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Preliminary Testing of Oyster Clumps

WRL TR 2019/08 | June 2019

By D Howe, I R Coghlan and W C Glamore

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1 Introduction

Oyster reef restoration is a growing field of reef rehabilitation. In functioning systems, oyster reefs improve water quality, provide habitat for other species and potentially reduce intertidal riverbank erosion from wind waves and boat waves. In Australia, OceanWatch Australia Ltd (hereafter "OceanWatch") has led the use of oyster shells in coir (coconut fibre) bags to regenerate reef structures. Deliberately utilising only organic materials, the fibres will naturally decay with the intention of leaving a new, intact oyster reef structure (a living shoreline) behind.

In 2015, the Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney completed preliminary two-dimensional (2D) physical modelling of (dead) oyster shell filled bags (Coghlan et al., 2016). The investigation identified threshold wave heights for initiation of oyster bag rocking and displacement. Additional investigations were subsequently undertaken by Dunlop (2016) to further detail oyster bag stability under various conditions.

For the present investigation, OceanWatch commissioned WRL to undertake additional physical modelling of live oyster clumps in three (3) different configurations. Completed on 26 February 2019, these tests included:

1. Unrestrained live oyster clumps (e.g. unbagged and no stakes);
2. Live oyster clumps restrained by timber stakes (e.g. unbagged); and
3. Live oyster clumps inside coconut coir bags supported by timber stakes (for direct comparison with previous loose-packed, dead oyster shell bag results).

Live clumps were tested as an alternative to (dead) oyster shells to accelerate and/or increase the chances of the successful formation of a new oyster reef structure prior to the decay of any additional organic materials (e.g. stakes, bags) present.

OceanWatch intends to install live oyster clumps (in one of the test configurations) at a range of Australian sites fronting relatively protected waterways. The outcomes from these preliminary tests, which assessed hydraulic stability and reduction in wave energy reaching the shoreline, will be provided to OceanWatch's partner organisations (such as the relevant local Councils) as evidence of design development. Note that this study was not site specific, other than considering relatively protected (locations not exposed to ocean swell) tidal sites in Australia. See Coghlan et al., (2016) for discussion of the adopted wave and water level conditions.

2 Model design

2.1 Model testing facility

2D testing was completed in the three metre wave flume at WRL. This flume measures approximately 32.5 m in length, 3 m in width and 1.3 m in depth. The flume walls are constructed of rendered brick. The permanent, horizontal floor of the flume is constructed of concrete. 2D testing was undertaken using the centre of three, 1 m wide mini flumes built internally within the wider 3 m flume (Figure 2.1), restricting the model oyster clump model crest length to 1 m.

Figure 2.1 WRL 3 m wide wave flume, with 1 m wide mini-flume

The wave generator in this flume is a paddle type powered by a 55 kW hydraulic piston system. The system is capable of generating both monochromatic and irregular wave spectra. The input signal is generated and delivered to the wave paddle using a PC and the National Instruments LabVIEW software package.

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 the responsible disposal of drained water.

2.2 Model scaling

All tests were completed at full scale (i.e. an undistorted length scale of 1:1).

2.3 Bathymetry

The oyster clump models were located on an existing impermeable false floor in the wave flume constructed from blue metal fill overlain with concrete capping and had the following characteristics:

- 1V:400H slope from the structure to 180 mm below the structure toe; and
- 1V:10H until it intersected the permanent flume floor at 610 mm below the structure toe.

While the 1V:400H false floor was not purpose-built for the oyster clump modelling, it was used opportunistically and considered within the range of foreshore profiles at possible deployment locations in relatively protected waterways in Australia. Note that the slope of existing 1V:400H false floor was milder than the previous tests conducted in 2015 (1V:55H) which resulted in slightly less aggressive wave breaking on the model structures (see Section 3) for the same wave period and water depth combinations.

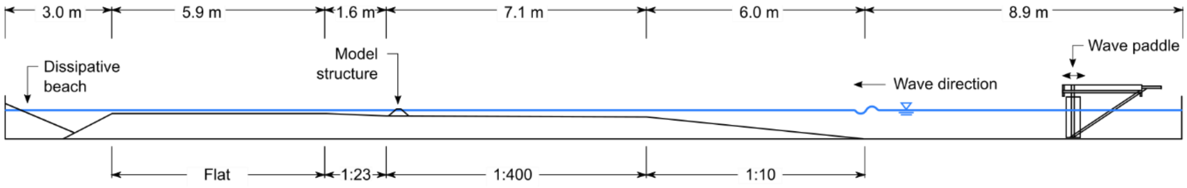

Figure 2.2 Model bathymetry in 3 m flume

There was a 6.5 m length of the 1V:400H bathymetric profile seaward of the model structure (Figure 2.2). At the highest water level tested (0.32 m depth at the toe), this length corresponds to 5 wavelengths with 1 s wave period, 2 wavelengths with 2 s wave period or 1.4 wavelengths with 3 s wave period. The tests for 2 s and 3 s wave periods are not in accordance with the minimum recommended value of 3-5 wavelengths recommended by Hydralab (2007) for physical modelling for coastal structures. However, given the preliminary nature of these tests, the shortened bathymetric profile length seaward of the oyster clump models is considered reasonable and allowed for the possible water depths and wave heights at the structure to be maximised on the existing false floor.

