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SIMULATING THE RUBBLE MOUND UNDERLYING ARMOUR UNITS PROTECTING A BREAKWATER

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Abstract

A variety of concrete armour units laid on top of rubble mounds are used to protect breakwaters and other harbour infrastructure. Coastal engineers build three-dimensional physical scale models to understand the dynamic processes caused by seas on such infrastructure. We are developing analytical techniques for understanding breakwater structural stability. We are modelling the infrastructure using a physics engine, which handles the rigid body mechanics. We report here on our attempts to model the rubble mounds underlying the armour units.

In its most primitive form, we model the rubble as a static structure with flat surfaces and then pack the selected armour units on top. This reduces the complexity, but the porosity of the packing close to the rubble is much higher than it would be in practice, because of the lack of inter-penetration between the rubble and the armour layer. Further, the armour units slide easily on the flat surface, making it difficult to simulate a realistic packing. The two approaches to solve this problem that are discussed here are the *height field* and *modelling individual rubble units*.

The height field is a rigid, square mesh with random heights distributed uniformly. It is computationally cheap to implement and largely solves the porosity and related problems, but it is rigid, so it cannot change shape to respond to movements by the armour units or the water. Modelling individual rubble units is computationally expensive, because of the number of objects required and their potential complexity. Currently, we have modelled the rubble using a simple sphere-like polyhedron, and have been able to model a very large packing of them.

1 Introduction

1.1 Project background

A variety of concrete armour units (such as dolosse) laid on top of rubble mounds are used to protect breakwaters, piers and other harbour infrastructure, serving both to absorb the impact of violent seas and to reduce overtopping (heavy seas flowing over harbour defences into the supposedly protected areas of harbours). Breakwaters can be built entirely of rubble, but it is expensive to get sufficient quantities of rocks large enough to withstand heavy seas. Armour units are cheaper, can be built *in situ* and have various design characteristics that enhance their functionality [1]. Coastal engineers build three-dimensional physical scale models of actual or planned harbours (as shown in Figure 1), in order to understand the dynamic processes caused by waves, tides, currents and storms. However, these models are expensive and time-consuming to build, while the effects of downscaling affect their predictive ability [2].

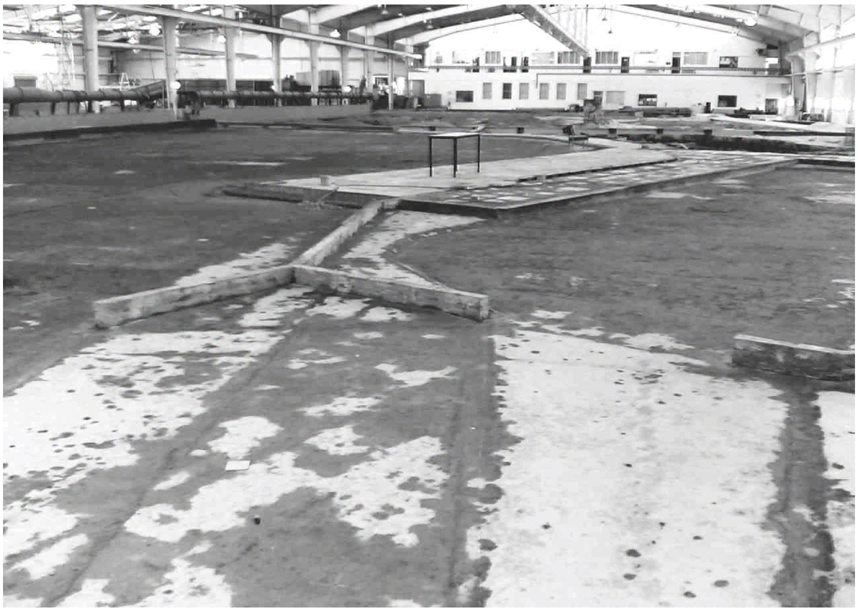

Figure 1: CSIR's physical model hall [2].

