Hydraulic modelling of oyster growth bricks under current action

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Executive Summary

Oysterheaven Ltd. (OH) proposes to place bricks of 0.3 x 0.15 x 0.2 m dimension into the subtidal zone as a base for the development of oyster reefs. 1:8 scale model tests were conducted at Southampton University's Hydraulic Engineering Laboratory to assess the stability under the effect of a (tidal) current of individual blocks, block mounds, block mats and block pallets of 0.85 m height. The tests showed that blocks laid in a pellet configuration (Test 1) remained stable up to an average full scale current velocity of 1.04 m/s ('impinging' or near bed velocity of 0.88 m/s). Linking the pellet configuration by a loose string did not substantially affect the stability of individual bricks (Test 2). However, once the linked blocks of the pellet are re-organised by the current on the bed (Test 3), they remain stable up to an average full scale velocity of 1.83 m/s ('impinging' velocity of 1.75 m/s). When not linked by the string, a mound of bricks laid on the bed (Test 4) withstood a maximum average full scale velocity of 1.56 m/s ('impinging' velocity of 1.21 m/s). Finally, a one-layer of bricks configured as a 3×3 matrix linked by a string (Test 5) was able to withstand a maximum average velocity of 1.47 m/s ('impinging' velocity of 1.07 m/s). These tests were conducted with bricks laid on a surface that is relatively smoother than the typical sediment sea bed environment. It is therefore possible that bricks on the sea bed may be able to withstand higher velocities than reported here.

In a second test series, groups of 84 bricks were dropped from the water surface to assess the spread of the bricks at the sea bed as a function of the water depth. The results indicated that the bricks drop with a spread through water angle of $\sim$33 degrees relative to the vertical. At full scale, the water depths would be of 2.4, 4 and 4.8 m with an average diameter of the spread on the sea bed of 4, 4.8 and 6.4 m.

The further analysis of the problem indicated that the stability of the bricks needs to be investigated further if there is wave action present at the deployment site or if the seabed characteristics (e.g. fine sand) may lead to the blocks sinking into the ground, or to the development of scour around the groups of bricks.

Contents

1 Introduction **4**

2 Experimental methods **4**
2.1 Experimental facilities 5
2.2 Measurement equipment 5
2.3 Scaling and similarity 9
2.4 Characteristics of the models and tests conducted 12

3 Results **16**

4 Summary and conclusions **19**

5 Limitations and further work **19**
5.1 Effect of wave action 20
5.1.1 Waves 20
5.1.2 Effect of waves and current on brick stability 20
5.1.3 Recommendation 21
5.2 Effects of sediment bed and other considerations 21

1 Introduction

This report was developed by the investigators at the University of Southampton (hereafter also referred to as UoS) as part of a consultancy contract between the University and Oyster Heaven (hereafter also referred to as OH). The duration of the project was approximately two months with the start date on 13 November 2023, and completion on 15 January 2024.

The activities described in this report were aimed at understanding the stability of blocks (hereafter also referred to as bricks) developed by OH under the action of current. These blocks are designed and manufactured by OH to facilitate the growth of oysters on seabed, with the aim of restoring native oyster reefs. Therefore, they are exposed to hydrodynamic action, such as current drag and, in certain scenarios, may also be exposed to wave action. These actions may destabilise the desired configuration of blocks, leading to failure. To design oyster reef restoration projects that will withstand those actions, it is important to understand precisely under what conditions the blocks fail (e.g. the value of the threshold flow velocity leading to the entrainment of blocks). To gain a detailed knowledge of these conditions, OH commissioned the UoS to conduct scaled model tests in one of the flume facilities at UoS.

In addition, to the study of stability under current, a group of tests were conducted to assess the spread of bricks deployed from the water surface. These tests are aimed at predicting the area of the bed surface that would be covered by the bricks when deployed by releasing a number of bricks from the water surface.

The following sections of this report describe the steps taken to determine the flow conditions under which blocks are set in motion by the current. Section 2 describes the methods used, including the facilities, measurement instruments, scaling considerations, the characteristics of the tests, and other relevant information. Section 3 presents the results of the tests. Section 4 presents a short summary of the conclusions of the work. Finally, section 5 discusses some of the limitations of the tests conducted, and presents further tests that would be required to overcome those limitations and reach more refined conclusions.

2 Experimental methods

This section describes the experiments used in this project. First, the experimental facility and measurement equipment are introduced. Second, the scaling considerations used to define the dimensions of the models are discussed. This analysis also defines the main scaling factors that can be used to convert variables measured in the physical model to predicted values at prototype (i.e. real-world) scale. Finally, a description of the tests performed and of the experimental procedure followed during each test is presented.

Figure 1: GUNT HM 161 Recirculating Flume at Boldrewood campus, University of Southampton.

2.1 Experimental facilities

The experiments described in this report were conducted in the GUNT HM 161 recirculating hydraulic tilting flume located at the Boldrewood Campus of the University of Southampton (Figure 1). The flume is 16 m long, 0.60 m wide and 0.80 m high. A tilting mechanism enables users to adjust the slope of the flume from a negative 0.5% to positive 2.5%. Two centrifugal pumps (shown on Figure 2) are used to recirculate water in the flume, with a combined maximum capacity of approximately 430 m^3/h (i.e. approx. 120 l/s). The slope of the flume and the flow discharge are selected by the flume operator via a panel located on the side of the flume (Figure 3). The panel also displays the readings from a Endress-Hauser Proline Promag 10 Electromagnetic flow meter, which is installed in the pipe that supplies water to the flume's inlet. Under sub-critical flow conditions, water surface elevations in the flume are controlled by a gate located at the downstream end of the flume (Figure 4). Flow straighteners are installed near the flume's inlet to reduce turbulence.

