# INNOVATIVE NUMERICAL SIMULATION TO STUDY THE FLUID MOTION WITHIN RUBBLE MOUND BREAKWATERS AND THE ARMOUR STABILITY

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**Abstract**
The paper provides some results of a new procedure, developed to analyze the hydrodynamic aspects of the interactions between maritime emerged breakwaters and waves, by integrating CAD and CFD software.
The filtration of the fluid within the interstices of a concrete blocks breakwater, is evaluated by integrating the Reynolds Averaged Navier-Stokes equations (RANS) inside the voids rather than making use of the widespread "porous media" approach, such as for example in Hsu et al (2002) and Lara et al (2006).
The structure is thus modelled, very much like in the real world or in the physical laboratory testing, by overlapping individual three-dimensional elements (Accropode™, Core-loc™, Xbloc®), and then the computational grid is fitted so as to provide enough computational nodes within the flow paths.
This approach is meant to match closely the physical laboratory test procedure, and it is oriented at analyzing the hydrodynamic aspects of the phenomenon (overtopping, breaking, run-up, reflection) as well as the stability of armour elements.

**Introduction**
Due to their interactions with complex natural system as the sea-beach, the emerged breakwater are normally designed (hydraulic efficiency and armour stability) by making use of numerical or physical models, rather than by applying the simple formulas available in literature theories.
However, until recently, the physical models in tank were the only way to investigate into some aspects which could not be evaluated by numerical modelling alone, such as the behaviour of rubble mound breakwaters made up of stone or concrete blocks where water flows through complex paths within the interstices, with a strongly non-steady regime, sometimes made even more complex by the presence of air.
Numerical solutions to the problems based on the full Reynolds Averaged Navier-Stokes equations (RANS) with the Volume of Fluid surface tracking method (RANS/VOF) have indeed been thoroughly tested, and have found their way into engineering practice. Interesting examples of how these issues have been addressed both physically and numerically are, for instance, reported in Karim et al (2009), Greben et al (2008), Hsu et al (2008), Lara et al (2008), Lin et al (2007), Lara et al (2006), Garcia et al (2004), Ting et al (2004), Hur et al (2003), Huang et al (2003), Hsu et al (2002), Requejo et al (2002), Tirindelli et al (2000), Lin et al (1998), van Gent (1995).
Within this context, the problems induced by the rock mound have so far been treated by the sometimes simplistic "porous media" approach which assumes a filtration flow (Darcy or Forchheimer for a linear or quadratic loss, respectively) between the blocks. In practice, an additional term is added to the equations to reproduce the interactions between the

fluid and the inner flow paths by using homogeneous coefficients for the entire filtration domain; this implies a solution with a scale much larger than the length scale of the random paths inside the breakwater.

Such an approach was reported in Hsu et al (2002), later implemented in the COBRAS numerical code and finally perfected by Lara et al (2006).

Even though such methods has provided good results in many applications, its main assumption can fail when the size of the blocks is high and the hydrodynamic inside the flow paths is characterized by relatively high values of Reynolds number; it, therefore, leads to overlooking the convective aspects of the flow and the structure of turbulence, and it also requires an empirical calibration of the numerical parameters of the filtration equations.

Indeed, as Hsu et al wrote in 2002"*: "In studying water wave and porous-structure interactions, it is still not practical to resolve the intrinsic flow field inside pores, whose geometry is usually random. It is more manageable if the flow equations are averaged over a volume that is larger than the characteristic pore size and is much smaller than the scale of the spatial variation of the physical variables in the flow domain*".

Recent advances in the computational technology of both fluid flow equations and computer graphics can provide now a new and more detailed approach: the solid structure can be reconstructed within the numerical domain by overlapping individual elements, arranged so as to form a calculation domain in the empty spaces delimited by the blocks.

Thus, by defining a fine computational grid, an adequate number of computational nodes can be located within the interstices so that a complete solution of the full hydrodynamic equations can be carried out including the convective effects and possibly the turbulence structure.

It is thus possible, at least in principle, to assess the rock stability of the armour layer; some examples are shown in the following by making use of two different approaches.

**Calculation model**

A well tested RANS-VOF code (FLOW-3D ®) has been used, with various turbulence techniques such as k-ε, RNG or LES, while the free surface time evolution is determined with the well know VOF (Volume Of Fluid) method (Hirt and Nichols, 1981).

Instead, for the schematization of complex geometries, such as those described in this article, the software uses the FAVOR™ technique, Fractional Area/Volume of Fluid. The software has been well tested for coastal hydrodynamics problems, as shown in Dentale et al (2008) and S. Chopakatla C. et al (2008).

The numerical reconstruction of the breakwater has been carried out by using a standard CAD software system for modelling 3D geometries. In the beginning, armour layers of various concrete blocks and stone shapes have been reproduced, such as: Stones, Accropode™*,* Core-loc™*,* Xbloc®*,* Xbloc® base (fig.1).

Based on the available literature formulas the breakwater structure has been designed, then it has been numerically reproduced by overlapping 3D individual blocks following real geometrical patterns, very much like in real size or physical model construction (fig.2 ).

Then, due to the obtained results, the new tests have also been performed with a more realistic breakwater design, building with the same criterion, including the toe protection and the filter layer (fig.2).

The simulations were carried out by integrating the RANS equations coupled with the RNG turbulence model on a nested computational grid, for various incident regular wave conditions. The numerical three-dimensional space, for all types of structures considered in this work, is made up by two blocks of mesh, a general one of 150,000 cells of size equal to 0.50 x 0.20 x 0.30 cm and a localized one of 2,025,000 cells with size lower or equal to 0.10 x 0.10 x 0.10 cm. (fig.3).