We are engaged in a wide-ranging project aimed at developing analytical techniques for application to breakwater structural stability and the development of associated numerical simulation and modelling technology, including the modelling of waves and using photogrammetry to record changes in breakwater structures [3, 2, 4, 5, 6, 7, 8, 9]. Various approaches are being followed and the ultimate goal is to integrate these into an advanced numerical analysis tool supplementing and exploiting the physical models [3, 7].

1.2 Physics engine

We are modelling the physical infrastructure of breakwaters using a physics engine, PhysX [10], which handles the rigid body mechanics. Physics engines were developed for computer games to provide realistic visual simulations of the real world, allowing one to set parameters such as for gravity, and the coefficients of restitution, linear and angular damping, and static and dynamic friction for individual objects in the modelled world. Figure 2 shows a digital model of armour units (Antifer cubes, in this case) developed in PhysX. One of the limitations of a physics engine is that it is optimised for visual display rather than the highly precise modelling of the mechanics, and we are currently exploring the implications of this [6].

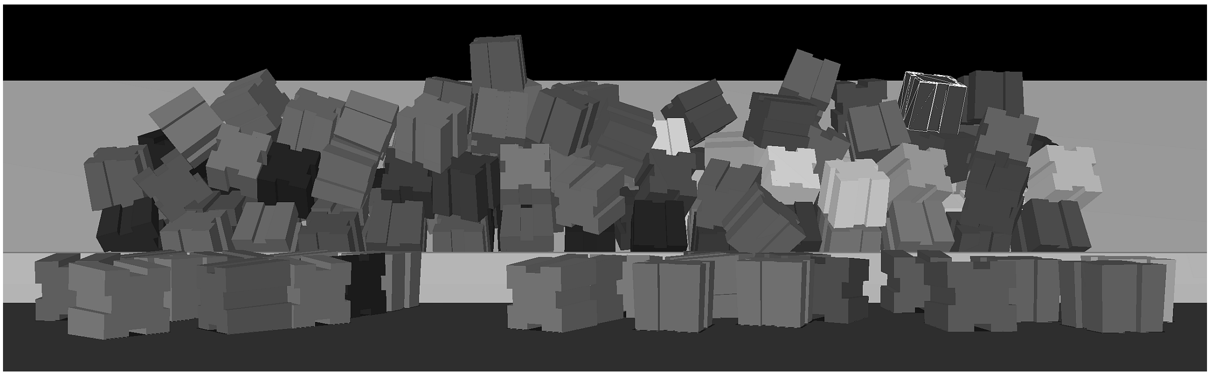

Figure 2: Antifer cubes modelled in PhysX.

We report here on our attempts to model in the physics engine, the rubble underlying the armour units around a breakwater. We have not yet attempted to model a breakwater built only of rubble, because of its complexity (see, for example, [11]).

