A New Numerical Approach to Study the

Wave Motion with Breakwaters

and the Armor Stability

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The design of breakwaters must be based on the full understanding of the interaction of a complex natural system (the sea and shores) with artificial structures (breakwaters). Typically, design work entails extensive physical modeling, which can be quite expensive and time-consuming. Until recently, the complex aspects of breakwater behavior were considered too challenging for detailed numerical simulations. This is especially the case for breakwaters consisting of rubble mounds composed of blocks of concrete or rocks in which water flows through complex paths with unsteady motion. 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.

Now thanks to the recent advances in the computational technology, both in fluid flow equations and computer graphics, the gap between numerical and physical investigations has narrowed, so to provide 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 armor layer; some examples are shown in the following by making use of two different approaches.

Figure 2

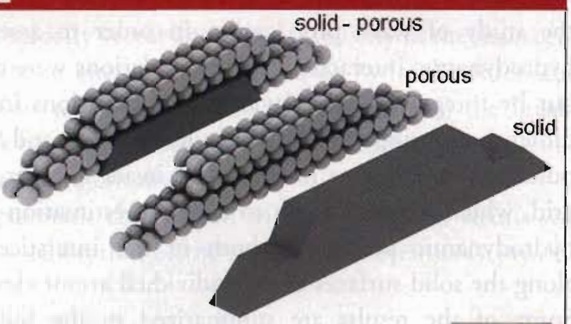


Fig.2a: Submerged Breakwaters

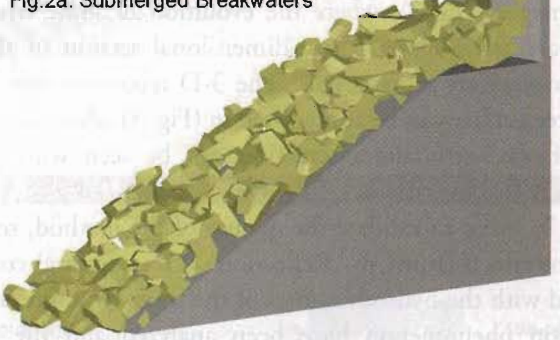


Fig.2b: Emerged Breakwater with Armour layer

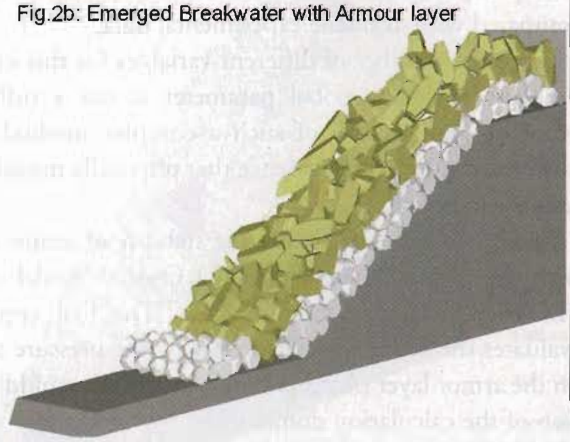


Fig.2c: Emerged Breakwater with Armour layer, Filter and Toe protection

Figure 3

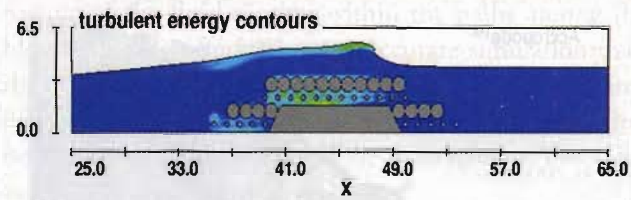


Fig.3a: Submerged Breakwater

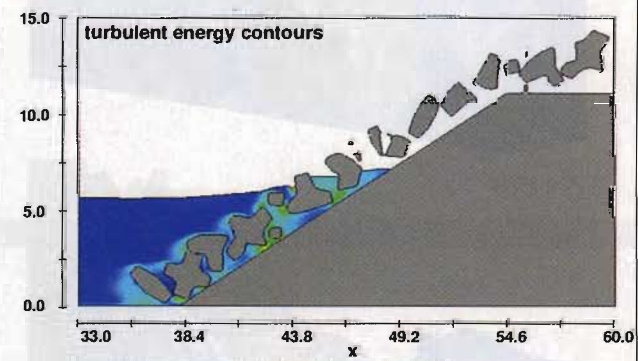


Fig.3b: Emerged Breakwater with Armour layer

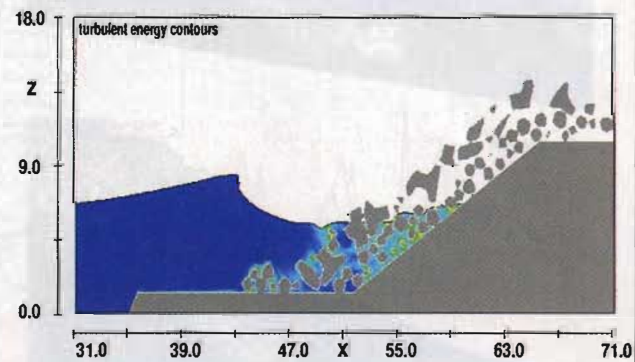
