ADVANCED NUMERICAL SIMULATIONS ON THE INTERACTION BETWEEN WAVES AND RUBBLE MOUND BREAKWATERS

F. Dentale [(1)] - E. Pugliese Carratelli [(1,2)] - S.D. Russo [(3)] - S. Mascetti [(4)]
[(1)] Department of Civil Engineering – University of Salerno
[(2)] C.U.G.Ri. – University Research Centre on Major Hazards
[(3)] PhD student in PhD in Environmental Civil Engineering – University of Salerno
[(4)] XC Engineering

Abstract
In the present article a new procedure is proposed to study the interactions between maritime breakwaters (submerged or emerged) and the waves, by integrating CAD and CFD software.
The 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, transmission) and the stability of primary armour elements.

Methodology and results
CFD applications are common practise in all sectors of engineering, and they are becoming increasingly important in maritime and coastal engineering.
The design of breakwaters, however, which must be based on the full understanding of the interaction of a natural system as complex as the sea and beaches with artificial structures, is necessarily based on extensive application of physical modelling testing. Laboratory scale tests, therefore, significantly affects on the economic framework of a specific project.
Until recently the complex aspects of breakwater behaviour were far too complex for numerical approaches, especially so for rubble mounds, composed by blocks of concrete or rocks in which water flows through complex paths with unsteady motion, sometimes in presence of air. The designer, who needs support for the hydraulic performance (overtopping, fringes, lifts, reflection, transmission) as well as for structural design, especially in relation to the stability of blocks, must necessarily rely on empirical formulas simple followed in most cases by ad hoc model tests.
Direct methods, based on numerical Navier-Stokes solution with various turbulence models, and fully tested in other fields of technology, have not yet reached their full maturity in coastal engineering, in particular for geometrical complex problems. As long as the calculation domain is made only by the liquid phase, the applications are relatively simple and can be tackled with a certain degree of confidence; very often, however, the reconstruction of the structure cannot faithfully represent the geometry of a real rubble mound made by the overlapping of individual elements (armour layer, under layer, core).
The greatest difficulty arises when the interactions between liquid and solid objects must be analysed: in this case the possible solutions to the problem are generally treated using two different approaches.
The first, and simplest, is based on the assumption that the porous geometry, while influencing the phenomenon, has not a predominant emphasis on the characteristics of the fluid motion and, hence, the solid element can considered as a single block within the calculation domain, thus neglecting the effects of porosity. The equations therefore are discretized by finite differences on a mesh that has no calculation nodes inside the structure.
The second methodology, which is now quite common, only takes into account the influence of porosity on the fluid motion by assuming that, within the rubble mound, the flow is purely viscous and can be treated by the classical Darcy Equations for filtration.
Of course, the finer the computational grid, the more points are located on the boundary layer of liquid-solid interface, and the greater is the accuracy of the calculation especially as regards to the interaction.
The references on this topic are far too many to be examined in detail here, however it may be useful to recall some interesting examples of how these issues have been addressed both physically and numerically: Karim, et al., 2009; Greben et al., 2008; Hsu et al., 2008; Lara et al., 2008; Li net al., 2007; Lara et al., 2006; Ting et al., 2004; Hur et al., 2003; Huang et al., 2003; Hsu et al., 2002; Requejo et al., 2002; Losada et al., 1995; van Gent, 1995.
It is easy to see, however, that such an 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.
This is made worse by the fact that in this case the stability of rocks is not easily assessable, unless considering some simplifications of the problem; consequently, this kind of analysis has been so far addressed mainly on an experimental basis.
The gap between the two kinds of investigation, numerical and physical, may be partially filled, thanks to the advancement of computing technology.
It seems now practically possible to represent the solid structure which interacts with the flow by overlapping individual elements, so to create a numerical calculation domain within the empty spaces between the blocks.

