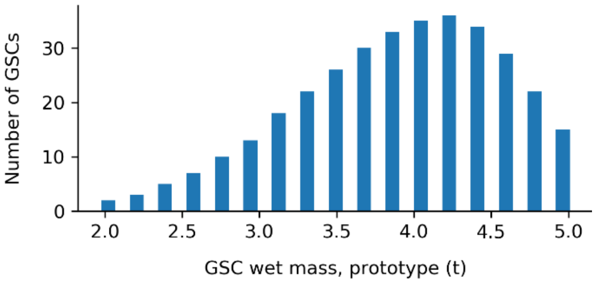

Figure 4 Mass distribution of GSC A units

Table 3 Comparison of target GSC dimensions with those achieved in the 19 scale model

Dimensions	**Units**	**GSC A**		**GSC B**		**GSC C**	
		Target	**Actual**	**Target**	**Actual**	**Target**	**Actual**
Typical length, L	m	2.40	2.36	2.40	2.36	3.60	3.61
Typical width, W	m	1.80	1.81	1.80	1.81	2.40	2.34
Typical depth, D	m	-	0.34 - 0.76	0.70	0.67	0.70	0.72
Mass of GSC after filling with air-dried sand	t	-	1.51 - 3.57	3.42 [1]	3.41	-	7.21
Mass of saturated GSC squeezed flat by hand	t	2.02 – 4.96	2.16 - 4.77	4.56	4.64	-	9.59
Submerged mass	t	-	0.82 - 2.09	1.76 [1]	2.06	-	4.37
Bulk volume	m^3	-	1.34 - 2.68	2.73 [1]	2.58	-	5.22
Dry bulk density	kg/m^3	-	1106 - 1333	1258 [1]	1322	-	1382
Saturated bulk density	kg/m^3	-	1596 - 1806	1673 [1]	1801	-	1838

1. Target values for some 2.5 m^3 GSC dimensions are average field measurements of 4 GSCs made by Blacka et al. (2008) [1].

GSC B was based on the initial GSC specification, with each unit filled to its design capacity. GSC C was a theoretical "double-size" design (not currently available commercially) that was calculated to have the same footprint as two 2.5 m^3 GSC units side by side, to allow tessellation with GSB A and GSC B.

To match the target specifications set out Table 2, GSC B units were fabricated first by filling them with air dried sand until the model GSCs matched the average inferred dry mass (3.42 t) of 2.5 m^3 GSCs measured in the field by [1]. The model GSCs were then saturated underwater, removed from the water, squeezed flat by hand and quickly weighed to determine their "wet mass" (4.64 t). This manual squeezing simulated the mechanical compression that occurred when the existing submerged GSCs at Maroochy were lifted out of the water in a net by an excavator [6]. This model GSC fabrication process increased the mass from the wet to the dry GSCs by approximately 35% and was repeated to confirm that the target specifications were also achieved by GSC A and C units.

GSC A units used the same size of geotextile material filled with varying masses of air-dried sand (less than, equal to and more than GSC B).

A target "wet mass" for GSC C units was not available prior to fabrication of the model GSCs. Instead, an empty geotextile container which would match the target dimensions was filled to qualitatively achieve a similar bulk density as GSC B units.

A comparison between the target geometric properties and those achieved in the model GSCs is shown in Table 3. The results indicate that the model GSCs were a good representation of the target prototype units.

2.5 Model construction

The footprint of the model structure extended across 50% of the total width of the flume, leaving space for waves to flow freely around the model. A short section of PVC pipe was installed against the flume wall, to allow recirculation and prevent artificially elevated water levels on the seaward side of the model. Model GSCs were marked with crosses (black for GSC A and C, red for GSC B) to aid in damage quantification during testing, and in subsequent photo and video analysis. The bottom two layers of the model structure were built to represent the base of Groyne 4 in its current condition (Figure 3 right). These same bottom two layers were re-used for all models.