2 Modelling slopes and toes

2.1 Base-line model

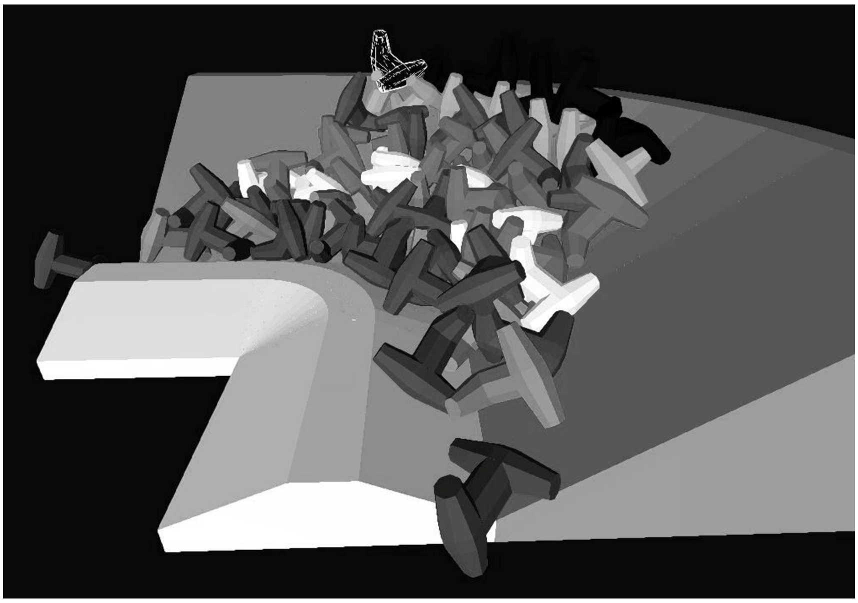

Figure 3: Dolosse packed on a curved slope in PhysX.

Typically, armour units are packed on a slope (or talus) of rubble that lies between the infrastructure being protected and the open water. A toe of rubble is also built along the bottom of the slope to support the armour units and to influence where the incoming waves will break. The designer of the breakwater determines the characteristics such as the shape, angle and height of the slope, the size and shape of the toe, and the size of the rubble used (typically, varying through the rubble layer, from smaller rubble in the core to larger rubble in the outer layer). The designer of the breakwater prepares a placing grid, which specifies where each armour unit should be placed under ideal conditions, whether by the packer in the model hall (model scale) or by the crane operator in the field (prototype scale) [1]. Similarly in the PhysX model, we lower the armour units one by one into their positions on the breakwater, where they are released to settle under gravity on the rubble mound and/or other armour units.

For the base-line model, we represent the underlying infrastructure (the slope and toe) as a rigid structure with smooth surfaces and then pack the selected armour units on top of this. This reduces the complexity of the model and facilitates understanding the process of packing the armour units on top of the slope. The model currently allows the slope to curve arbitrarily, as required (as shown in Figure 3) [5].

However, a problem with using a smooth surface for the rubble layer is that the porosity of the packing close to the surface in the physics engine is higher than it would be in practice, because of the lack of inter-penetration of the boundaries of the rubble mound and armour layer. This is illustrated by the graph in Figure 4, which shows how the void fraction varies through a sample packing of dolosse in PhysX. As can be seen, the void fraction is close to 1 close to the surface. While it might be useful to validate the void fraction of the numerical model against that of a physical model, we are not yet able to produce a numerical model that is an exact replica of a physical model, save for trivial cases.

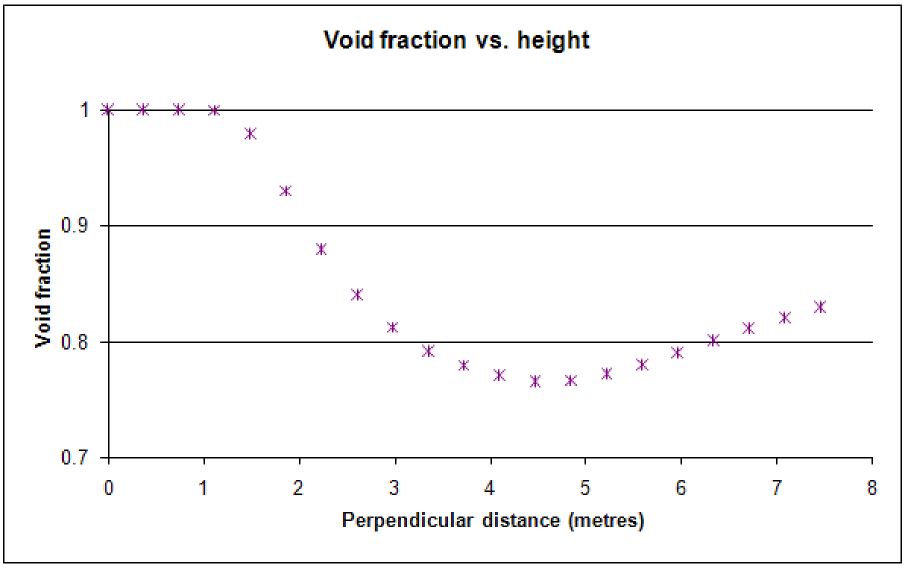

Figure 4: Void fractions for dolosse packed on a smooth slope.