It is thus possible to evaluate the effect of the full hydrodynamic behaviour, including convective terms, and the effects of turbulence, which cannot be taken into account with the classical Darcy scheme, clearly inadequate in such kind of situations.
An example of this is briefly exposed in the following examples where, by using advanced digital techniques, rubble mound maritime structures are modelled on the basis of their real geometry, taking into account the hydrodynamic interactions with the wave motion: further developments might also lead to evaluate the stability of the individual elements of the mound.

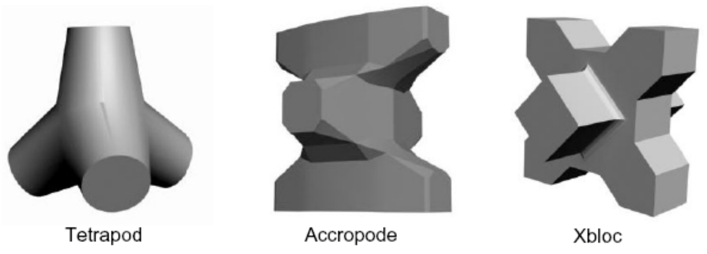

Fig. 1: Artificial blocks

By using a CAD software system for the three-dimensional modelling it is possible to reproduce the different types of blocks used for the primary armour.
The work has taken into consideration a very schematic representation of a natural stone mound, reproduced as a set of spheres, and has been developed to consider commonly used artificial blocks such as the cube, the modified cube, the antifer, the tetrapod, accropode, accropode II, coreloc, xbloc, xbloc base (fig. 1).
Breakwaters, both submerged and emerged, have been sized by making use of standard empirical formulas as available in the literature and numerically constructed by overlapping individual blocks following real geometric patterns, modelling the structure as it happens in the full size construction and in the physical modelling (fig.2).

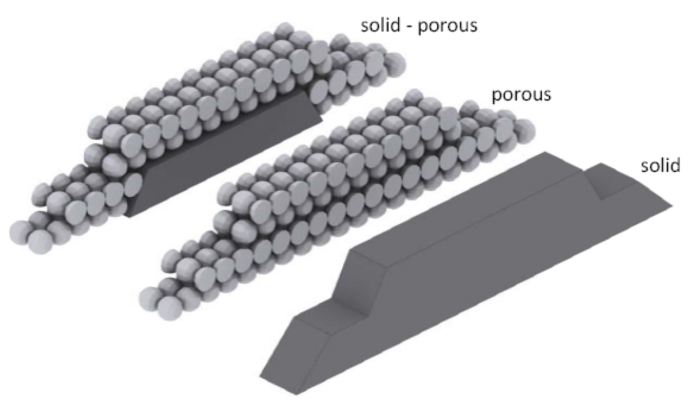

Fig. 2a: Submerged Breakwaters

In order to validate the quality of the proposed procedure, three different geometries have been considered for the submerged breakwater: solid, porous, solid-porous (fig. 2a), while for the emerged one, two different kinds have been used, according to the elements configuration: regular and random (fig.2b - 2c).