2.2 Measurement equipment

To characterise the flow conditions inducing the motion of the blocks, flow velocity and depth measurements were undertaken. The depth of the flow was measured using a point gauge. Two methods were used to determine the flow velocity. The first method was the Particle Imagery Velocimetry (PIV), by which the motion of seeding particles in suspension in the water is recorded via

Figure 2: Centrigufal pumps used to recirculate water in the flume. Notice that the small pump on the left is used to recirculate sediment, and was not used in the experiments described in this report.

Figure 3: Control panel used to set the flume's slope and the flow discharge.

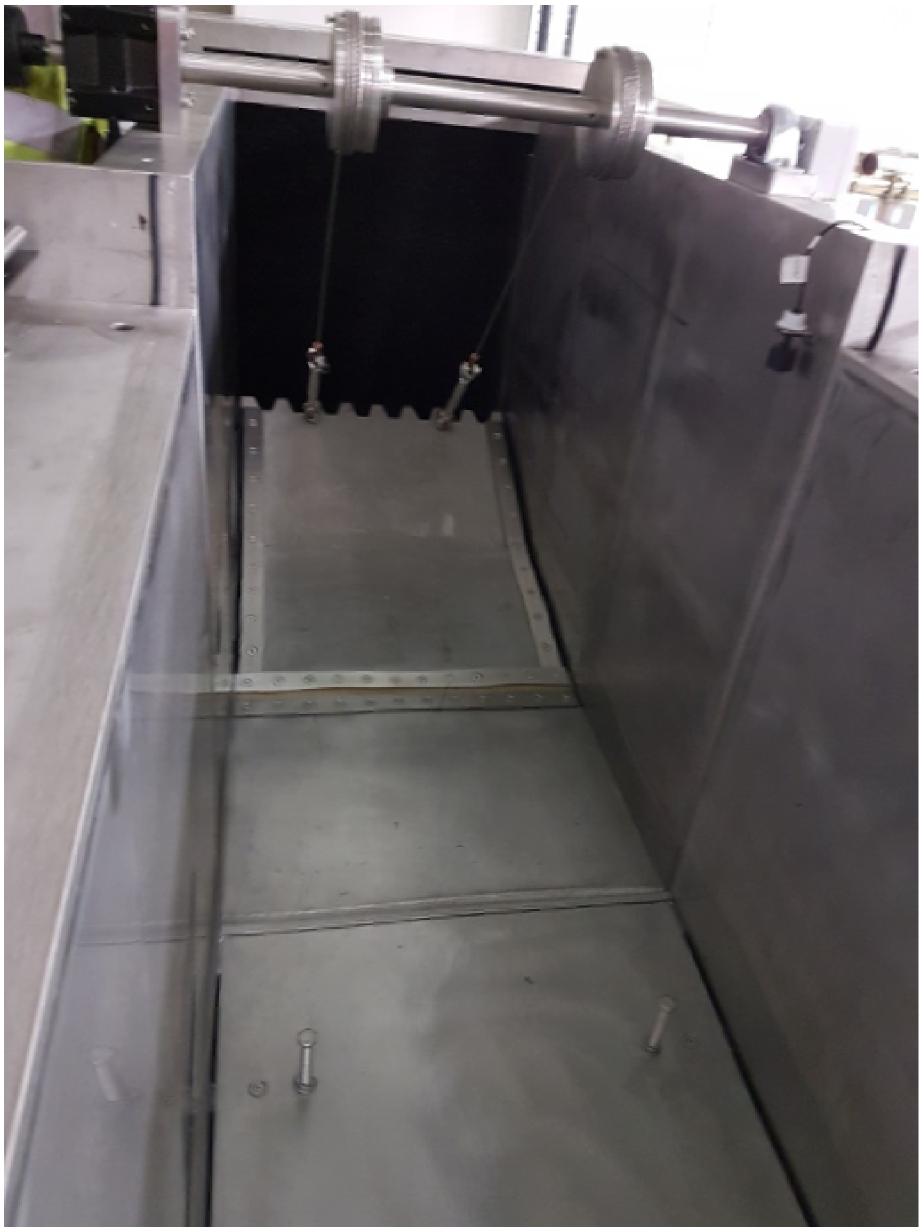

Figure 4: Downstream gate used to control the water surface elevation in the flume.