## Results

Some of the results are shown in the figures below. Initially, the main objective of this stage was to test the capability of the grid to represent the wave-structure interaction phenomena, in particular with regard attention to the filtration motion inside the block's voids.

In the figures 4, the turbulent kinetic energy evolution, along 2D section of the domain and 3D free surface configuration are shown. The numerical grid used is fine enough to allow an estimation of the hydrodynamic parameters both in the interstices and along the solid surfaces of the individual armour elements. This can easily be appreciated in the three-dimensional reconstruction of the free surface (figg.4) where the effects of wave-structure interaction can be seen with greater details.

In order to validate the quality of the method, some of the effects (RunUp - Reflection) connected with the hydrodynamics of the wave-structure interaction phenomenon have been analyzed and the results compared with available experimental data.

An example of what has been obtained is shown in figure 5, where the time series of the run-up and the effects of reflection, generated by regular waves, is presented for one of the studied structures.

The reflection effects, as summarized by the reflection coefficient, have been determined and successfully compared with similar laboratory tests reported in the literature (Zanuttigh and Van der Meer 2006). It is obvious that, given the number of different variables for this kind of problem, fitting a global parameter is not a sufficient proof of the accuracy of such a complex method; it is however, an encouraging evidence that physically meaningful results can be obtained.

Finally, we started to study the stability of armour units using two approaches (fig. 6): the first one evaluates the forces generated only by the pressure acting on the armour layer (Accropode™), located at the middle section of the calculation domain. In figure 6 the resulting pressure acting on some elements is represented; this could be taken as an index of stability, even though the effects of interlocking due to the conformation of the armour layer are not taken into account.

In the second approach, the full motion equations are considered taking into account the blocks' weight and the interlocking effects, so the previously considered elements have been defined, in the calculation domain, as heavy objects with six degrees of freedom. The resulting hydraulic forces are represented as the sum of hydraulic pressure and shear stresses action (fig. 6).

Having all the information to fully characterize the motion of a block (movement coordinates, components of the velocity vector and angular velocity of the mass centre, kinetic energy, components of hydraulic force and hydraulic torque referred to the mass centre) the breakwater's block movement and the structure failure will can be analyzed numerically.

A systematic comparison with experimental results will allow a calibration of the method and eventually provide a useful design tool.

## Conclusions

Numerical techniques have been used to simulate the interactions between rubble mound breakwaters and the waves; while the general procedure, based on integrating the Navier-Stokes equations has been in use for a number of years and can be considered to be well tested, a new approach has been proposed whereby the equations are integrated well into the passages between the single concrete blocks or stones, rather than by adopting a seepage flow procedure, such as it is now common practise.

Up-to-date CFD software, integrated with CAD techniques, make this approach possible with reasonable computational resources, and reliable enough to fit available experimental parameters.

Forces acting on single blocks can be evaluated and the possibility of gathering a deeper understanding of failure mechanisms is thus open.

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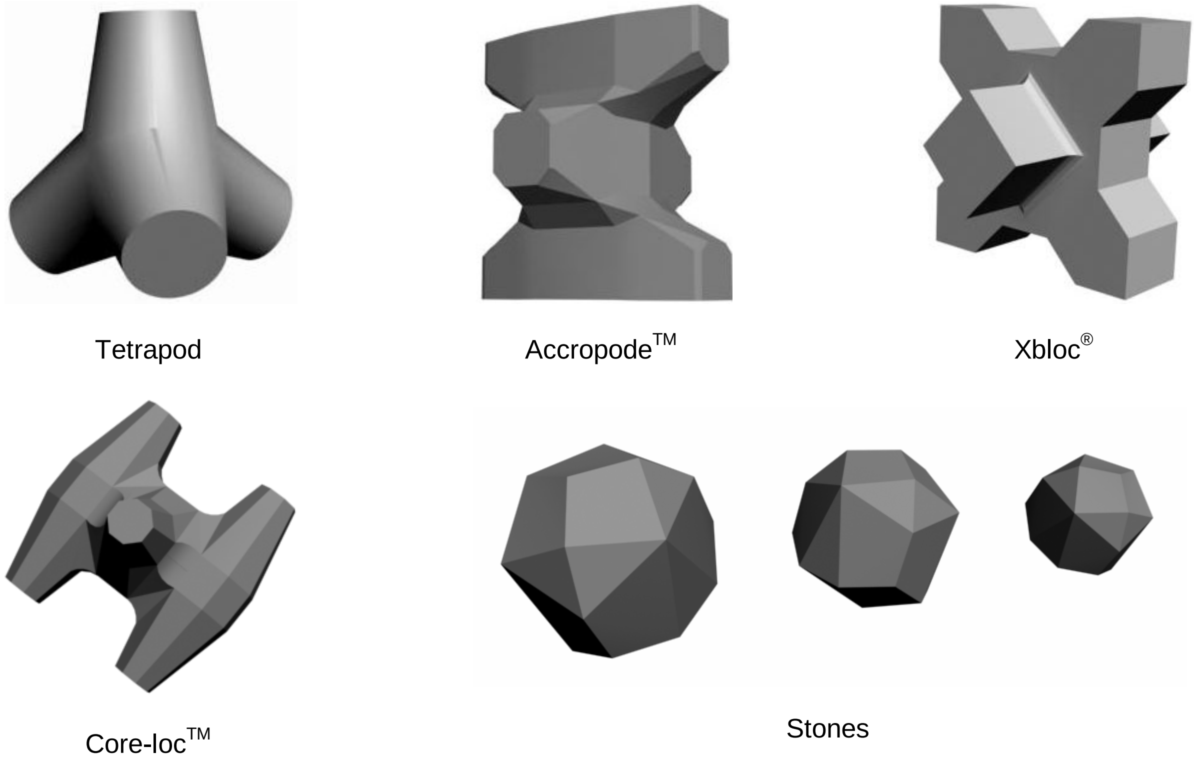



