our future through science

Numerical modelling of structures of dolosse and their interaction with waves

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A variety of armour units (such as dolosse) is used to protect breakwaters, piers and other harbour infrastructure around South Africa, serving both to absorb the impact of violent seas and to reduce overtopping (when heavy seas flow over harbour defences into the supposedly protected areas of harbours). The CSIR's coastal engineering group builds three-dimensional physical scale models of actual or planned harbours in the model hall in Stellenbosch, 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, as forces do not scale similarly.

We are engaged in a wide-ranging project aimed at analytical techniques for application to breakwater structural stability and the development of associated numerical simulation and modelling technology. Various approaches are followed and the ultimate goal is to integrate these into an advanced analysis tool. On the one hand, we model armour units (especially dolosse), their contact dynamics, and their packing. This work is carried out via a physics engine (PhysXTM), which handles most of the rigid body mechanics. Structures of up to 350 dolosse can now be treated and various characteristics of the packed array of armour units, such as the number of contact points and the porosity of the structure, can be calculated. The aim is to derive the stability of these structures by expressing it in terms of these structural properties.

To determine the stability of these simulated structures, it is important to expose them to simulated violent wave movements. These wave forces cannot be directly introduced in the physics engine, but must first be generated using fluid dynamic models. These models require different approaches, such as Reynolds-averaged Navier-Stokes models and Discrete Element Methods (DEM). Ideally, these tools will provide approximate inputs to the physics engine with the right physical calibration. The fluid dynamics program is also underway, and one of the challenges is to combine the wave and structural approaches.

The calculations will be tested against specific model hall experiments. If reliable predictions can be made with the developed numerical toolset, then the software can assist in carrying out breakwater studies for current or future harbours. Important advantages of the numerical approach are that the costs are much less than those of physical modelling, while scaling can be done exactly. The disadvantage is that various simplifying assumptions are required to make the calculations feasible. Hence, these numerical models are not intended to replace the physical models – they aim at improving the understanding of the dynamics in the physical models and at supplementing them. In order to avoid some of the simplifying assumptions, it may be necessary to carry out very sophisticated calculations that will require the use of special computing facilities, such as the C4 at the CSIR or the Centre for High Performance Computing.

In this poster we present new results from the PhysXTM engine simulation that demonstrate our ability to model greater numbers of dolosse (currently up to 350). In the conference paper we review our work on breakwater stability and demonstrate the power of PhysXTM to calculate relevant parameters.

Figure 1: Dolosse protecting Cape Town's harbour. The dolos is a common type of armour unit, invented in East London in the 1960s. The word dolos derives from the Dutch words dollen (playing wildly) and os (ox). While the sea is playing wildly with the dolos through its waves, the numerical project team is 'playing' with them using the game engine PhysXTM. The dolos is made from un-reinforced concrete and weighs up to 20 tons. It looks like the letter 'H' with one arm rotated through 90°. This allows dolosse to interlock with one another, forming a porous layer between the sea and the harbour infrastructure. There are over 30 other designs for armour units in common use, with different properties (eg: the pierced-pyramids in the background of the photograph).

Figure 2: Close-up of dolosse, showing damage and wear.

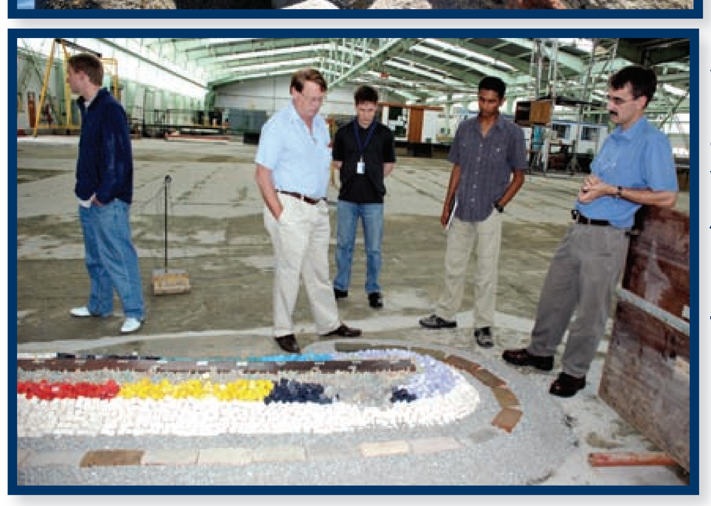

Figure 3: Part of a physical model in the CSIR's physical model hall at Stellenbosch. This photo was taken during a visit of the numerical modeling project team. Members of the team shown are Rui Viera (computer scientist), Jan Greben (theoretical physicist), Frans van den Bergh (computer scientist), Kishan Tulsi (ports engineer, not part of the numerical team but involved in the physical hall experiments) and Wynand Steyn (roads engineer).