Wave climate calibration was completed for five different water levels (Table 4) and one wave period. The wave climate consisted of 200 monochromatic waves with a wave period (T) of 12 s (40 minute total prototype test duration). Water levels were measured using four capacitance wave probes at different locations in the flume.

The incident wave height was adjusted until depth-limited breaking conditions were achieved, with waves plunging directly onto the structure, or as close to the structure as the bathymetry allowed.

Table 4 Measured test wave heights at structure

ID	Location	Water Level (m AHD)	H_{median} (m)	H_{max} (m)
T1	Offshore	0.51	0.2	0.3
	Structure	0.51	1.3	1.5
T2	Offshore	1.05	0.5	0.6
	Structure	1.05	1.6	1.9
T3	Offshore	1.55	0.7	1.1
	Structure	1.55	1.8	2.3
T4	Offshore	2.05	0.7	1.0
	Structure	2.05	2.4	2.9
T5	Offshore	2.55	0.9	1.2
	Structure	2.55	2.3	2.9

2.6 Model structures

Four different model configurations were tested (Table 5). Model 1 was constructed following the original design drawings for the Maroochy River Mouth erosion control works as closely as possible. Note that the variability of the Model 1 crest level (1.1 to 1.6 m AHD over a 20 m crest length) compared well to the March 2017 survey of the existing groyne crest level (0.8 to 2.1 m AHD over a 57 m crest length). Models 2 to 4 were constructed over the bottom two layers of Model 1. Sketches and photographs of the four models are shown in Figure 5.

The configurations for Model 2 (herringbone placement pattern) and Model 3 (5 m^3 GSCs) were novel and have not been tested in the field.

Table 5 List of model structures

Model	GSC ID	GSC dimensions (L×W×H; m)	Wet mass (t)	Crest Level (m AHD)	GSC count [1]
Model 1	A	2.4 x 1.8 x 0.7 [2]	2.0 – 5.0	average 1.3 (range 1.1 - 1.6)	130
Model 2	B	2.4 x 1.8 x 0.7	4.6	average 1.9 (range 1.8 - 2.0)	203
Model 3	C	3.6 x 2.3 x 0.7	9.4	average 1.8 (range 1.7 - 2.0)	77
Model 4	B	2.4 x 1.8 x 0.7	4.6	average 1.6 (range 1.5 - 1.7)	136