Fig. 1: Armour Units

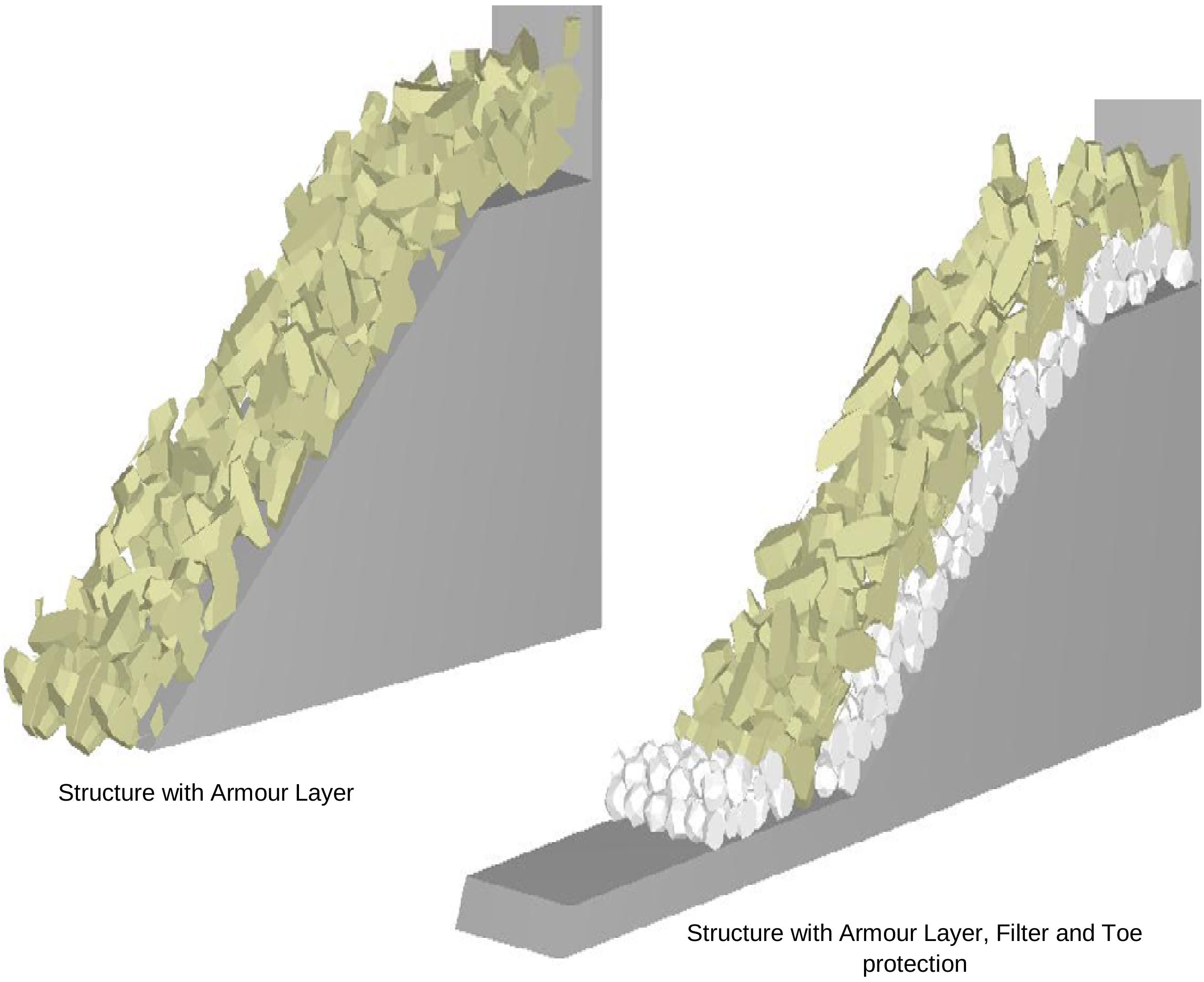



Fig. 2: 3D Numerical Structures

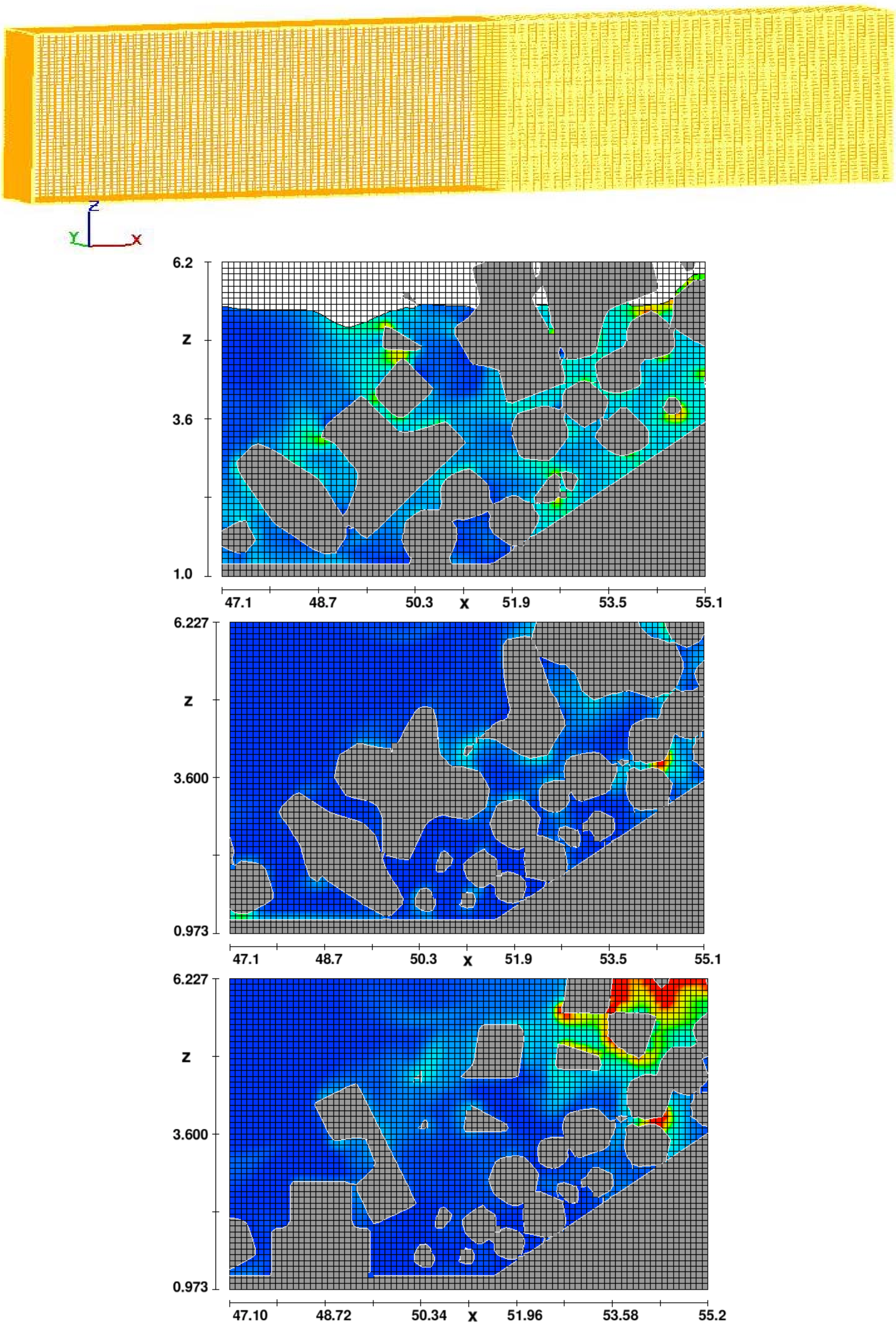



Fig. 3: Numerical Mesh

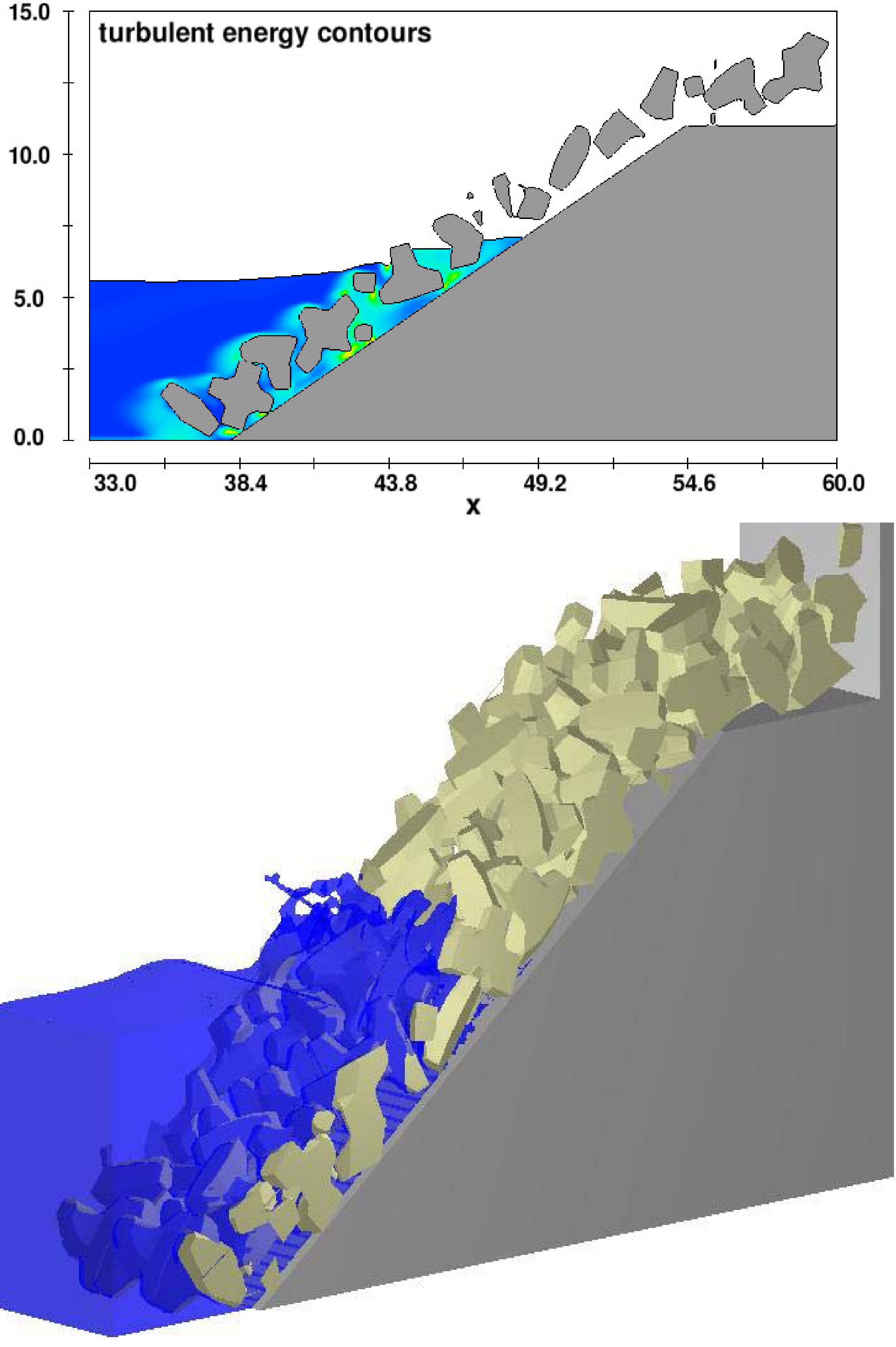