2.4 Characteristics of oyster clumps

The clumps were supplied by OceanWatch and were made up of Sydney rock oysters (*Saccostrea glomerata*) sourced from Brisbane Water, NSW (Figure 2.3 and Figure 2.4). The clumps were removed from the estuary the day prior to testing and returned to Brisbane Water the day after testing. A small number of native mussels were included within the clumps of oysters.

Figure 2.3 Example oyster clumps being removed from an oyster lease in Brisbane Water (Source: OceanWatch)

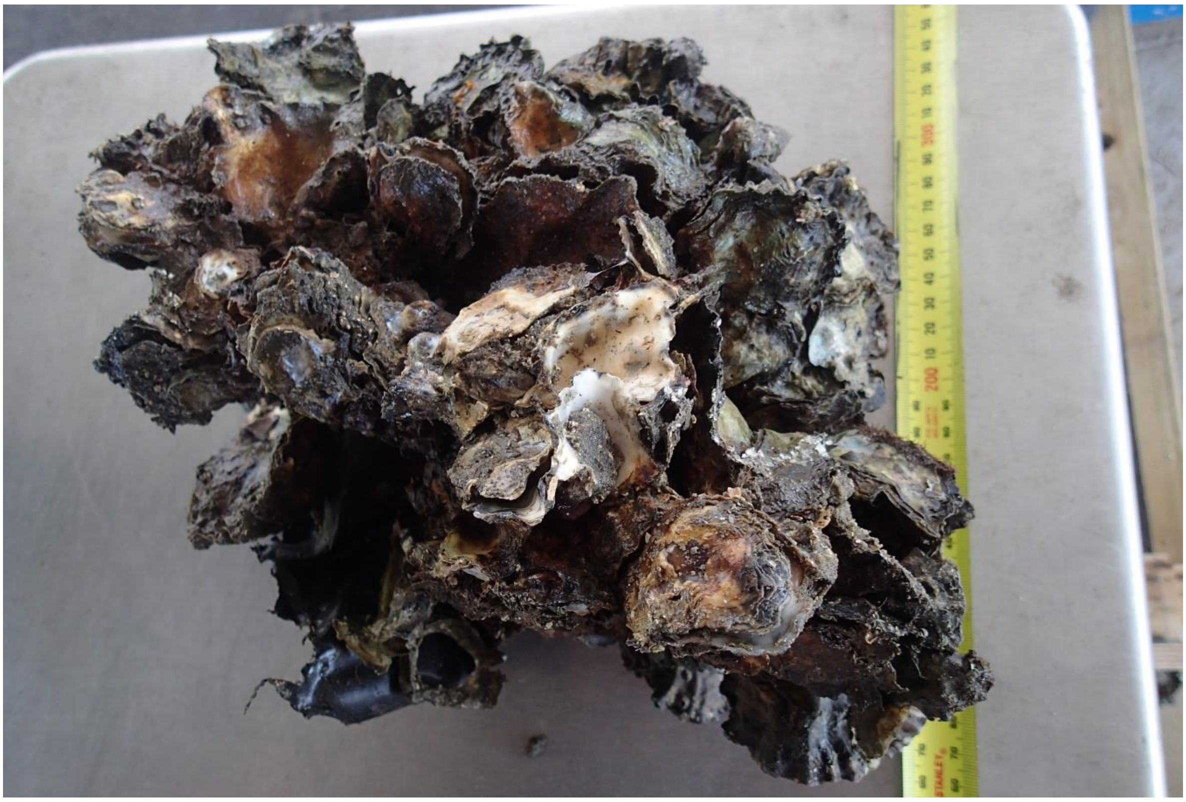

Figure 2.4 Example oyster clump tested

The total mass of the oyster clumps used in the modelling was 72 kg (e.g. 72 kg of oyster clumps per lineal metre of structure). The full mass of oyster clumps was used for Models 1 and 2, however approximately 60 kg was used for Model 3. Each oyster clump was weighed using electronic scales, and the dimensions of a representative sample of clumps were also measured (Figure 2.5). Distributions of length, width, and height are shown in Table 2.1 and Figure 2.6.