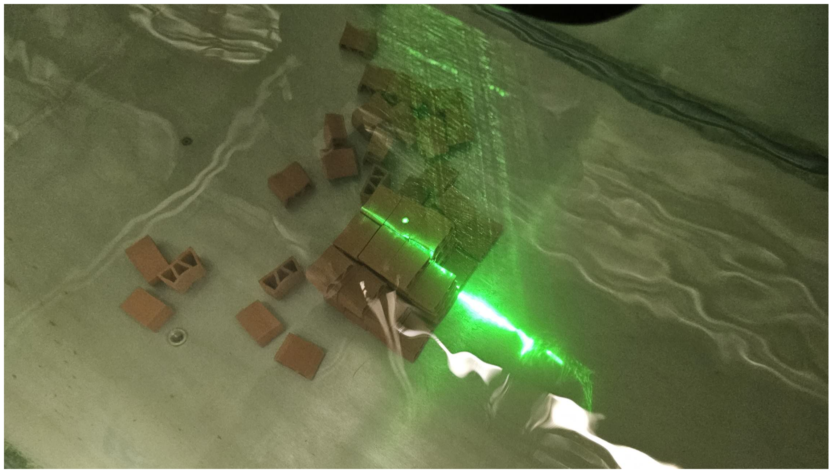

Figure 5: The sampling plane illuminated by a laser sheet.

a high speed camera. A thin laser sheet is used to illuminate a plane in the flow, as shown in Figure 5. The sequence of images recorded by the high-speed camera were processed using the software PIVLab, which produces velocity fields (two-dimensional velocity vectors) on the plane defined by the laser sheet. The velocity field is then post-processed to determine the vertical profile of the streamwise flow velocity. The main strengths of this technique is that it is non-intrusive (i.e. does not require a probe to be insterted in the flow field, which disturbs the flow), and the fact that it enables the visualisation of the whole flow field instantaneously. The second method used a Vectrino® Acoustic Doppler Velocimeter (ADV). The ADV is an instrument that measures the three components of the flow velocities at particular points within the flow. The instrument is based on acoustic signals emited and received by probes that are inserted into the flow. It uses the Doppler Effect, i.e. the change in frequency that is produced as the signal is reflected by moving particles (seeding particles) travelling in suspension in the water. The instrument takes velocity measurements at a rate of up to 200 Hz. Measurements undertaken in this study were conducted at 200 Hz, over the period of 120 seconds. The sequence of nearly instantaneous readings at each point were then averaged to produce the time-averaged velocity at each point of measurement. By repeating the process at each height, it is possible to determine the vertical distribution of streamwise velocity (also referred to as 'velocity profile').

2.3 Scaling and similarity

Scale models (also commonly referred to as physical models) are widely used in fluid mechanics and other areas of engineering to test real-life prototypes (i.e. full-scale, or 'real-world' scale) at low cost. Scale models are reduced physical representations of a prototype, often geometrically similar (i.e. the ratio of lengths and angles in the model and prototype is constant), and most importantly 'dynamically similar' (i.e. the ratio of forces acting on the model and prototype is constant). Crucial to the accurate representation at model scale of the general physics operating at prototype scale is the definition of appropriate scaling factors relating dimensions in the model to those in the prototype:

$$\lambda_L = \frac{L_p}{L_m} \tag{1}$$

where λ_L is the scaling factor and L is the characteristic length, and the subscripts p and m are used to denote the prototype and the model, respectively.

A scale model would produce results similar to the full-scale prototype if it could fully satisfy three scaling conditions of geometric, kinematic and dynamic similarity. However, it is often difficult, if not impossible, to fully satisfy all of the scaling conditions when defining scaled model representations of real-world problems. Instead, models are usually designed to capture the most relevant features of the prototype, while other effects that are assumed to have only small influence on the flow are neglected. Errors introduced by neglecting prototype scale physics are usually referred to as 'scale effects' and can be significantly reduced by an appropriate model design. If the model is designed correctly, these scaling effects may be suppressed or become negligible, and the measurements in the model will provide accurate and reliable predictions of the dynamics (e.g. flow patterns, forces, etc) at prototype scale. Scale models have been extensively used in engineering, and methods to overcome or minimise scaling effects are well established.

Flow in coastal zones is classified as 'open channel flow' (i.e flows with a free-surface that is in contact with the atmosphere), which are typically scaled under the assumption that inertial and gravitational forces are dominant. In these instances, **Froude similarity** is normally applied. Froude similarity consists of setting the same the value of the Froude number for both the model and the prototype. The Froude represents the ratio between inertial and gravitational forces and is defined as:

$$Fr = \frac{u}{\sqrt{gL}}, \tag{2}$$

where u is the characteristic velocity ($\mathrm{m\,s^{-1}}$), L the characteristic length (m) and g is the gravitational acceleration ($\mathrm{m\,s^{-2}}$), which is also assumed to have the same value at model and prototype. The Froude condition defines the scaling factor for various other physical quantities. As an example, the ratio of prototype to model velocity, λ_u, can be obtained as

$$Fr_p = Fr_m = \frac{u_p}{\sqrt{gL_p}} = \frac{u_m}{\sqrt{gL_m}} \tag{3}$$

$$\lambda_u = \frac{u_p}{u_m} = \sqrt{\frac{L_p}{L_m}} = \lambda_L^{1/2} \tag{4}$$

Table 1: Scale ratios for (undistorted) Froude models

Parameter	Dimension	Froude
	Geometric similarity	
Length	[L]	λ_L
Area	[L^2]	λ_L^2
Volume	[L^3]	λ_L^3
	Kinematic similarity	
Time	[T]	$\lambda_L^{1/2}$
Velocity	[LT^{-1}]	$\lambda_L^{1/2}$
Acceleration	[LT^{-2}]	1
Discharge	[L^3T^{-1}]	$\lambda_L^{5/2}$
	Dynamic similarity	
Mass	[M]	λ_L^3
Force	[MLT^{-2}]	λ_L^3
Pressure and stress	[$ML^{-1}T^{-2}$]	λ_L

This simple condition [i.e. Eq. (3)] also allows us to define the scaling factors for other quantities, which are shown in Table 1 assuming that the same fluid is used in the model and prototype.