Fig. 4: 2D_3D Numerical Results: Structure with Armour Layer (Accropode™)

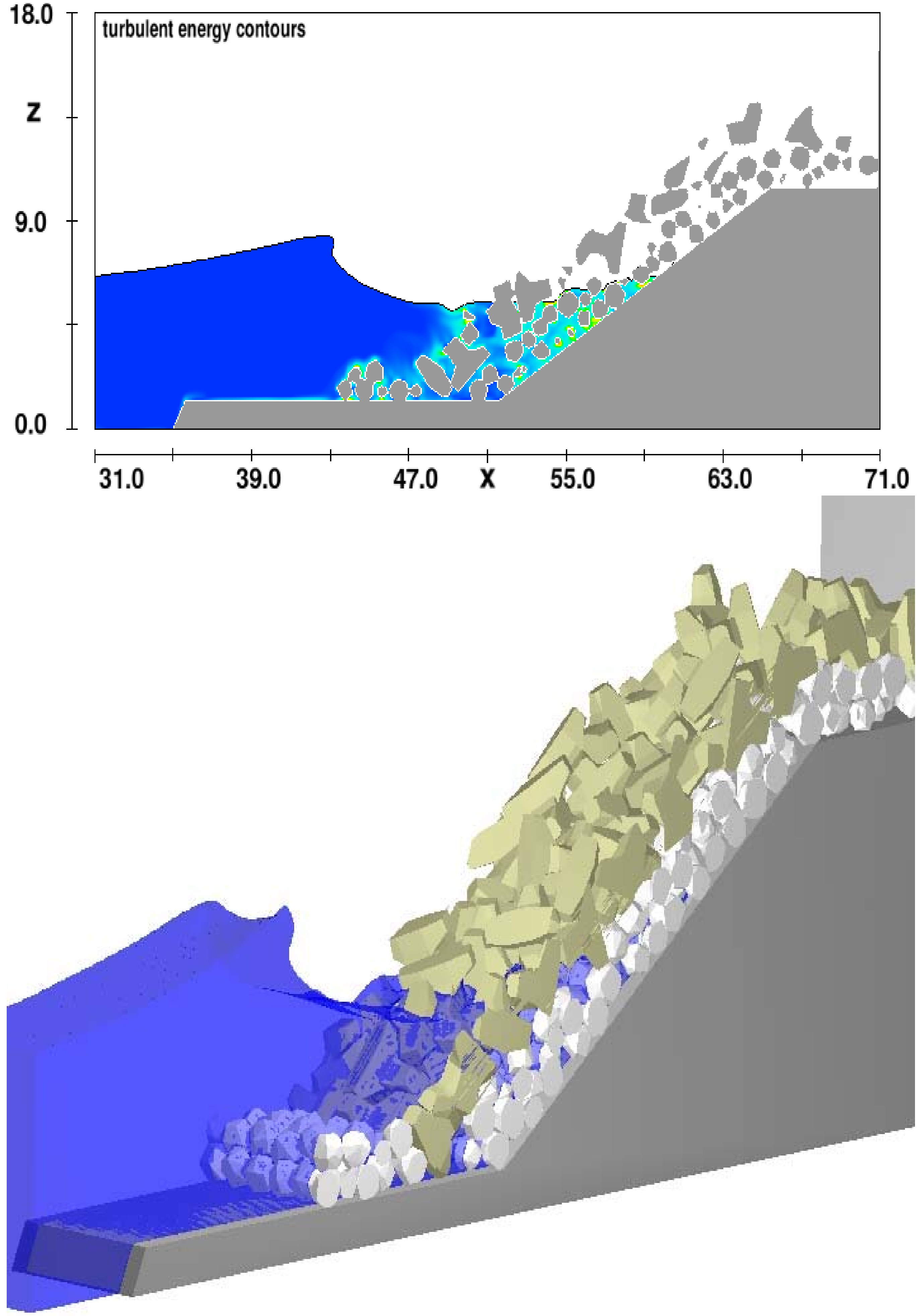



Fig. 4: 2D_3D Numerical Results: Structure with Armour Layer, Filter and Toe protection (Accropode$^{TM}$)