Figure 2.5 Weighing and measuring oyster clumps

Table 2.1 Dimension statistics of oyster clumps

	Length (mm)	Width (mm)	Depth (mm)	Mass (kg)
Minimum	70	60	30	0.01
Median / M_{50}	110	110	80	0.51
Maximum	270	230	170	3.26

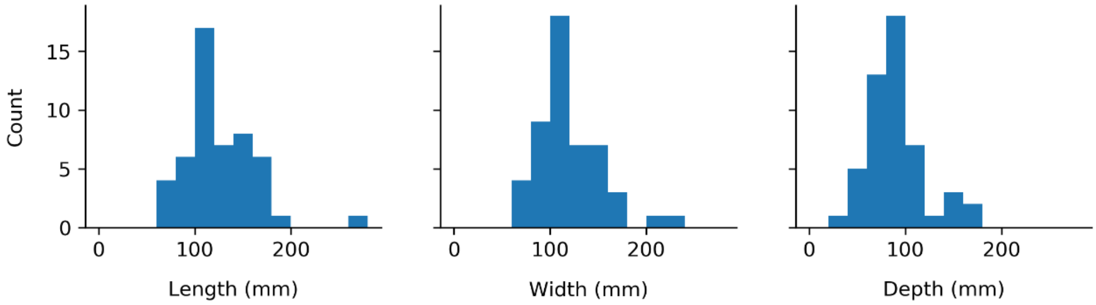

Figure 2.6 Dimension distributions of oyster clumps

The mass grading of the oyster clumps is shown in Figure 2.7. The median oyster clump density was calculated to be 1780 kg/m^3, based on measurements of dry and submerged mass from six (6) clumps with a range of sizes (Figure 2.8 and Figure 2.9).

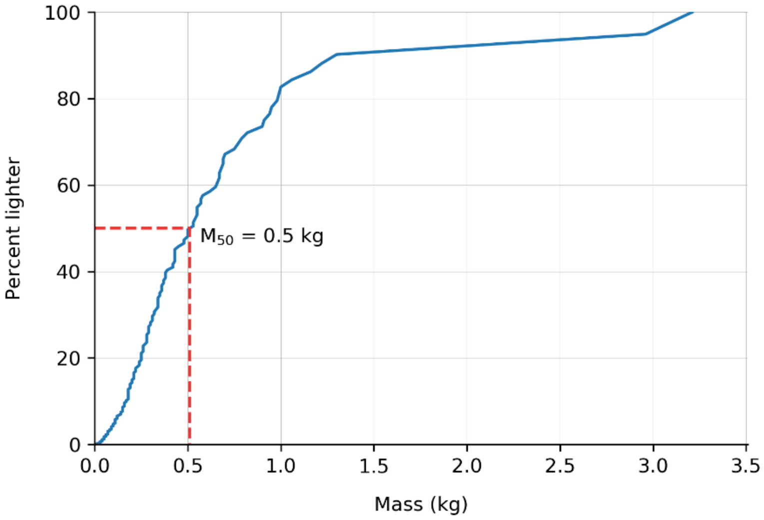

Figure 2.7 Mass grading curve of oyster clumps

Figure 2.8 Photograph of sample oyster clumps tested for density

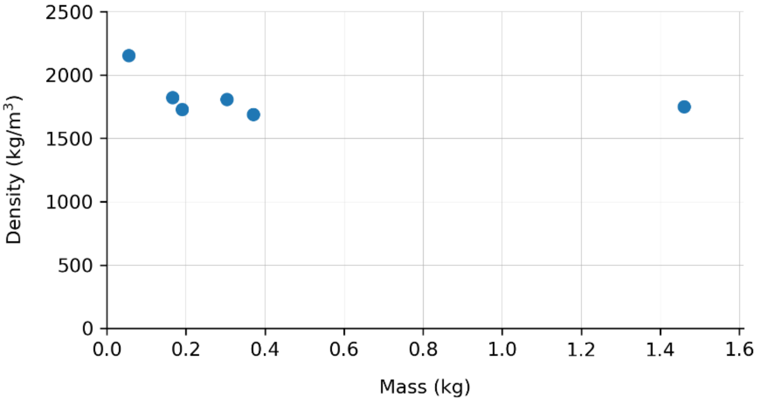

Figure 2.9 Density of a sample of oyster clumps

The following key parameters for Models 1 and 2 were estimated:

Bulk Volume:	0.144 m^3
Bulk density:	501 kg/m^3; and
Porosity (based on oyster clump density of 1780 kg/m^3):	0.72 %.

Each of the three (3) single bags filled with live oyster clumps (Model 3) was measured and weighed prior to testing. Key measurements are summarised in Table 2.2. Treating the bags as elliptical cylinders, bulk volumes were estimated for each bag. Bulk densities were inferred from these calculations with a range between approximately 430 and 485 kg/m^3. Based on the median oyster clump density of 1780 kg/m^3, the porosity of the oyster clump bags was approximately 73-76%.