Another dimensionless number that is often relevant in scaled hydraulic models is the Reynolds (Re) number. This number, which represents the ratio between inertial and viscous forces is defined as:

$$Re = \frac{uL}{\nu} \tag{5}$$

where u is the characteristic velocity, L a characteristic length ad ν is the kinematic viscosity of the fluid. The Reynolds number plays an important role in fluid mechanics, in particular in the characterisation of turbulence. However, it is not possible to fulfil both Froude and Reynolds similarity in scaled models, unless the fluid's viscosity in the model is changed. Fortunately, there exists a wide range of values of Reynolds number for which the general behaviour of a fluid (and of the fluid-solid interactions) remain mostly unchanged. This is the so-called Reynolds-invariance condition. For instance, the coefficient of drag (a relevant parameter determining the forces exerted on solid objects under the action of currents) is known to remain nearly constant within the range of approximately $2 \times 10^3 < Re < 4 \times 10^5$. The blocks object of the current study will be exposed to maximum velocities of the order of 10^0 m/s and have dimensions of the order of 10^{-1} m. Therefore (assuming $\nu = 10^{-6}\ m^2/s$), $Re_p \sim 10^5$. An approximate theoretical assessment of the conditions leading to the motion of the blocks (i.e. using a simple balance between drag and frictional forces) in the model was conducted, which indicated that bricks with dimensions of the order of 10^{-2} m would move at velocities of the order of 10^{-1} m/s, thus leading to $Re_m \sim 10^3$. The model scaling factor of $\lambda_L = 8$ was first chosen from this analysis. This scaling factor ensures that tests with individual bricks and groups of bricks (later described in section 2.4) do not result in large blockage ratios, which might cause a distortion of the results (flow acceleration due to the proximity between the bricks and the wall of the flume). It was later also confirmed that the experimental conditions observed in the model near the threshold of motion of brick fall within the Re boundaries mentioned above.

A comprehensive representation in the model of real-world conditions would also require a similarity condition for the friction between the seabed and the blocks. Bricks laid on a seabed are likely to be partially submerged into the bed, conferring additional resistance against current action. To represent such condition in the laboratory, a bed composed of loose sediment would have been required. However the threshold of motion of fine sediment is less than the corresponding conditions for the motion of the bricks. As a result, sediment would be scoured from the bed before the critical condition for the brick motion could be reached. To prevent this gradual scour of the bed, more sediment would need to be constantly fed from upstream. While such experiments can be technically conducted in the same flume described previously (which includes a sediment trap and a separate pump to recirculate the sediment), this type of experiment is substantially more complex and time-consuming. For these reasons, OH and UoS decided to conduct this study with the blocks laid on a fixed bed (e.g. the bottom of the flume). This condition is likely to represent the worst-case scenario for the stability of the bricks. That is, the bricks laid on a sediment bed are likely to withstand larger velocities than the velocity threshold reported in this document.

2.4 Characteristics of the models and tests conducted

A CAD model of the prototype brick was provided by OH, which is shown on Figure 6. The brick is 300 mm wide, 150 mm high and 200 mm deep. The density of the brick material (also provided by OH) is 2000 kg/m^3. The corresponding model dimensions at the 1:8 scaling factor defined in section 2.3 are 37.5 mm $\times$ 18.75mm $\times$ 25mm.

The model bricks were 3D-printed. To achieve the same density as in the prototype, Copper-Filled Metal Composite HTPLA filaments (density of 2.30 kg/m^3) commercialised by the company Protopasta were used, while the infill density was set to 87%. Figure 7 shows the 3D-printed bricks.

Two sets of tests were conducted. The first group of tests was aimed at determining the conditions leading to the motion of the bricks under current action. Before each of these tests, model bricks were placed at the bottom of the flume according to the configurations requested by OH, which are described next.

- **Test 1:** Blocks piled according to the arrangement illustrated in Figure 8. The pile contains a total of 57 blocks. In this test the threshold of 'failure' was defined as the removal of one of more blocks from the pile by the flow.

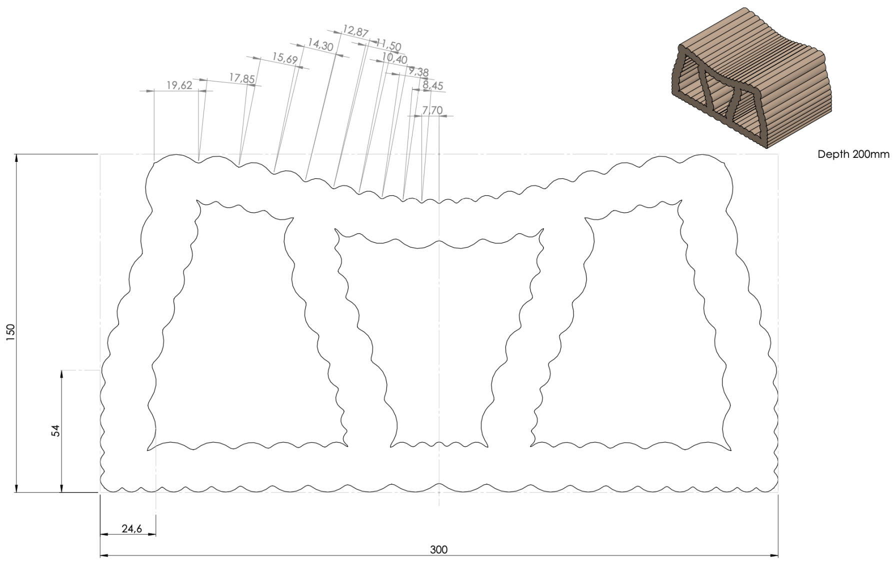

Figure 6: CAD model of the prototype-scale brick.