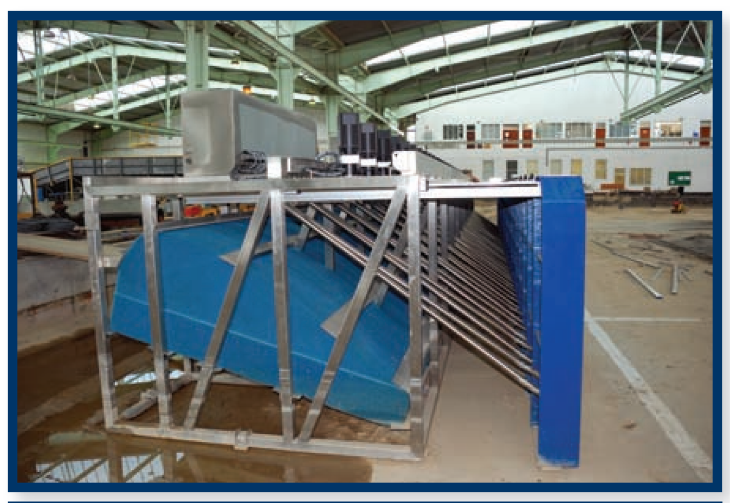

Figure 4: The new wave generators in the CSIR's physical model hall. These are programmable to produce model waves with specific characteristics.

Figure 5: A view of an experiment in progress with generated waves interacting with the model breakwater structure under study. The wave generators are to the right of the photograph. The instrumentation set up around the model records the characteristics of the waves during the run. Changes in the physical model are recorded using photography.

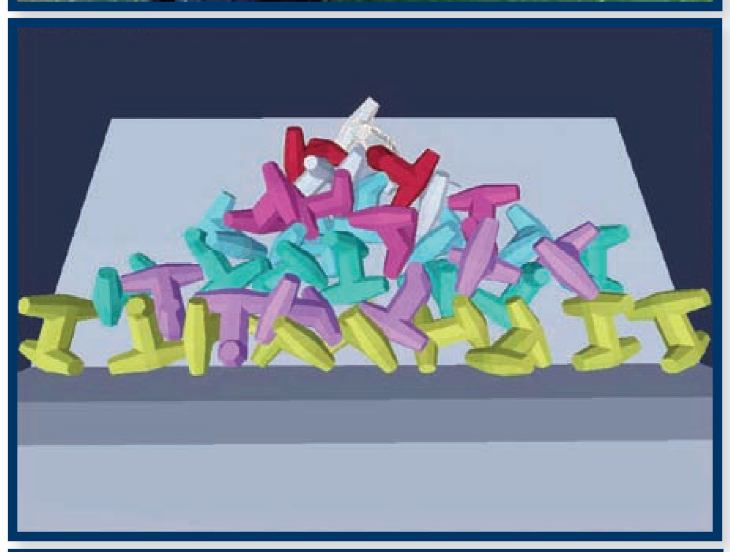

Figure 6: A synthesised layout of model dolosse on a straight slope with a toe. The model has been constructed in PhysXTM, a physics engine, which is used for simulating realistically physical forces, such as gravity and friction. The rows of dolosse have been coloured differently, so that they can be followed more easily through simulations.