A key problem with this is that when fluids are introduced to the structure, excessive channelling could occur along the boundary because the fluid velocity is likely to be higher there [12]. This is likely to lead to the incorrect artifact of increased scour along the boundary in the model between the rubble layer and the armour units, and increased hydrodynamic forces on the armour units.

Further, placing armour units on a smooth slope can generate an unrealistic packing, because the armour units slide down too easily when placed on the smooth surface, as we have found in our experiments. We have tried tempering this by increasing the static and dynamic friction of the slope, but the friction needs to be very high to take effect. While that might produce a more accurate packing *ab initio*, it is likely to distort the movement of the armour units (or lack thereof) when subjected to the forces simulating waves and other fluid dynamics, as the much higher friction will requirer higher forces to move the armour units.

One approach to simulating the rubble layer could be to vary randomly the parameters for each armour unit when they are packed. While this might provide a more realistic packing of the armour units, it will not deal with the porosity, channelling and scouring problems at the boundary with the slope, as discussed above. Hence, we have not attempted this method. The two approaches that we have implemented are the *height field* and *modelling individual rubble units*, as discussed below.

2.2 Height field

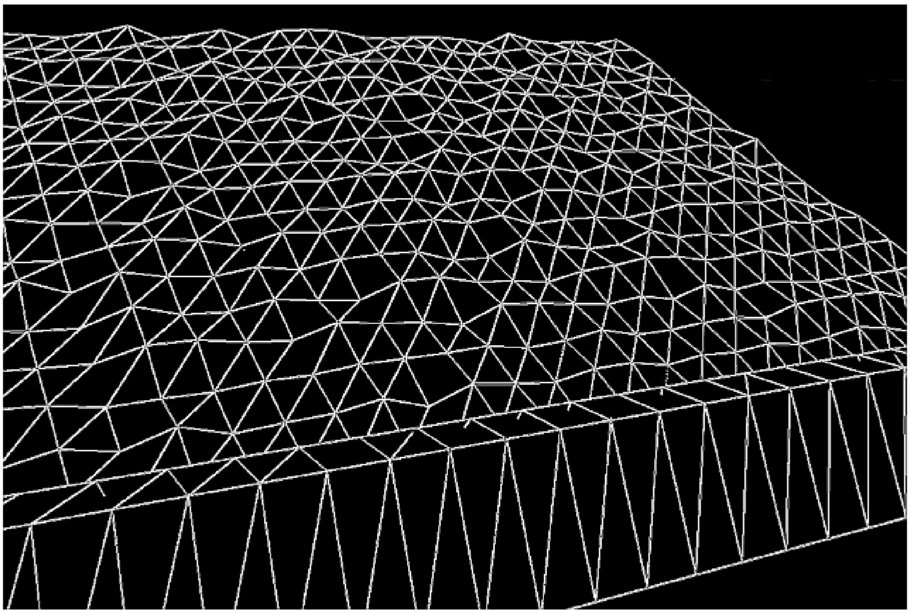

Figure 5: Mesh for a height field in PhysX.

The height field capability in PhysX allows us to provide a rough surface for the rubble layer. We create the basic shape of the slope and toe using rigid objects and then drape over this the height field, a rigid, square mesh with random heights distributed uniformly. Each square in the grid is modelled as two triangles. The spacing of the grid and the range of the heights can be varied, depending on the size of the rubble being modelled. The basic height field draped over the slope and toe is shown in Figure 5.