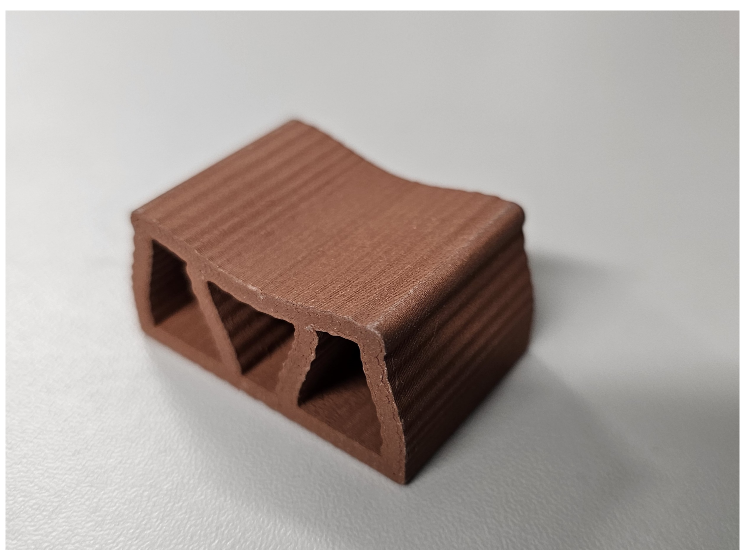

Figure 7: Photo of the 3D-printed brick.

Figure 8: Distribution of bricks in Test 1.

- **Test 2:** Blocks piled according to the arrangement illustrated in Figure 9. This is the same arrangement as in Test 1, but in this configuration a string was used to maintain the bricks together. In this test the threshold of 'failure' was defined as the collapse of the initial configuration.

- **Test 3:** Blocks piled according to the arrangement illustrated in Figure 9 (i.e the same arrangement as in Test 2). However, in this test the threshold of 'failure' was defined as a more extreme condition, in which the group of bricks formed after the collapse of the initial pile starts to be dragged by the flow (even though they are kept together by the string).

- **Test 4:** Blocks piled according to the arrangement illustrated in Figure 10 (a total of 55 blocks arranged as an irregular pile). The threshold of 'failure' in this test represents the conditions leading to the motion of a substantial number of blocks.

- **Test 5:** Blocks arranged according as in Figure 11 (bricks arranged in a 3 $\times$ 3 matrix, and linked by a string). The threshold of 'failure' in this test represents the conditions leading to the motion of a substantial number of blocks.

Before the start of the tests, models were carefully placed on the bottom of the flume at a distance of 11 m from the inlet. Previous studies conducted in this facility confirmed that at this position the boundary layer is fully developed. Each test started by filling the flume slowly to ensure that blocks were not set in motion before the desired conditions were achieved. The depth of the flume was set initially to 0.40 m, which corresponds to a depth of 3.2 m at prototype-scale. The depth was achieved by adjusting the gate at the end of the flume. Once the

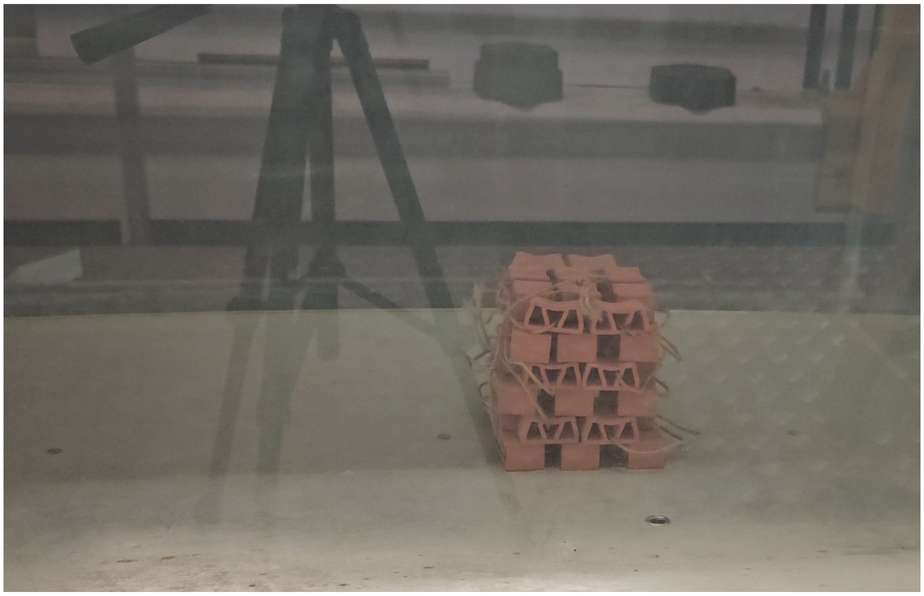

Figure 9: Distribution of bricks in Test 2.