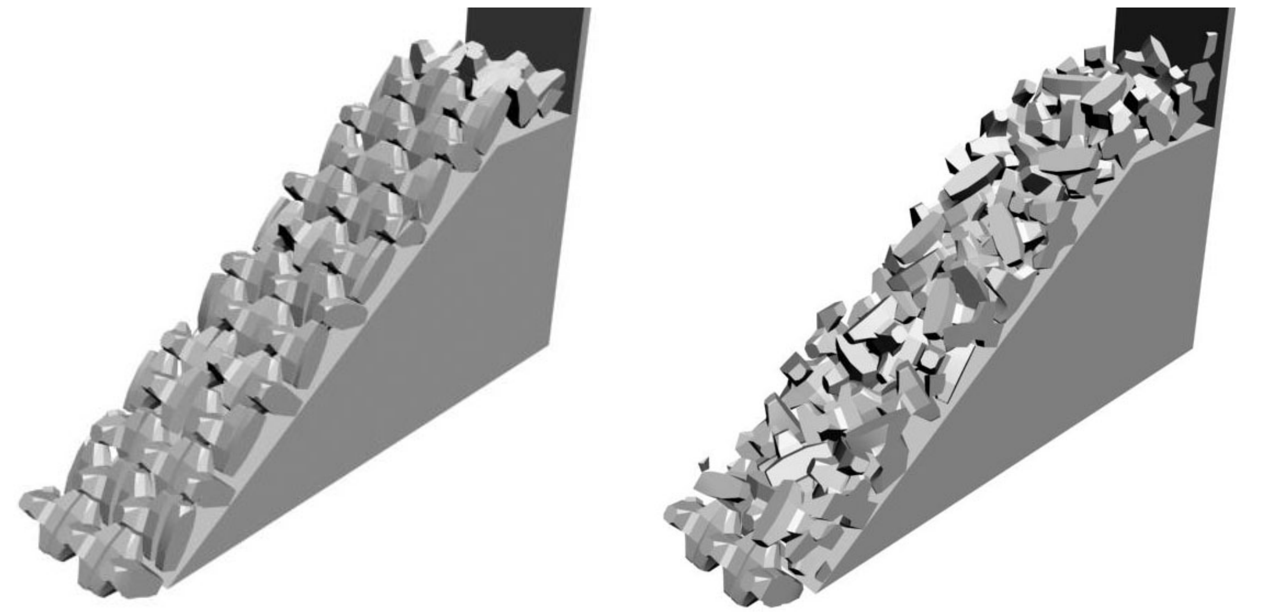
Fig. 2b: Emerged Breakwater - Accropode regular   Fig. 2c: Emerged Breakwater - Accropode irregular

Once the breakwaters defined, the geometric configuration has been imported into FLOW-3D® and extensively tested for the study of wave propagation (Dentale et al 2008, Chopakatla SC et al 2008) in order to assess the hydrodynamic interactions.
The simulations were carried out by integrating the Navier-Stokes equations in the complete form (3D), with a RNG turbulence model, and using a two mesh “nested” computational grid.

For the submerged barrier (calculation domain 90x1.9x6.5m), the general mesh was built with 46,200 elements of equal size of 0.30x0.27x0.30m, while the inner one was located at the breakwater with 2,353,412 elements of equal size of 0.061x0.055x0.061m.
The same criterion was adopted for the emerged breakwater: general mesh with 150,000 elements - size 0.50x0.20x0.30m, local with 2,025,000 elements - cubic dimension 0.10m. (fig 3).
Some of the results are summarized in the following images. In figure 4 the evolution of pressure and turbulent energy along a two-dimensional section of the 3D domain is represented, while in figure 5 the three-dimensional configurations of the free surface, caught in different moments of time, are showed.
The variation of the hydrodynamic quantities both along the flow paths and along the contour of the individual solid elements of