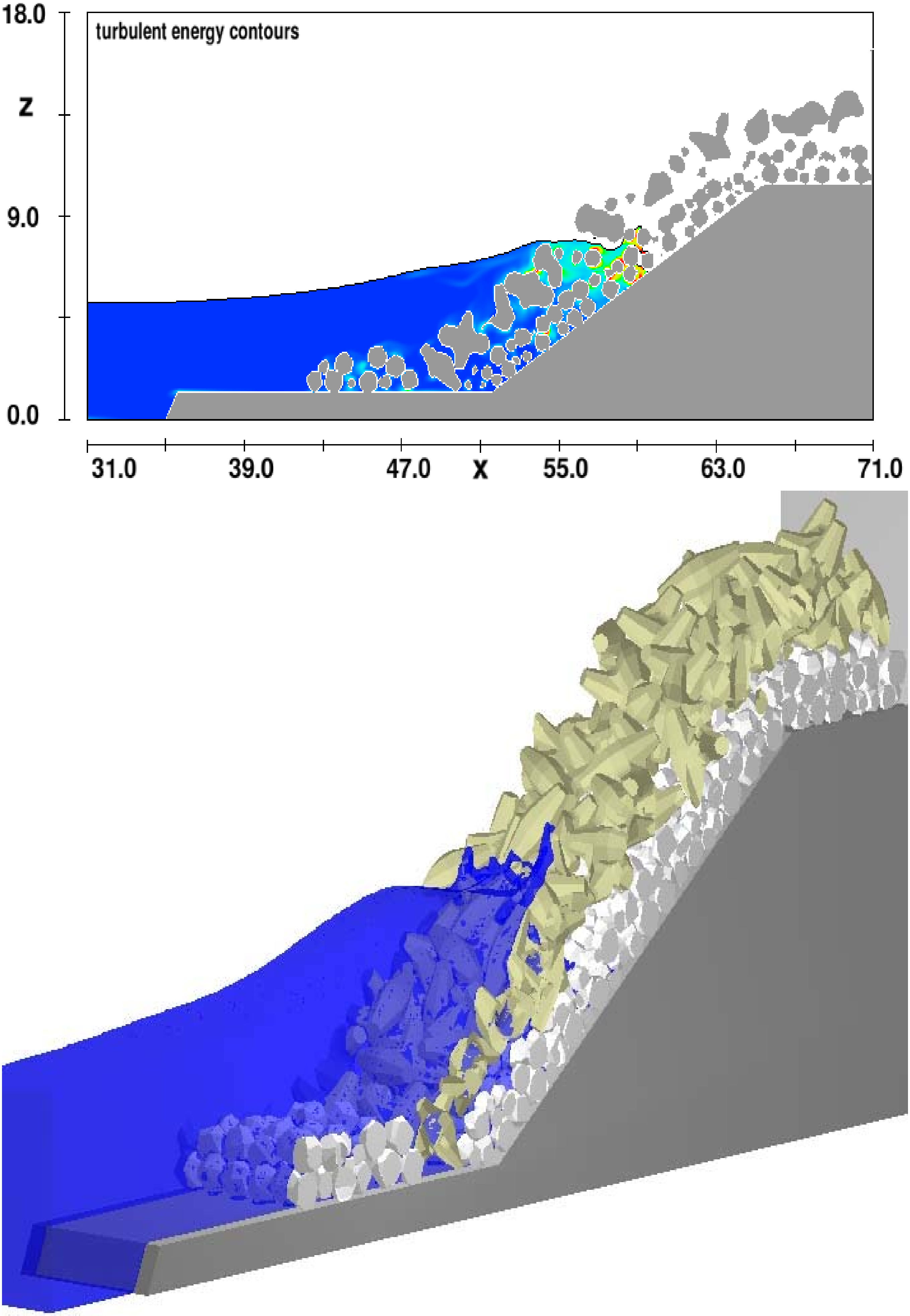



Fig. 4: 2D_3D Numerical Results: Structure with Armour Layer, Filter and Toe protection (Core-loc™)