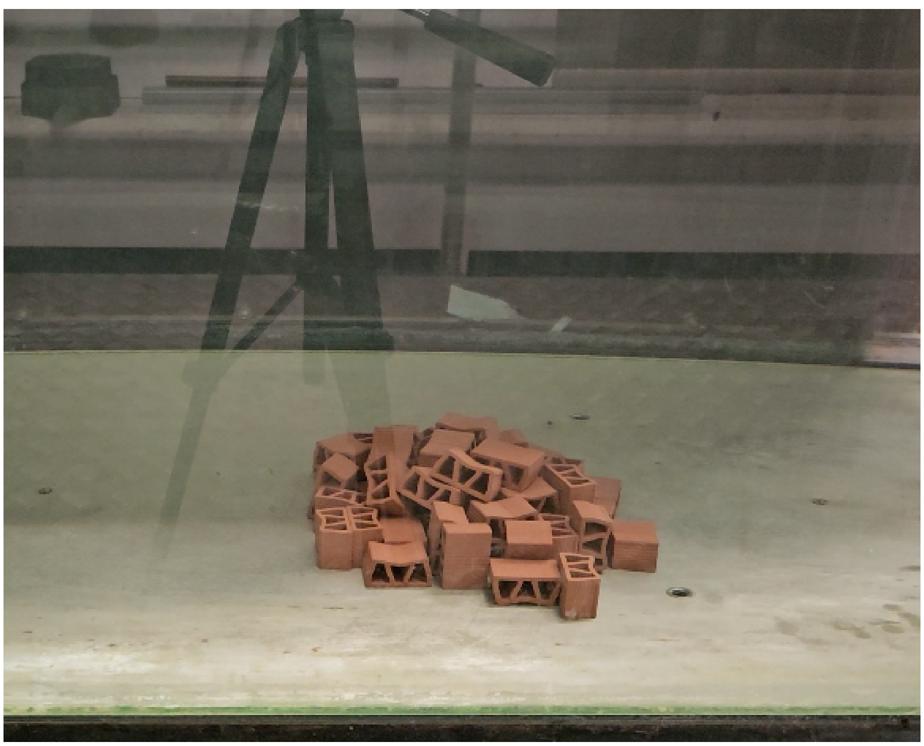

Figure 10: Distribution of bricks in Test 4.

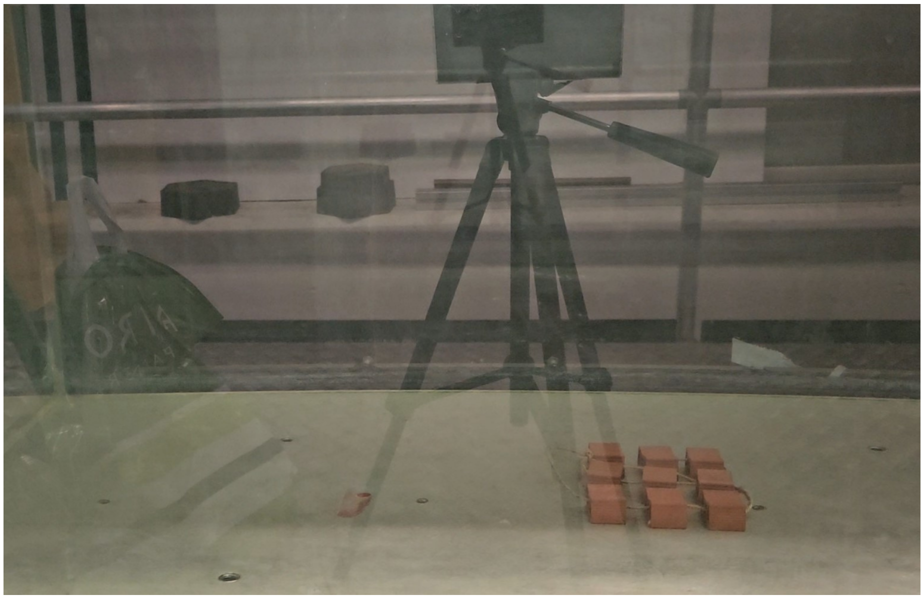

Figure 11: Distribution of bricks in Test 5.

desired depth was reached, the flow discharge was increased at small increments. At each flow increment, the depth of the flow was re-adjusted, so that it was kept in the vicinity of 0.40 m, with only small deviations. This produced two increments in the flow velocity for each change in the flow discharge (i.e. the first by the increase in the flow discharge, and the second by the reduction in depth constant discharge). In some of the tests, (e.g. Test 3), it was not possible to reach the failure velocity using this fixed depth. In this case, the depth was reduced further, so that the threshold of motion could be reached.

The second group of tests was aimed at assessing the spread of blocks when they are deployed from the water surface (see Figure 12). In these tests, 112 blocks were released from the water surface at different depths of 0.40 m, 0.50 m and 0.60 m, which correspond to depths of 3.2 m, 4.0 m and 4.8 m at full scale. The tests were conducted under null flow velocity. Each test was repeated three times, and recorded using a camera. The images were then post-processed to determine the width of the area covered by bricks as they reach the bottom of the flume. Further lateral spread of individual bricks (i.e. by sliding) after they have reached the bed was ignored, under the assumption that this effect would be muted at full scale as a result of increased resistance by the sediment bed.