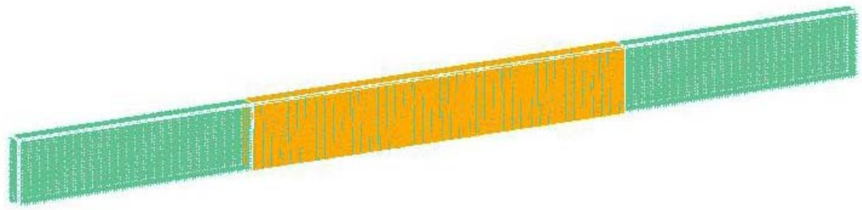

Fig. 3a: Mesh submerged breakwaters

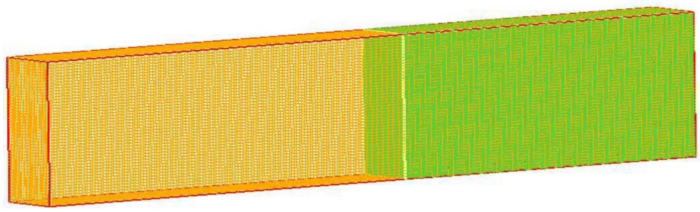

Fig. 3b: Mesh emerged breakwaters

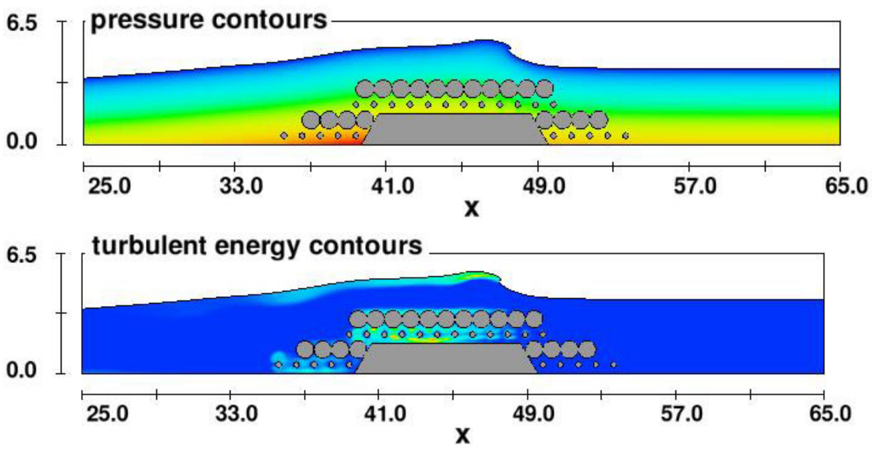

Fig. 4a: Submerged breakwater

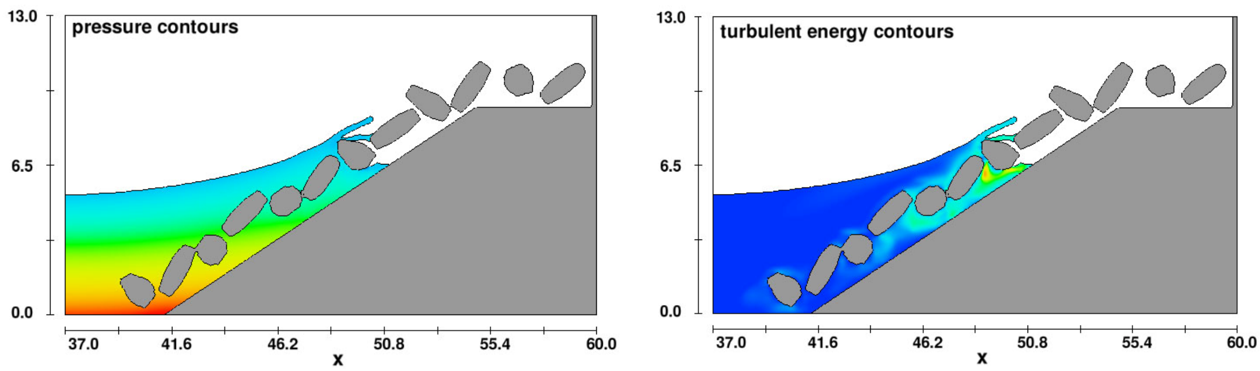

Fig. 4b: Emerged Breakwater - Accropode regular

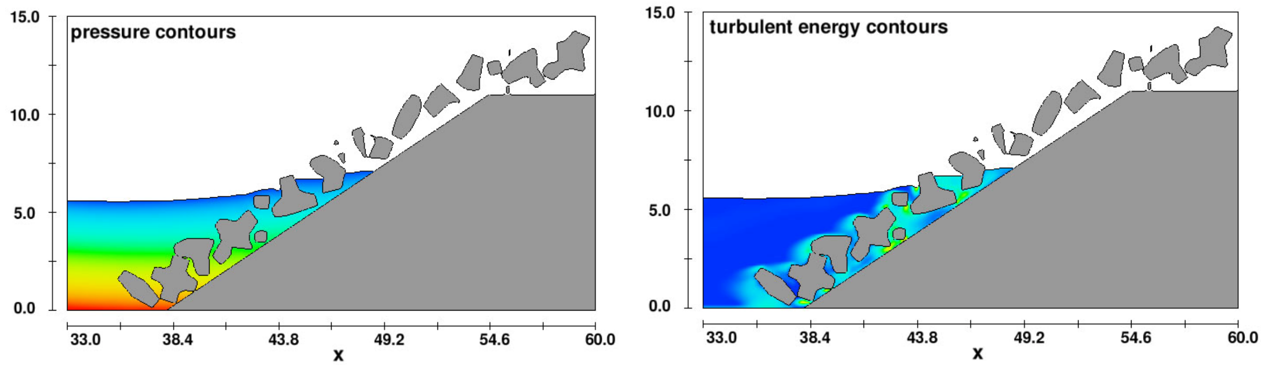

Fig. 4c: Emerged Breakwater - Accropode irregular

the primary armour are easily detectable. This is most visible in three-dimensional reconstruction of the free surface (fig.5) where the effects of wave action on the breakwater are represented with greater details.

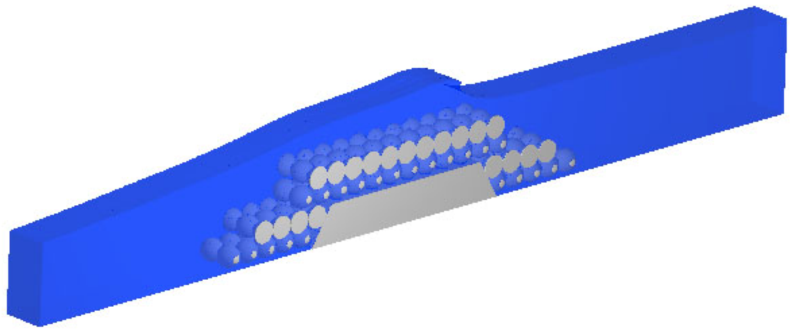

Fig. 5a: Submerged breakwater

Conclusions

A new methodology has been proposed to integrate CAD and Navier-Stokes simulation to provide an accurate representation of the interactions between a maritime structure, either submerged or