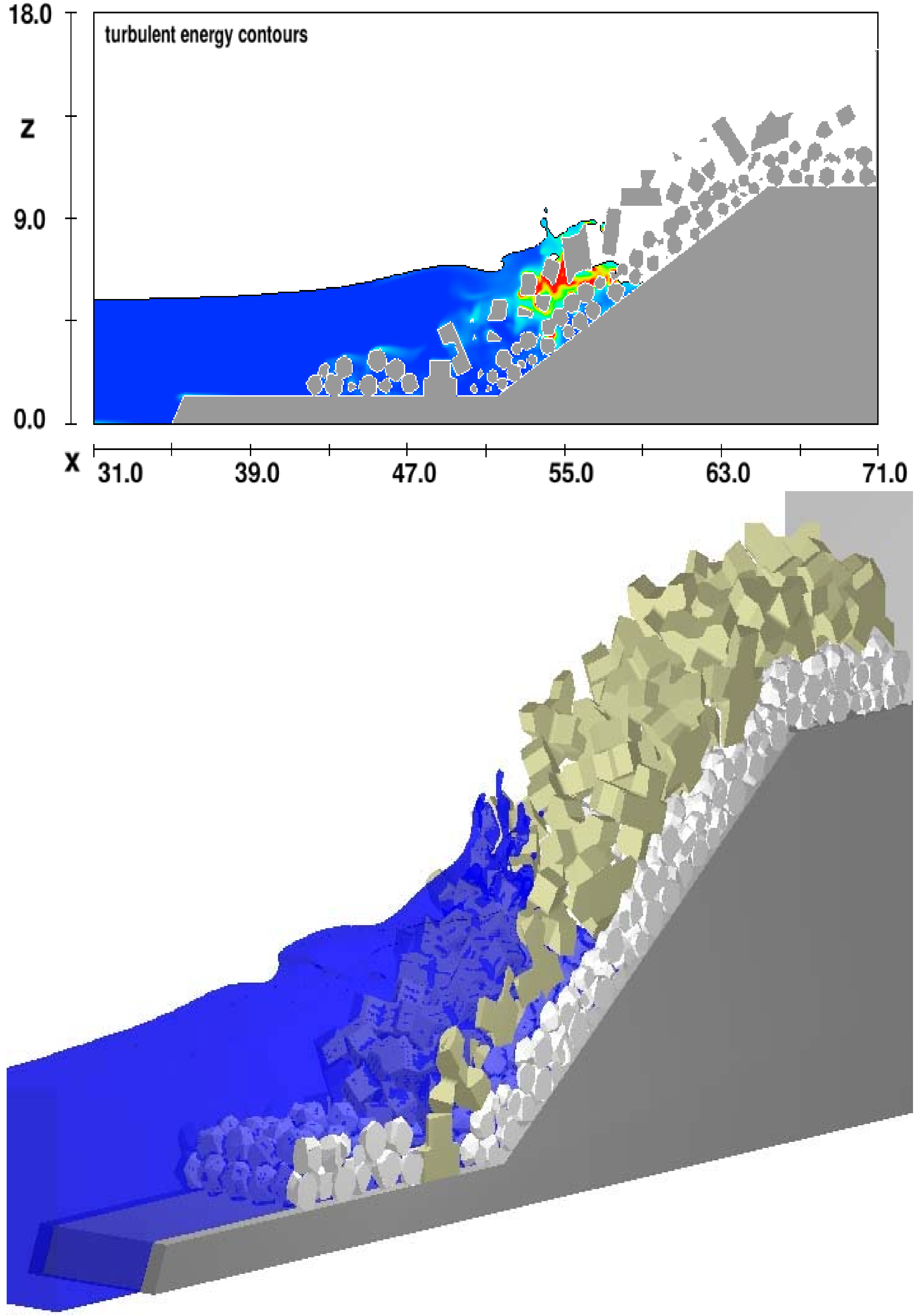



Fig. 4: 2D_3D Numerical Results: Structure with Armour Layer, Filter and Toe protection (Xbloc®)