Table 2.2 Summary of live oyster clump filled bag dimensions (Model 3)

Bag ID	Mass (kg)	Length (mm)	Width (mm)	Depth (mm)	Bulk Volume (m^3)	Bulk Density (kg/m^3)	Porosity (%)
1	19.63	0.95	0.30	0.19	0.041	482	0.73
2	19.45	0.99	0.32	0.18	0.045	434	0.76
3	21.35	0.97	0.31	0.20	0.045	471	0.74
Total	60.43				0.131		

2.5 Model construction

Three different model configurations were tested (Table 2.3, Figure 2.10 and Figure 2.11). The cross-section of the three models was constructed to approximately match that of the two (2) tier (dead) oyster shell filled bag structure tested previously (Coghlan et al., 2016). Models 2 and 3 used timber stakes (25 mm × 50 mm × 450 mm; includes 110 mm spike length), which were screwed into the concrete false floor via hot dipped galvanised steel brackets and a marine plywood plate. For Model 3, the same bag material was used as per previous tests (Coghlan et al., 2016): coconut coir netting with 12 mm × 12 mm aperture with seams sewn with Manila rope.

Table 2.3 Model configurations

Model	Stakes	Bags	Description
1			Unrestrained live oyster clumps
2	✓		Live oyster clumps restrained by timber stakes
3	✓	✓	Live oyster clumps inside coconut coir bags supported by timber stakes

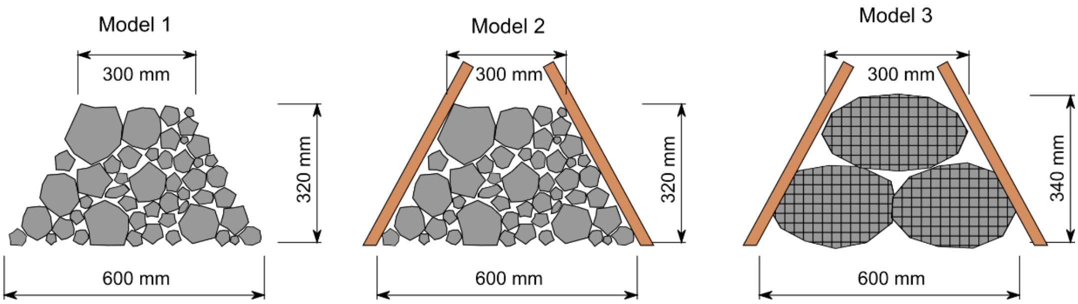

Figure 2.10 Cross sections of different model configurations

Figure 2.11 Different model configurations (top: Model 1, middle: Model 2, bottom: Model 3)

2.6 Instrumentation

Wave heights were measured at four (4) locations using capacitance wave probes (Figure 2.12). The 'deep' and 'seaward' probes were used to validate the incident waves before significant shoaling had occurred. The 'leeward' wave probe was located 430 mm from the leeward toe of the structures and was used to measure wave transmission through/over the model structures. After the test program was complete, the tests were repeated with the model structure removed from the flume. Incident wave heights at the location of the model structure were measured using the 'structure' probe in these repeat tests, to minimise the impact of wave reflection.

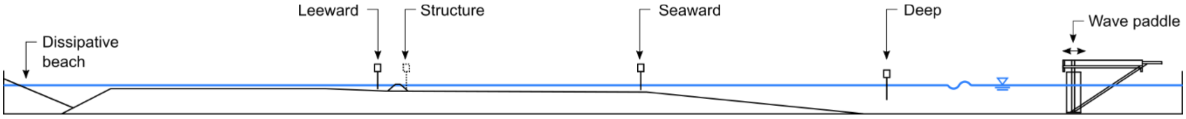

Figure 2.12 Wave probe locations

2.7 Test conditions

Each of the three models was tested at two water levels: 0.16 m and 0.32 m. At each water level, the model was exposed to 5 – 10 regular waves of different periods: 1 s, 2 s; and 3 s (Figure 2.13).

These wave and water level conditions are equivalent to those used for testing the (dead) oyster shell filled bags previously. The two water depths correspond to the top of first and second tiers of a 2 tier (dead) oyster shell filled bag structure. Please refer to Coghlan et al. (2016) for discussion of the adopted wave and water level conditions.

Wave heights were initially small (~0.02 m), but were progressively increased (in increments of ~0.01 m), until one of two criteria was satisfied:

- The model experienced structural failure; or
- The maximum (depth-limited) wave height was reached for that water level.

Model 2 was not tested with a water level 0.16 m, because it was assumed to be stable for all waves at this depth. Model 3 was only tested at the maximum depth-limited wave height for each depth/period combination, because of its greater stability. A total of 78 tests were completed (42 tests on Model 1, 30 tests on Model 2, and 6 tests on Model 3).

All reported wave heights are median values. Waves smaller than 50% of H_{max} were ignored.