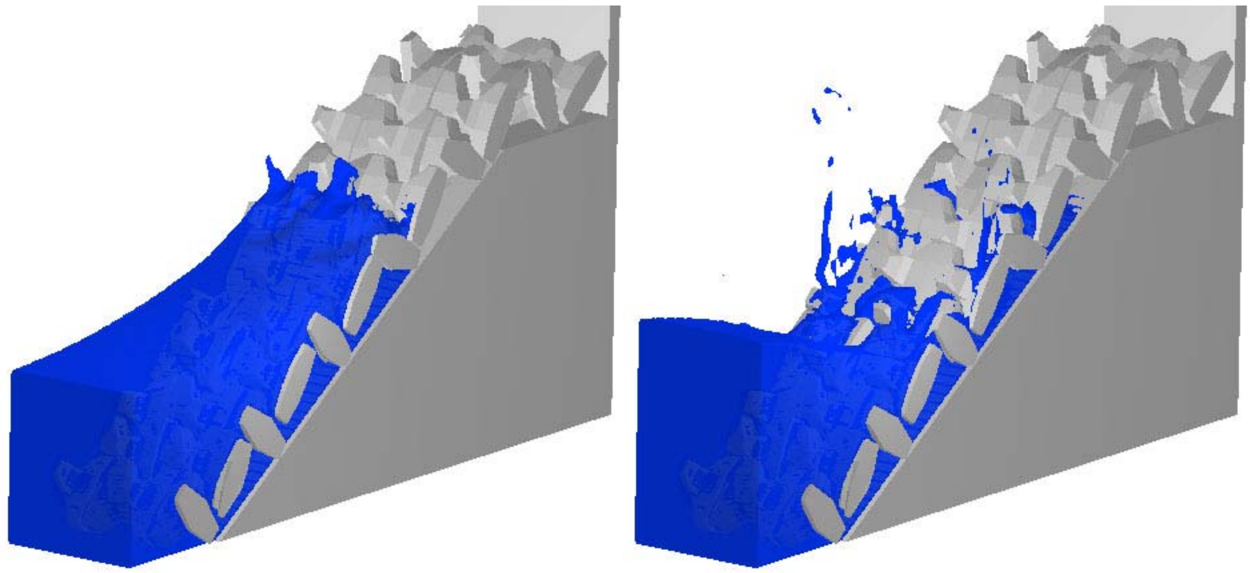

Fig. 5b: Emerged Breakwater - Accropode regular

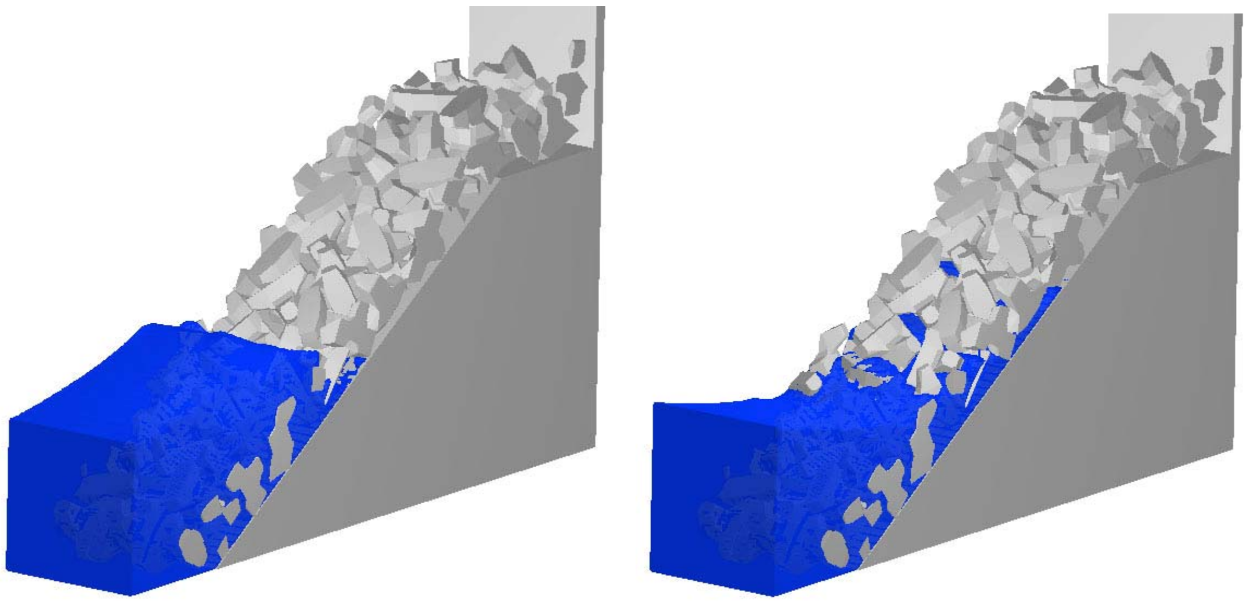

Fig. 5c: Emerged Breakwater - Accropode irregular

emerged, and motion. Simulation were carried out by making use of an advanced computational fluid dynamic software system (FLOW-3D®), involving RANS for turbulence simulation and VOF for free surface computation.

As shown by the obtained results, the procedure provides a detailed picture of the fluid motion within the paths among blocks, thus allowing, at least in principle, a more accurate simulation than the conventional seeping flow methods.

In principle, there are no limitations on the possibility of simulating the structure, both submerged and emerged, in all its relevant parts (filter, core and toe).
Further developments should be aimed at assessing the stability of individual blocks, possibly through the already implemented GMO (General Moving Obstacles) model in the computational fluid dynamic software used.

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