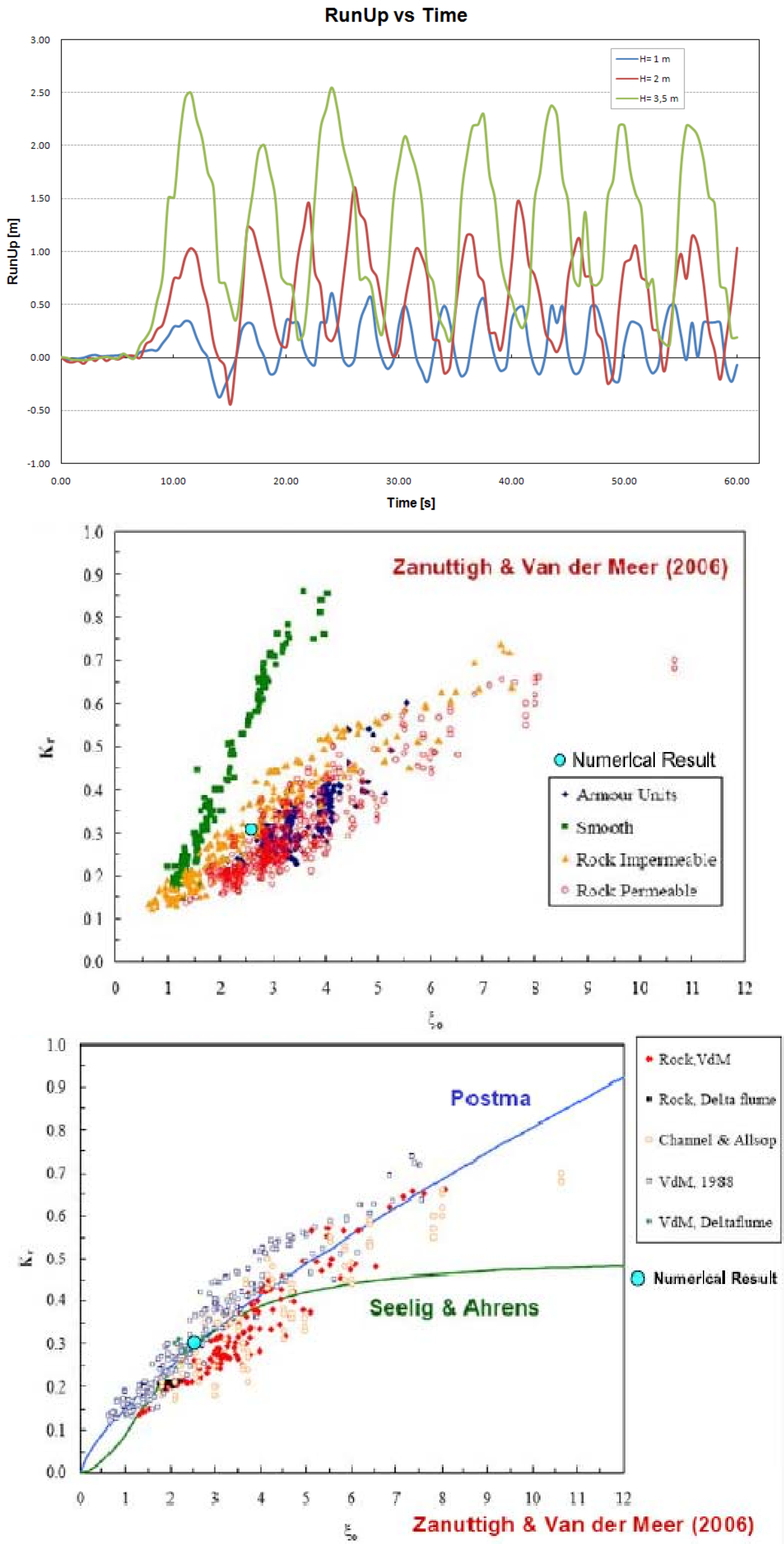
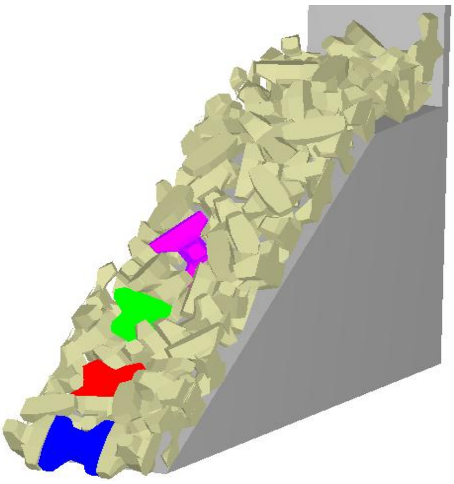
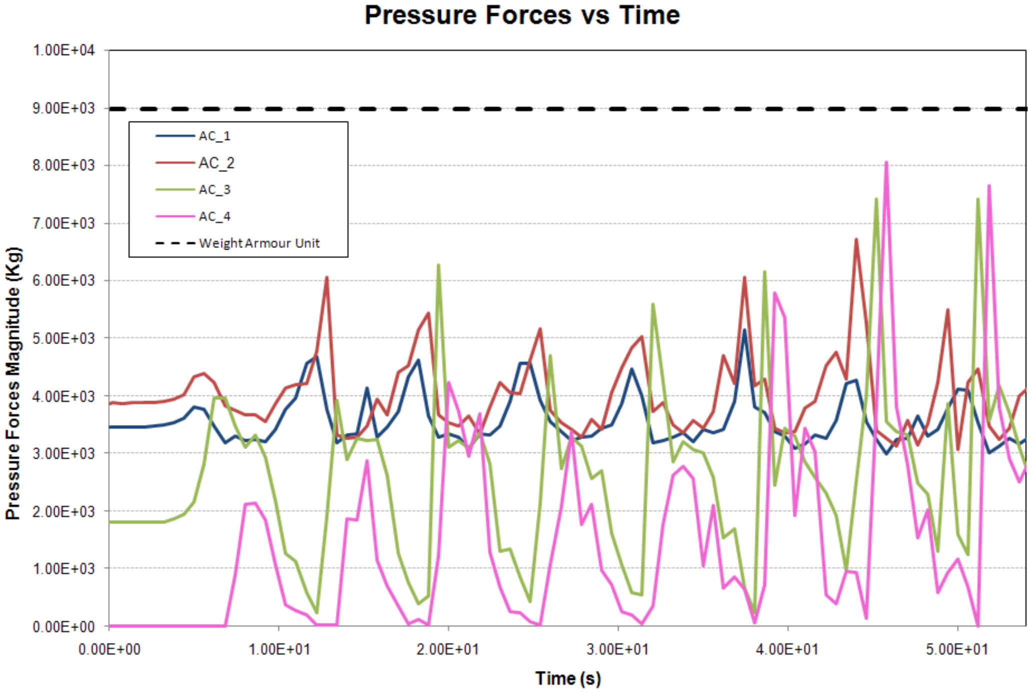