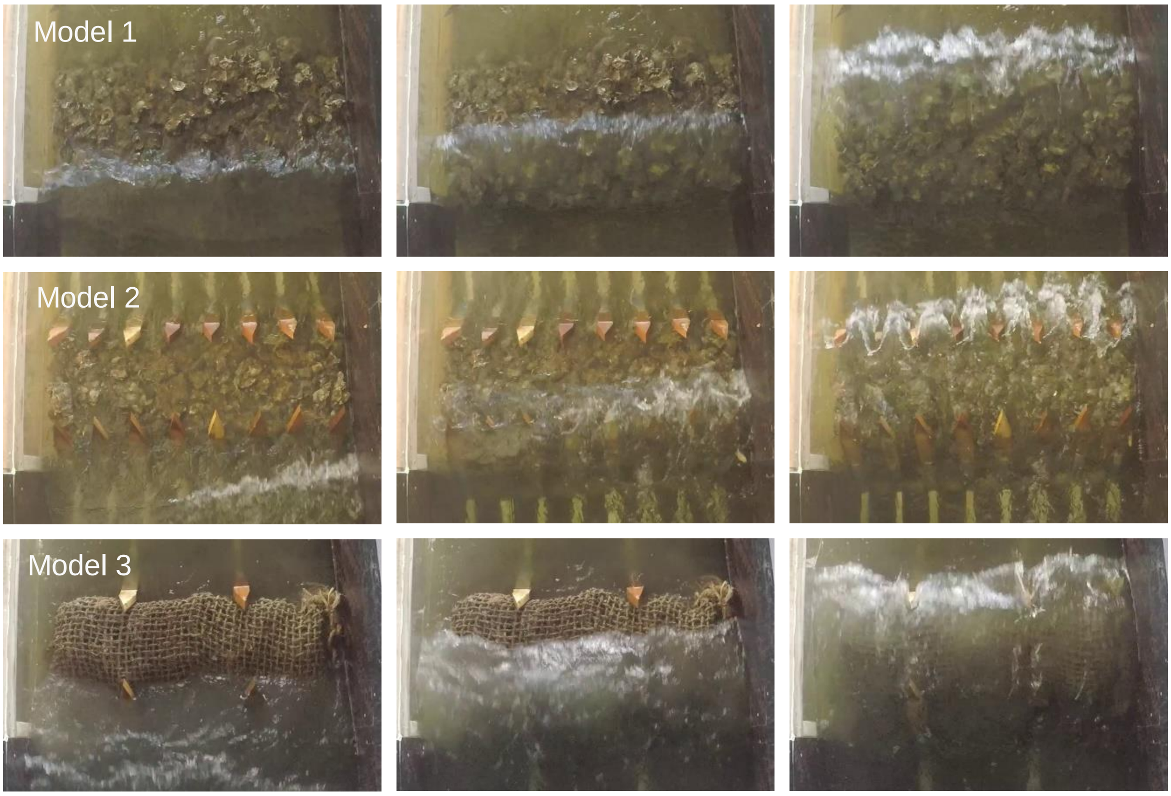

Figure 2.13 Sequence of waves breaking on oyster clump models

3 Results

3.1 Oyster clump stability

Structural damage was defined using three descriptors:

- Rocking: visible back-and-forth movement of clumps (Figure 3.1);
- Displacement: permanent removal of oyster clumps from the structure; and
- Failure: loss of more than 2% of the total mass of clumps from the structure (Figure 3.2).

Figure 3.1 Rocking of clumps in Model 1 with D=0.32 m, T=2 s, and H= 0.08 m

Figure 3.2 Failure of Model 1 with D=0.32 m, T=1 s, and H= 0.11 m

Model 1 was stable at the lower water level of 0.16 m, but experienced structural failure at the higher water level of 0.32 m for wave heights between 0.06 m (T=3 s) and 0.11 m (T=1 s). The oyster clumps displaced after the structural failure of Model 1 were identified and weighed, with M_{50} values of 0.58 kg (T=1 s), 0.2 kg (T=2 s), and 0.18 kg (T=3 s). Models 2 and 3 were stable for all depth/period combinations (Table 3.1).

Table 3.1 Maximum wave heights tested

	Depth (m)	H_{median} (m)		
		Period = 1 s	Period = 2 s	Period = 3 s
Model 1	0.16	0.06	0.07	0.06
	0.32	0.11 A	0.08 A	0.06 A
Model 2	0.16	(-) B	(-) B	(-) B
	0.32	0.12	0.16	0.20
Model 3	0.16	0.05	0.05	0.06
	0.32	0.10	0.16	0.20
Coghlan et al (2016) C	0.16	0.09	0.13	0.14
	0.32	0.15	0.24	0.23

A – Structure failed at this wave height.

B – Structure not tested at this water level (assumed to be stable).

C – Depth-limited wave heights were larger in Coghlan et al., (2016) because the bathymetry was steeper.