Figure 6 shows Antifer cubes placed on a height field. The base of each Antifer cube is 2.674m x 2.674m, the mesh for the height field is 1m x 1m and the height of the mesh is varied randomly between 0m and 0.4m. So, even though the vertical variation in the height field is fairly modest relative to the size of the armour units, one can see clearly that it affects the packing of the

Antifer cubes, as is planned. Figure 7 shows dolosse (of a similar size to the Antifer cubes shown in Figure 6) placed on a height field, where the height is more pronounced (varying randomly between 0m and 0.9m), and showing the inter-penetration of the rubble layer with the dolos layer. The height field is translucent, which is why one can see the shadows of the dolosse underneath it.

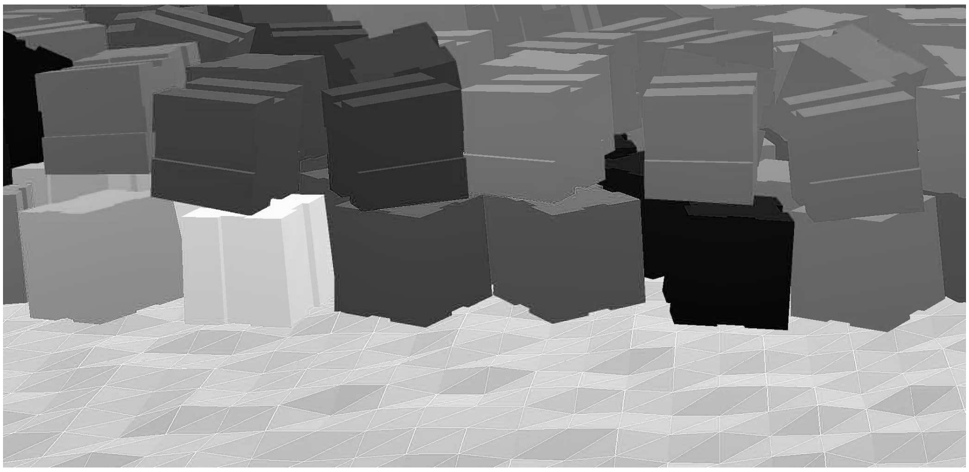

Figure 6: Antifers placed on a height field simulating rubble.

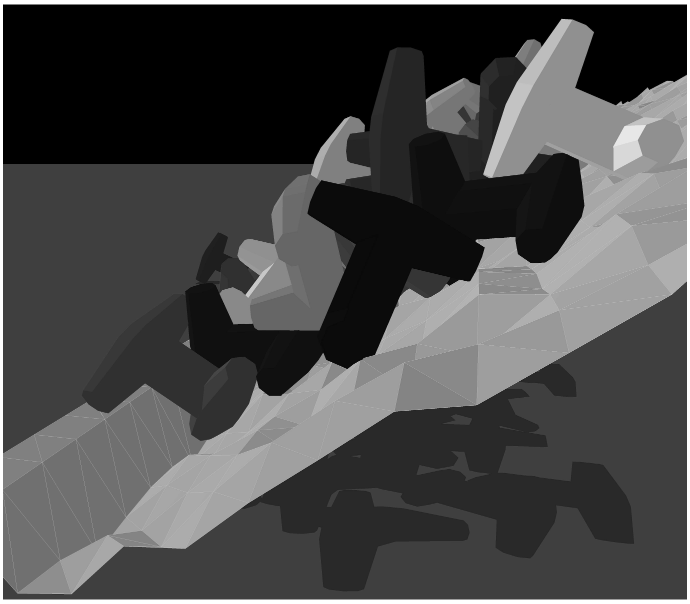

Figure 7: Dolosse placed on a height field simulating rubble.