1. Does not include 216 GSCs in bottom two layers.
2. Height is smaller for partially-filled GSCs.

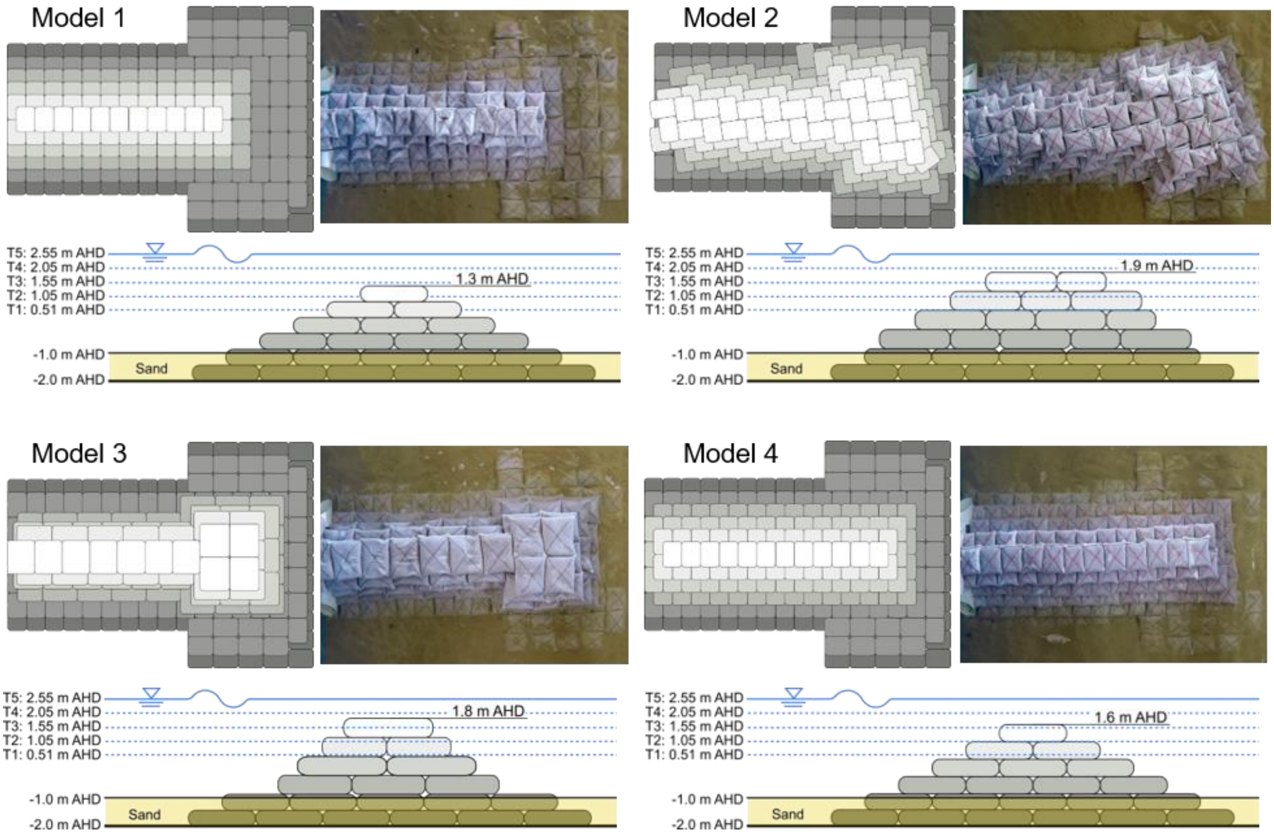

Figure 5 Model configurations

3. Testing and results

Structural damage was quantified using three damage classes: minor, major and loss (Table 6).

Table 6 Damage definitions

Damage type	**Description**
Minor	GSC rocking; or GSC sliding (distance < 0.25 GSC lengths); or GSC twisting (angle < 5º).
Major	GSC sliding (distance > 0.25 GSC lengths); or GSC twisting (angle > 5º).
Loss	GSC completely displaced from structure.

Model 1 was tested at water levels T1, T2 and T3. Models 2 to 4 were tested at all five water levels. The models were not repaired between tests.

The progressive damage sustained on each structure is shown in Table 7. An example illustration identifying where different damage types occurred for the current condition (Model 1) for each water level is shown in Figure 6 (refer to [4] for illustrations for the other three models). Damage that occurred close to the flume wall (within 3.6 m prototype; the width of 2×2.5 m^3 GSCs) was not included in the totals if it was determined to be caused by edge effects from the wall or the recirculation pipe.

The current condition (Model 1) sustained substantial damage (consistent with field observations) and was not tested at the higher water levels. Models 2, 3 and 4 all had greater overall GSC stability than Model 1.

The 13 GSC A units completely displaced from the Model 1 structure (lost) after the three-test sequence were predominantly from the lower half of the "wet mass" distribution; only two GSCS were heavier than the median "wet mass" of 4.04 t.