Fig. 5: RunUp and Reflection Coefficient



In the figures below are shown the forces for coloured Accropode$^{TM}$:

- AC_1 = blue
- AC_2 = red
- AC_3 = green
- AC_4 = fuchsia



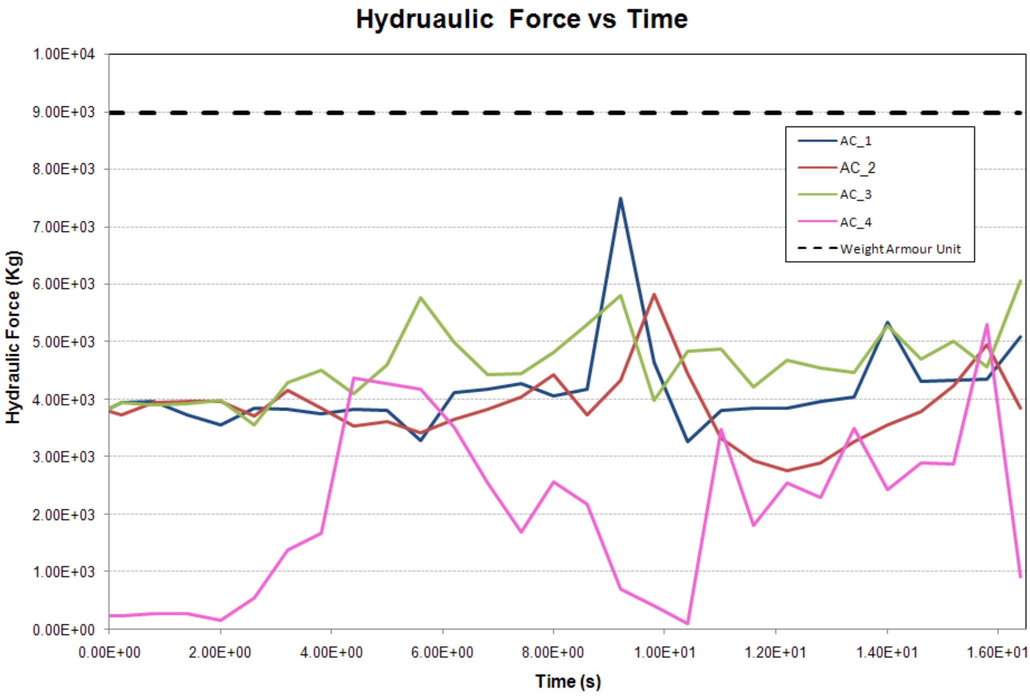




Fig. 6: Armour Units Stability