3 Results

The model results of the stability tests described in section 2.4 are summarised in table 2. In this table, U_{c_a} is the average velocity of the flow, U_{c_i} is the

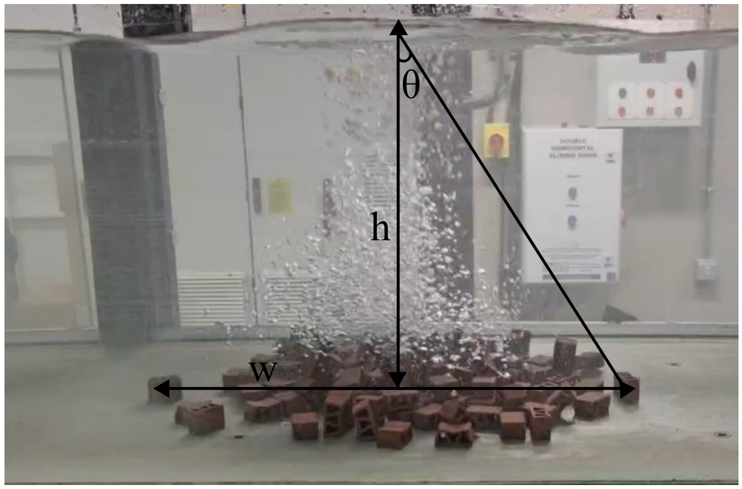

Figure 12: Photo of the spread of the bricks. w is the width of the spread area, h is the water depth and θ is the spread angle.

'impinging' velocity (i.e. the velocity averaged from the bottom to the height of the blocks), defined as:

$$U_{c_i} = \frac{1}{h} \int_{z=0}^{z=Z_t} u(z)\, dz \;, \tag{6}$$

where Z_t is the height corresponding to the top of the initial block configuration (i.e. before failure).

The full-scale results presented in Table 3 were obtained using the scaling factors defined in section 2.3. These results show bricks on a pellet configuration start to move at values of impinging velocity larger than 0.80 m/s (i.e. tests 1 and 2). However, once the blocks are laid on the floor (tests 3 to 5) they may withstand velocities that are substantially larger (> 1 m/s) than the thresholds of motion observed in tests 1 and 2. When linked together by the string (i.e. test 3), the bricks only became unstable when the impinging velocity (full-scale) reached 1.75 m/s. The mound of (not linked) blocks (Test 4) was observed to withstand a maximum full scale impinging velocity of 1.21 m/s. It is important to note that (a) the values discussed here represent the 'impinging' velocity (i.e. Eq. 6), which is less than the depth-averaged velocity and (b) that the results were obtained through experiments with a rigid bottom. It is therefore expected that the bricks may be able to withstand larger current velocities than those reported here when deployed on the seabed.

Table 2: Flow conditions in the model at the thresholds (i.e. 'critical' denoted by the subscript 'c') defined in section 2.4 for each test. U, h and Q are used to denote the flow velocity, depth and discharge, respectively.

Test	$U_{c_a}(m/s)$	$U_{c_i}(m/s)$	$h_c(m)$	$Q_c(L/s)$	$Z_t(m)$
1	0.37	0.31	0.4	86.5	0.106
2	0.36	0.30	0.4	85.1	0.106
3	0.65	0.62	0.3	117.9	0.106
4	0.55	0.43	0.36	117.7	0.04
5	0.52	0.38	0.38	117.8	0.016

Table 3: Flow conditions at full-scale for the thresholds (i.e. 'critical' denoted by the subscript 'c') defined in section 2.4 for each test. U and h are used to denote the flow velocity and depth, respectively.

Test	$U_{c_a}(m/s)$	$U_{c_i}(m/s)$	$h_c(m)$	$Z_t(m)$
1	1.04	0.88	3.2	0.85
2	1.02	0.84	3.2	0.85
3	1.83	1.75	2.4	0.85
4	1.56	1.21	2.88	0.32
5	1.47	1.07	3.04	0.13

The model results of the second group of tests described in section 2.4 (spread of bricks deployed from the water surface) are summarised in table 5. h is the water depth, w is the width of the area covered by bricks, w_a is the average width of the three tests and θ is the spread angle (refer to Figure 12).

Table 4: Spread of bricks deployed from the water surface at different water depths (model dimensions).

$h(m)$	Test	$w(m)$	$w_a(m)$	$\theta(°)$
	1	0.5		
0.4	2	0.49	0.52	33
	3	0.57		
	1	0.56		
0.5	2	0.67	0.6	31
	3	0.58		
	1	0.86		
0.6	2	0.75	0.8	33.7
	3	0.78		

Table 5: Spread of bricks deployed from the water surface at different water depths (full-scale dimensions).

$h(m)$	Test	$w(m)$	$w_a(m)$	$\theta(^{\circ})$
	1	4.0		
3.2	2	3.92	4.16	33
	3	4.56		
	1	4.48		
4.0	2	5.36	4.8	31
	3	4.64		
	1	6.88		
4.8	2	6.00	6.4	33.7
	3	6.24		

4 Summary and conclusions

This reported assessed, through scale model experiments, the stability of bricks developed by Oyster Heaven under the action of currents. In addition, the work also examined the spread of bricks deployed from the water surface as they fall to the bottom under the action of gravity.

Five different configurations of bricks were tested, as detailed in the report. Results showed that bricks arranged as in a pellet were set in motion at a (full-scale, 'impinging' or 'near bed') velocity of approximately 0.85 m/s (Tests 1 and 2). After this configuration is reorganised by the flow and the bricks are arranged as an irregular pile on the floor, they withstand higher velocities (e.g., $>$ 1.0 m/s impinging velocity), as observed in Tests 3 and 4. In addition, experimental results showed that when the bricks are linked by a string (Test 3), the group may withstand maximum velocities of up to 1.75 m/s (full-scale impinging velocity). Bricks laid in a 'mat' configuration (a matrix of 3×3 bricks linked by a loose string; Test 5) withstood a maximum near bed velocity of 1.07 m/s.