The structural damage observations for Model 1 and Model 2 are shown in Figure 3.3. The movement of oyster clumps in Model 2 was limited to the region inside the stakes, with one exception (one oyster clumps was displaced outside the stakes for D=0.32 m, T=1 s, and H= 0.12 m; see Figure 3.4). No rocking or displacement was observed for Model 3.

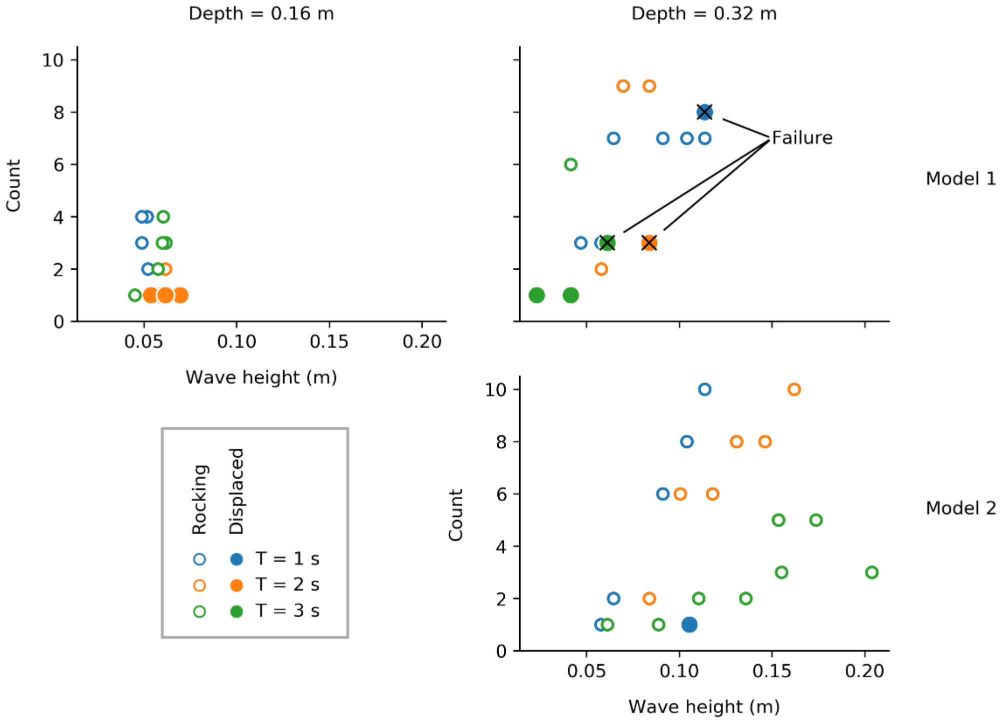

Figure 3.3 Observations of structural oyster clump damage

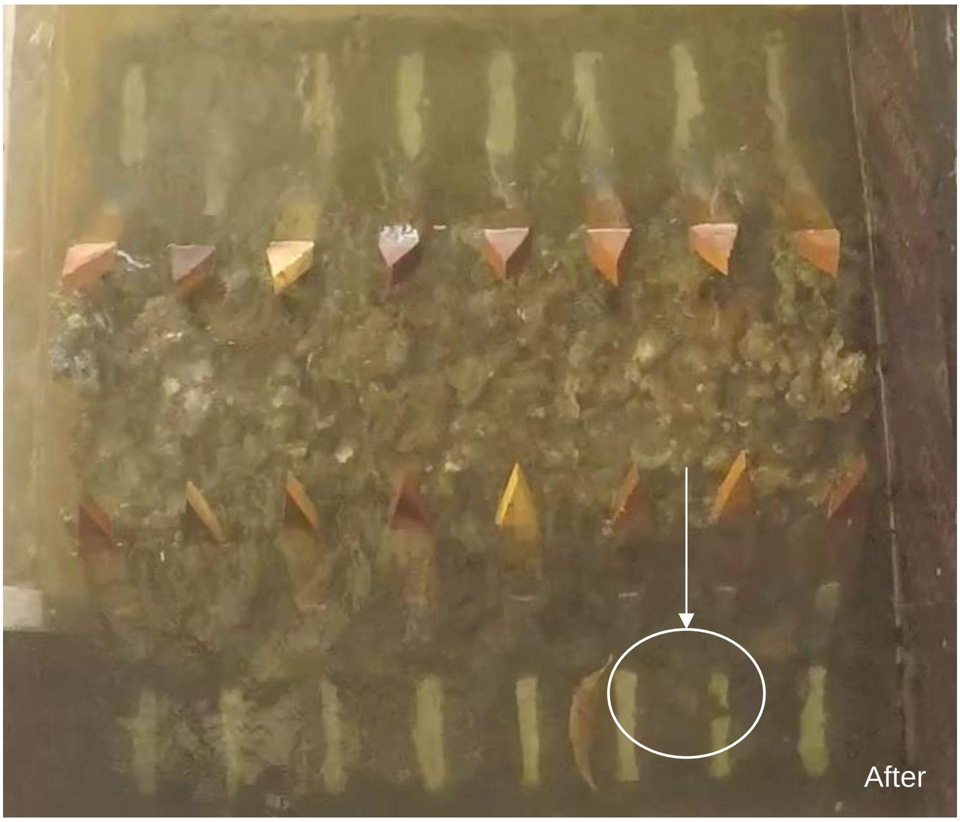

Figure 3.4 One oyster clump outside stakes of Model 2 with D=0.32 m, T=1 s, and H= 0.12 m