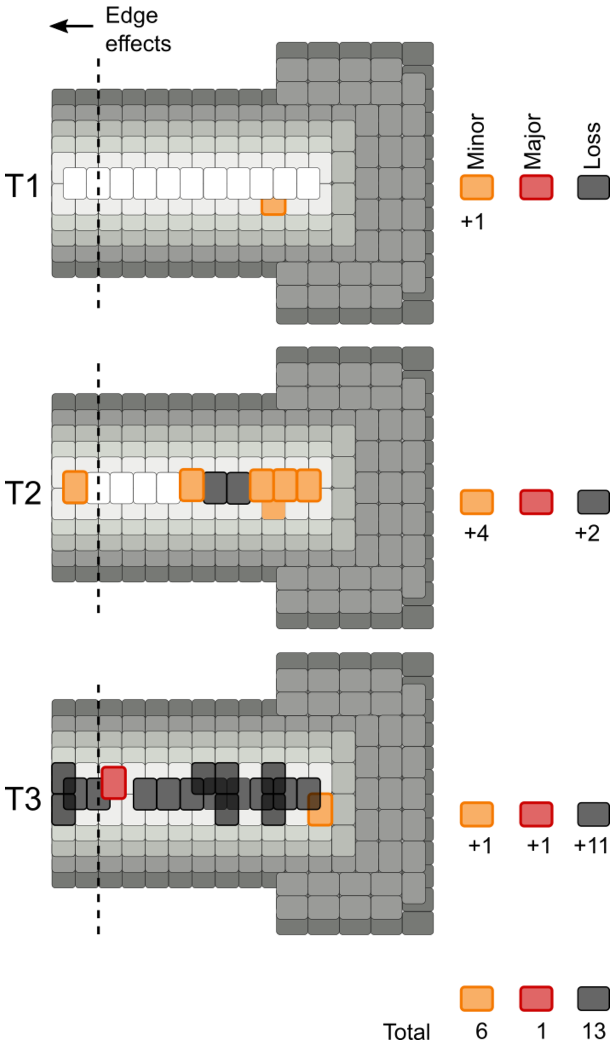

Figure 6 Progressive damage for Model 1; the current condition (note waves were travelling from bottom to top)

Table 7 Summary of damage (number of GSC units per damage type)

Water level	**Model 1**			**Model 2**			**Model 3**			**Model 4**		
	Minor	**Major**	**Loss**	**Minor**	**Major**	**Loss**	**Minor**	**Major**	**Loss**	**Minor**	**Major**	**Loss**
T1: 0.51 m AHD	1	0	0	0	0	0	0	0	0	0	0	0
T2: 1.05 m AHD	4	0	2	1	0	0	0	0	0	11	0	0
T3: 1.55 m AHD	1	1	11	0	5	2	7	0	0	0	0	7
T4: 2.05 m AHD	(1)			0	1	0	0	0	0	0	0	0
T5: 2.55 m AHD	(1)			0	2	3	0	1	0	2	0	2
Total	**6**	**1**	**13**	**1**	**8**	**5**	**7**	**1**	**0**	**13**	**0**	**9**

1. Water levels T4 and T5 not tested for Model 1 due to extensive model damage in prior tests.

4. Comparison with previous modelling

A preliminary stability line (Figure 7) for groynes constructed from 2.5 m^3 GSC in a stretcher bond arrangement was published previously [2]. This was based on generic GSC groyne physical model tests conducted at 13 scale by WRL in 2008 using monochromatic waves (10 s wave period) and the performance of an existing GSC groyne at Cardwell in Queensland during Tropical Cyclone Yasi in 2011 (8-9 s peak spectral wave period near storm peak).

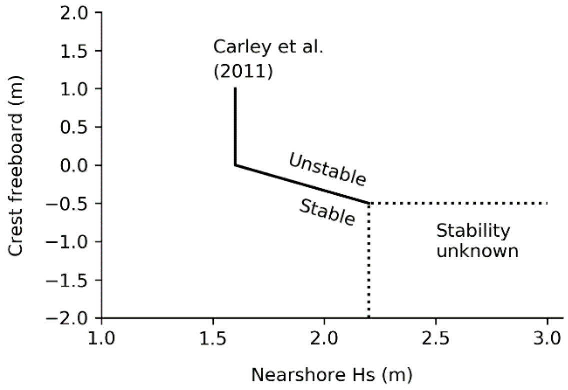

Figure 7 Original 2.5 m^3 GSC groyne stability line from [2]

The Model 4 (2.5 m^3 stretcher bond) results for the Maroochy project were then analysed in the same terms: crest freeboard versus wave height. Damage incurred at the highest water level (2.55 m AHD) occurred in the region of previously unknown stability [2]. As a result, the preliminary stability line for 2.5 m^3 stretcher bond GSC groynes has been updated (Figure 8). It is acknowledged that the new data points used a longer wave period of 12 s and that no additional GSCs were lost at 2.05 m AHD.