Tests of brick deployment from the water surface were conducted at three different water depths (full-scale depths equivalent to 3.2, 4.0 and 4.8 m. When released from the free-surface, bricks were observed to spread as they fall to the bottom due to gravity, with an angle of approximately 33^o relative to the vertical (total angle of approximately 66^o).

The following section discusses further considerations and work that may be needed in the future.

5 Limitations and further work

There are a number of effects such as wave action, or the sinking of the bottom layer of bricks into a bed made up of fine sediment which may need consideration. This would need to be assessed for specific sites where these problems may occur.

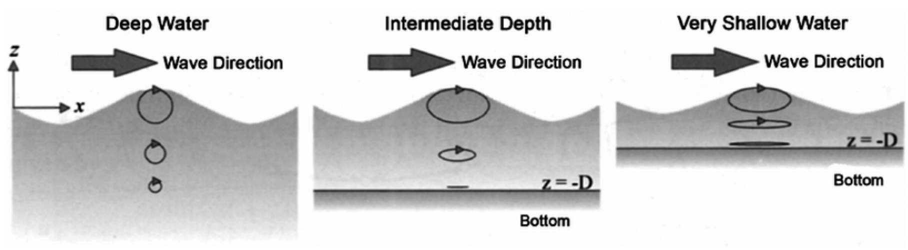

Figure 13: Particle motion in waves

In addition, possibilities exist to strengthen brick mounds if necessary. In the following, these effects will be described briefly.

5.1 Effect of wave action

5.1.1 Waves

Waves are characterised by an orbital particle motion in deep water which reduces to an elliptical or linear back- and forward motion in shallow water, Figure 13.

The envisaged deployment depth of 1 to 5 m can be considered as shallow or very shallow water. The bricks are therefore not only exposed to forces generated by the current, but also to the back- and forward forces generated by the waves. These combined forces will likely reduce the threshold current velocity for the beginning of motion. In other words, when waves and a current are present the bricks will move at lower current velocities. While there are theories available for the combined effect of waves and currents on sediment transport, they are not very accurate and were mainly developed for sand, i.e. very small elements compared with the bricks.

5.1.2 Effect of waves and current on brick stability

If a deployment in an area with combined waves and currents is intended, then the uncertainties about transport onset under combined wave and current action make model tests desirable. There are some test facilities available for such problems. These facilities are however designed for comparatively deep water situations (offshore wind energy installations), they often contain incident and reflected waves (undesirable) and they suffer from secondary currents and interaction effects due to the wave generation paddles. At the University of Southampton we have developed a wave paddle system including wave absorption for combined wave-current problems which works with a minimum interference with the flow, and which eliminates the wave reflection. The system can operate at shallow water depths down to 0.20 m.

5.1.3 Recommendation

If a brick deployment is intended in areas where there is a current and significant wave action (0.2 – 0.3 m wave height in 1 – 2 m water depth), then the effect of waves on the stability of the bricks should be investigated. Here, initially the wave and current parameters (wave period and height, water depth and current velocity) need to be assessed. Based on these parameters, it will be decided whether laboratory tests are required or not.

5.2 Effects of sediment bed and other considerations

As previously mentioned, a decision was made to conduct experiments with a fixed bed, although the full-scale bricks will be deployed on a bed composed of movable sediment. There are several effects where the existing sediment bed can affect the brick deployment and stability:

- **Spread of dropped bricks:** current tests determined the spread of bricks dropped from the water surface falling onto a solid bed. Here a sideways movement of individual blocks (i.e. by sliding after having reached the bed) is comparatively easy. If a more realistic assessment of the horizontal dispersal of the bricks is required, then tests are recommended where a shallow sand tray is located on the bed of the channel. The bricks will, when hitting the sediment bed, at least partially be buried in the sediment which in turn will reduce the horizontal spread.

- **Sinking of the bricks:** the current will probably form eddies at the corners of the front bricks. These eddies will remove sediment so that the bottom layer will likely sink partially into the seabed. This is a well-known phenomenon observed to occur in bed revetment structures such as riprap. If this effect may be present at a particular site (say a site with very fine sediment), then further model tests can be conducted to assess the rate and magnitude of the vertical motion.

- **Measures to prevent sinking of brick mounds:** geotextile mats may be dropped first onto the seabed to prevent sinking of the bricks. This effect and the required dimension of the geotextile can be determined / assessed in model tests, along with potential countermeasures. The most commonly used methods to counteract this issue is to a a 'filter' material (usually a layer of sediment that is coarser than the bed sediment) or geotextiles.

- **Measures to increase the stability of brick mounds:** a deployment may be required in an area with comparatively strong currents. Here, tree branches or geotextile mats made from natural material can be used to in crease the stability of brick mounds. This will be done by dropping a first layer of bricks, then the branches or geotextile, then another brick layer, The friction between branches / geotextile and bricks provides tensile resistance and increases the stability similar to “reinforced earth” civil engineering structures or stone beaver dams.

The complexity of this apparently simple strengthening technique means that model tests are required to quantify the increase in strength.