3.2 Wave transmission

To quantify the reduction in wave height (attenuation) as a direct result of the presence of the oyster clump model structures, wave transmission through/over the clumps was evaluated using Equation 3.1.

$$C_t = \frac{H_t}{H_i} \qquad (3.1)$$

where: C_t = transmission coefficient

H_i = the incident wave height on the seaward toe of the structure

H_t = the transmitted wave height on the landward side of the structure

Wave transmission coefficients were calculated for all wave heights at each depth/period combination (Figure 3.5). For each wave period and water depth combination, wave transmission was similar for all three (3) models. However, it is acknowledged that at the higher water level of 0.32 m, the wave transmission results are not directly comparable because Model 3 was 20 mm higher than Models 1 and 2 (refer to Figure 2.10).

Since wave energy is proportional to the square of wave height, when the water level was equivalent in elevation to the crest of the oyster clump structure (D=0.32 m):

- wave heights were reduced by 0-55% and wave energy was reduced by 0-30% for both Model 1 (unrestrained clumps) and Model 2 (clumps restrained by stakes); and
- wave heights were reduced by 25-60% and wave energy was reduced by 5-40% for Model 3 (bagged clumps).

When the water depth was half the height of the oyster clump structure (D=0.16 m):

- wave heights were reduced by 55-85% and wave energy was reduced by 30-70% for Model 1 (unrestrained clumps); and
- wave heights were reduced by 65-75% and wave energy was reduced by 40-60% for Model 3 (bagged clumps).

While Model 2 was not tested at the lower water level of 0.16 m, on the basis that the wave reduction characteristic of Models 1 and 2 were nearly identical at the higher water level of 0.32 m, Model 2 is expected to have similar wave height and energy reductions as Model 1 at D=0.16 m.

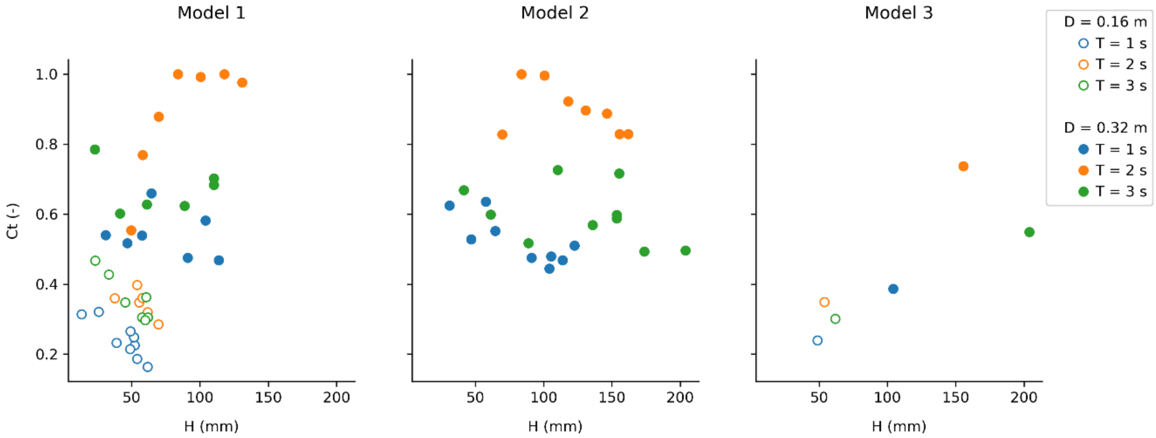

Figure 3.5 Wave transmission coefficient (Ct) for different wave heights and periods

The wave transmission coefficients for the six (6) Model 3 tests compared favourably with the results of Coghlan et al. (2016) for unrestrained bags filled with (dead) oyster shells, with C_t values typically within 10-20% of the values from the previous study (Figure 3.6). However, in contrast to Coghlan et al. (2016), the transmission coefficients were largest for waves with T=2 s, rather than T=3 s.