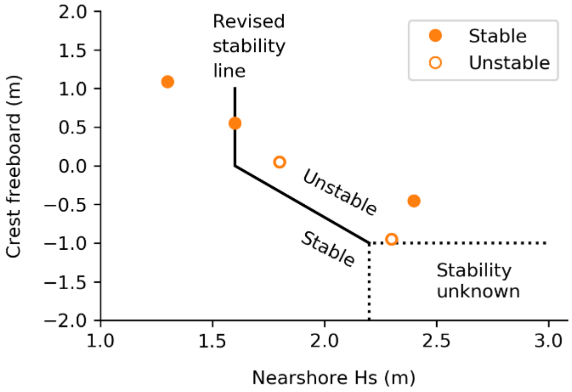

Figure 8 Model 2 data & revised 2.5 m^3 GSC stability line

5. Conclusion

WRL completed Q3D physical modelling for the replacement of existing GSC groynes near the mouth of the Maroochy River at 19 scale. Model 1 was based on Groyne 4 in its current condition, and Models 2 to 4 re-used the bottom two layers of Model 1 and represented potential upgrade strategies to improve the stability of Groyne 4.

The models were tested with plunging depth-limited waves at five different water levels starting at 0.51 m AHD and increasing up to 2.55 m AHD. Each of the model test structures is listed below in order of increasing stability under wave attack:

- Model 1: current condition, 2.5 m^3 GSCs filled to their in-situ distribution;
- Model 4: stretcher bond (long axis of GSCs perpendicular to wave crests), 2.5 m^3 GSCs;
- Model 2: herringbone pattern, 2.5 m^3 GSCs; &
- Model 3: stretcher bond (alternating GSC orientation for each layer), 5.0 m^3 GSCs.

The stability results for the current structure condition (Model 1) emphasise the importance of quality control during filling of GSCs on site and of ongoing monitoring to ensure that the design stability is achieved and maintained for groynes.

These tests have been used to improve the preliminary design guidelines for groynes comprising 2.5 m^3 GSC in a stretcher bond arrangement which can be used to plan other structures elsewhere on the eastern Australian coast. They have also highlighted the potential improvement in hydraulic stability that can be achieved by placing these in an alternative herringbone arrangement. Additional testing is recommended to develop a generic stability line for this novel placement method.

If 5 m^3 GSCs can be reliably assembled at prototype scale, they show great promise for producing very stable GSC groyne structures in the future.

6. References

[1] Blacka, M.J., Carley, J.T. and Cox, R.J. (2008), Field Measurement of ELCOMAX® ELCOROCK® Geocontainers at Clifton Springs Boat Harbour, Victoria, WRL Technical Report 2006/06, Report prepared for ELCO Solutions Pty Ltd, July 2008.

[2] Carley, J.T.; Coghlan, I.R.; Blacka, M.J.; Cox, R.J. and Hornsey, W. (2011), Performance of sand filled geotextile container (geocontainer) structures in North Queensland during Tropical Cyclone Yasi, , Proceedings of the Coasts and Ports Conference, Engineers Australia.

[3] Coghlan, I., Carley, J., Cox, R., Blacka, M., Mariani, A., Restall, S., Hornsey, W. and Sheldrick, S. (2009), Two-Dimensional Physical Modelling of Sand Filled Geocontainers for Coastal Protection, Proceedings of the Coasts and Ports Conference, Engineers Australia.

[4] Howe, D., Coghlan, I.R. and Carley, J.T. (2019), *Physical modelling for the Maroochy River groyne field renewal project*, WRL Technical Report 2018/42, Final Report Revision 1, 29 March 2019.

[5] Hughes, S.A. (1993), *Physical models and laboratory techniques in coastal engineering*, World Scientific.

[6] JPB, (2018), “In situ bag inspections (DRAFT)” – Note to file, JBA Project Code 2018s0702, Jeremy Benn Pacific, Brisbane.