The height field is computationally cheap to implement and largely addresses the porosity, channelling and scouring problems of the smooth surface by ensuring inter-penetration of the boundaries of the rubble mound and armour layer. However, the height field is rigid, which means that it cannot change shape to respond to movements by the armour units or by the water. We are also currently exploring if the orientation of the triangles introduces a systematic bias into the height field and, more importantly, into the packing of the armour units on top of the height field.

2.3 Modelling individual rubble units

Modelling individual rubble units is computationally very expensive, because of the number of objects required. The rubble is also not uniform in practice (for both prototype and model scale), varying both in shape and size. It is difficult and tedious to model a wide variety of rubble shapes [11], but we are exploring techniques for generating these automatically. For example, our colleagues in road engineering are producing accurate three-dimensional models of pieces of aggregate used for road building (the same technique used by [11] to produce sample rubble units), and we are exploring with them the possibility of using their models to simulate rocks in our models.

Currently, we have modelled the rubble using a sphere-like polyhedron. We have been able to optimise the software to produce a very large packing of these simple polyhedra on a standard personal computer, with over 6400 in the model shown in Figure 8. The next step will be to add armour units on top of the rubble layer. We are exploring if using one shape but varying its size will produce suitable rubble, or if we need a greater variety of shapes as well. As [11] have done, we will also explore the extent to which each shape used can be simplified. It might also be necessary to use hardware acceleration, which is provided directly for PhysX by some graphics cards [10].

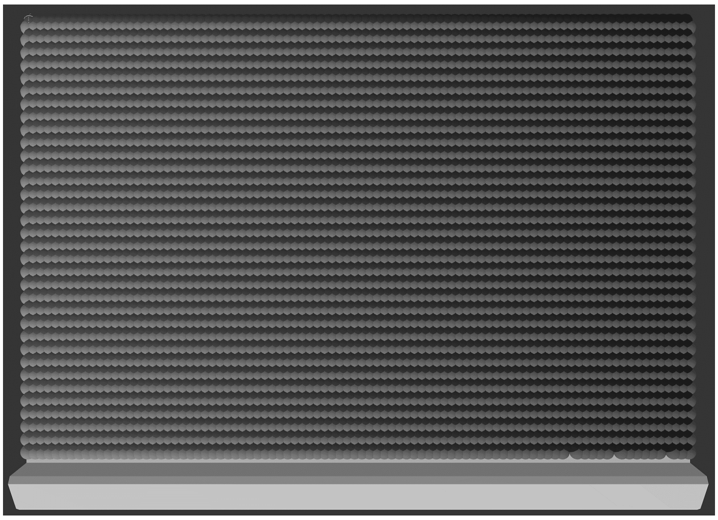

Figure 8: Rubble simulated in PhysX with sphere-like polyhedra.

3 Conclusion

We have reported here on two methods that we have developed to try to produce realistic models in a physics engine, of the rubble mounds underlying the concrete armour units laid to protect breakwaters and other harbour infrastructure. The key issue is dealing with the interface between the rubble mound and the armour layer, which should inter-penetrate one another to provide accurate porosity there, to prevent channelling and scouring problems in the model. The rubble mound should also be flexible to accommodate movements by the armour units and the water.

The two approaches to solve this problem that are discussed here are the *height field* and *modelling individual rubble units*. The height field is a rigid, square mesh with random heights distributed uniformly. It is computationally cheap to implement and largely solves the porosity and related problems, but it is rigid, so it cannot change shape to respond to movements by the armour units or the water. Modelling individual rubble units is computationally expensive, because of the number of objects required and their potential complexity. Currently, we have modelled the rubble using a simple sphere-like polyhedron, and have been able to model a very large packing of them.

We are exploring techniques to improve the accuracy of the models using the height field and understanding how to model individual rubble units effectively. We are also exploring the possibility of combining the two techniques, using the height field to model the core of the rubble mound that is static, and then packing the outer layers of individual rubble units on top of the height field. At this conference, we have also reported on our work on calibrating the physical models [6], calibrating the fluids models [9], and integrating the models [7].

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