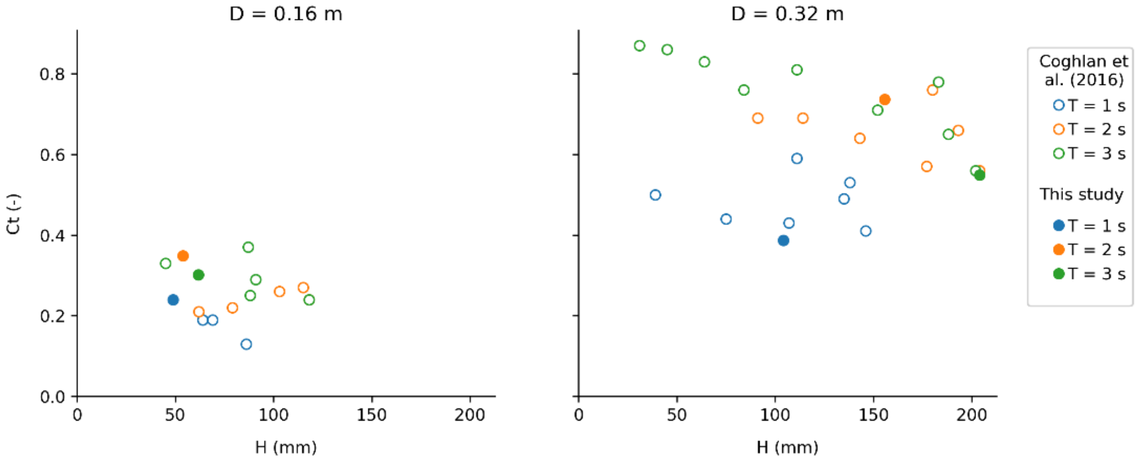

Figure 3.6 Comparison of wave transmission results for bagged live oyster clumps (Model 3) with bagged dead oyster shells (Coghlan et al., 2016)

As a direct result of the presence of an oyster clump structure, some existing wave-driven foreshore erosion processes are expected to be attenuated immediately landward of the structure. However, the reduction in wave energy impacting the shoreline leeward of a structure will vary with water depth. Note that this attenuation may not occur during very high tides.

4 Conclusion

Physical model testing of live oyster clumps was undertaken in a 1 m wide section of a wave flume. Three different configurations were tested:

- Model 1: Unrestrained live oyster clumps;
- Model 2: Live oyster clumps restrained by timber stakes; and
- Model 3: Live oyster clumps inside coconut coir bags supported by timber stakes.

Model 3 was included for direct comparison with previous loose-packed, dead oyster shell bag results described in Coghlan et al. (2016). The models were exposed to wave attack from packets of 5 – 10 monochromatic waves of period 1 s, 2 s, and 3 s, at water levels of 0.16 m and 0.32 m (as per Coghlan et al., 2016).

Model 1 was stable at the lower water level of 0.16 m, but experienced structural failure at the higher water level of 0.32 m for wave heights between 0.06 m (T=3 s) and 0.11 m (T=1 s). That is, for water depths up to 0.32 m, unrestrained oyster clumps are stable for wave heights up to 0.05 m.

Models 2 and 3 were stable for all depth/period combinations. That is, live oyster clumps had equivalent hydraulic stability whether restrained by stakes or placed within coconut coir bags. This is an important finding if OceanWatch considers restraining oyster clumps by timber stakes to be a less laborious construction method in the field than bagging (with stake supports).

The longevity and durability (e.g. lifetime fatigue, biological decay and vandal resistance) of the bag material for Model 3 were not tested in the wave flume but are critical considerations for establishing the design working life for a similar structure in the field. To a lesser extent, the timber stakes for Models 2 and 3 are also susceptible to biological decay. In comparing the advantages and disadvantages of restraining clumps with stakes (Model 2) versus bagging clumps with stake supports (Model 3), biological parameters outside the scope of this study need to be taken into consideration. For example, the bag material for Model 3 is expected to provide the additional benefits of predator protection and restriction of clump movement during spat settlement.

The calculated wave transmission values for bagged live oyster clumps (Model 3) were broadly consistent with the previous results for bagged dead oyster shells (Coghlan et al.,2016). As such, whether live oyster clumps or dead oyster shells are placed in coconut coir bags, similar attenuation of wave-driven erosion processes are expected immediately landward of the structure.

5 References

HYDRALAB III (2007), Wolters, G., Van Gent, M. R. A., Mühlestein, D., Kirkegaard, J., Allsop, W., Gironella, X., Fortes, J., Capitão, R., Sousa, I., Pinheiro, L., Santos, J., Hamm, L. and Bonthoux, L., *Guidelines for Physical Model Testing of Breakwaters: Rubble Mound Breakwaters*, Deliverable NA3.1-2, Final Report (Version 1.3), European Commission.

Coghlan, I. R., Howe, D., and Glamore, W. C. (2016), *Preliminary Testing of Oyster Shell Filled Bags*, WRL Technical Report 2015/20. Water Research Laboratory, School of Civil & Environmental Engineering, UNSW Sydney.

Dunlop, T. (2016), *Optimal Oyster Reef Design for Shoreline Protection Using Combinations of Oyster Shell Filled Bags and Sandbags*. Honours Thesis, UNSW, Sydney, 184 pages.