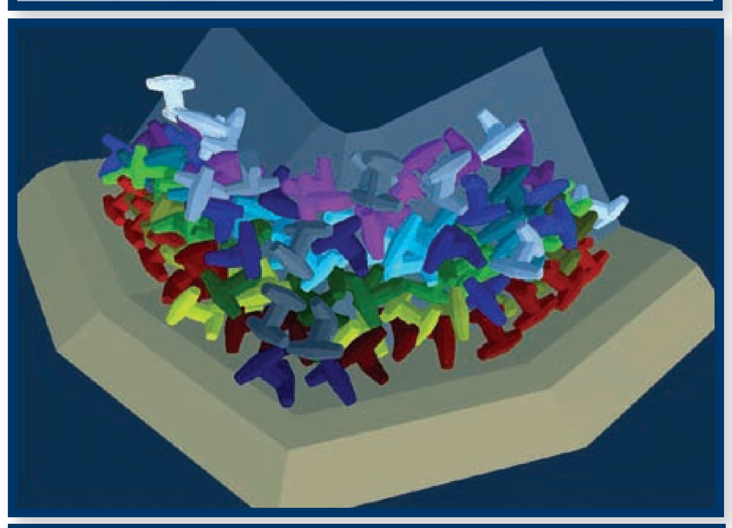

Figure 7: A synthesised layout of model dolosse along a more complicated toe. Such profiles are relevant because damage to structures often occurs at or near the corners of the profile. Also, the packing has to be adjusted near corners, where numerical modeling can help as well.

Figure 8: A synthesised layout of 351 model dolosse, the current limit for the computer on which the models have been run. Actual harbour structures may contain thousands of individual armour units, so it is important to extend the upper limit by using advanced computers and computing techniques. For studying theoretical questions, like the stability of breakwater structures and their porosity, smaller numbers are more suitable.

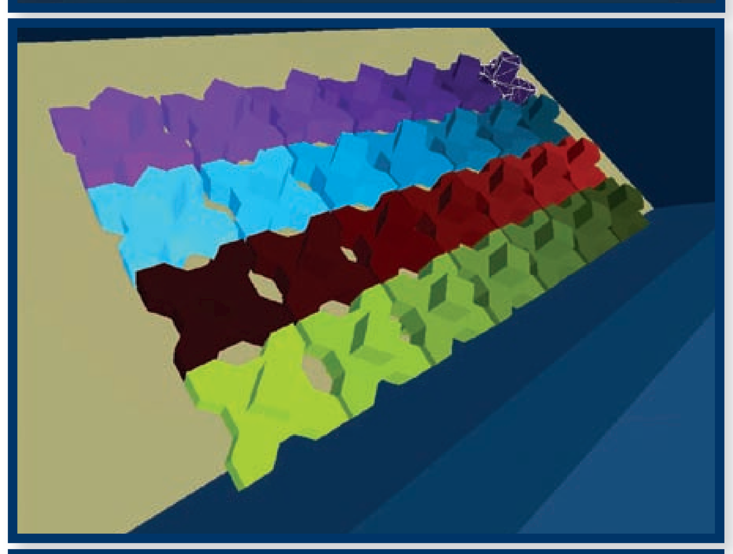

Figure 9: A synthesised layout of X-blocs, a different type of armour unit. We can now model several different types of armour units. Other types include Tetrapods, core-loc, accropodes, ecopodes, A-jack, Akmon and pierced pyramids.

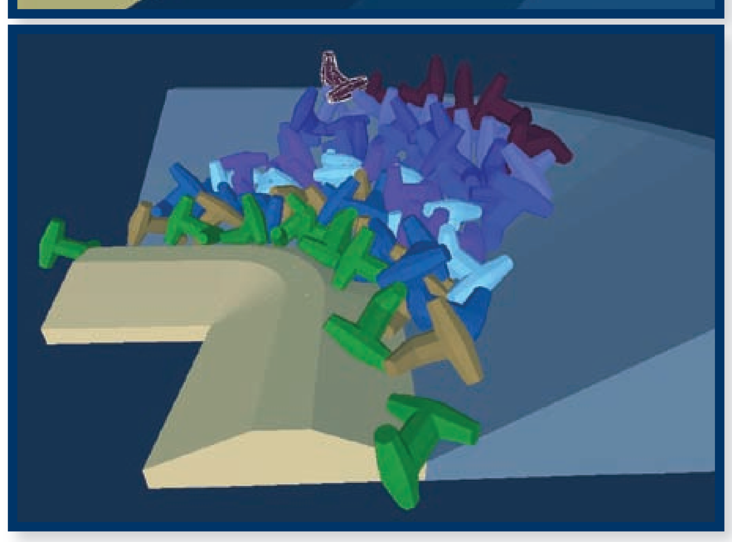

Figure 10: A synthesised layout of dolosse packed round an inner curve. A key issue now is to simulate the process actually used in the field or in the model hall to pack armour units in practice, so that we can make our synthesised packing arrays as realistic as possible.

CSIR researchers have applied various numerical techniques to describe the stability of breakwater structures under the exposure of waves.

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