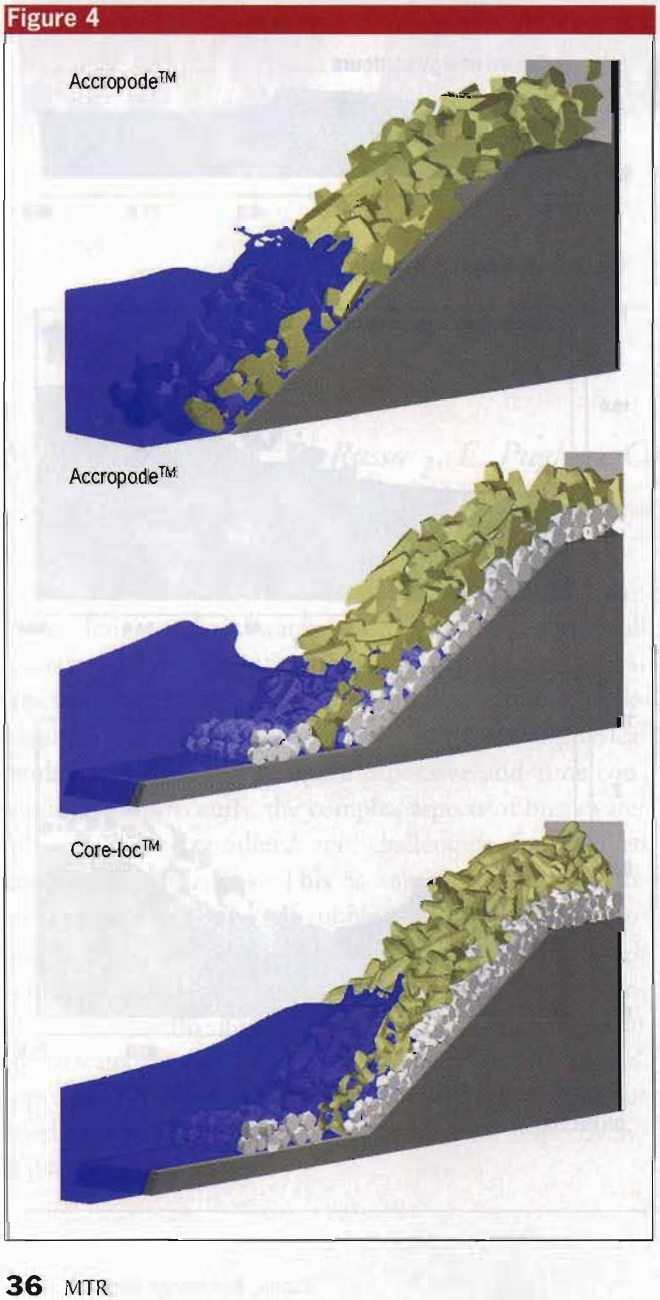


Fig.3c: Emerged Breakwater with Armour layer, Filter and Toe protection

Modeling Rubble Mound Breakwaters

The following examples describe cases where rubble mound breakwaters are modeled on the basis of their real geometry, taking into account the hydrodynamic interactions with the wave motion. The research work started by considering a schematic representation of a natural stone mound, reproduced as a set of spheres, and was further developed to consider commonly-used artificial blocks such as the cube, the modified cube, AccropodeTM, Core-locTM, Xbloc, stones.

Figure 4



Breakwaters, both submerged and emerged, were sized by making use of standard empirical formulas as available in the literature and numerically constructed by overlapping individual blocks following real geometric patterns, modeling the structure as in the full size construction and in the physical modeling. Due to the CAD and CFD capabilities it is possible to build the structure with all its details as the filter layer and the toe protection. Some examples are provided in Fig. 2.

Once the breakwaters were defined, the geometric configuration was imported into FLOW-3D and tested for the study of wave propagation in order to assess the hydrodynamic interactions. The simulations were carried out by integrating the Navier-Stokes equations in three dimensions, using the RNG turbulence model and a computational grid with a mesh, nested inside a larger coarse grid, which is fine enough to allow an estimation of the hydrodynamic parameters both in the interstices and along the solid surfaces of the individual armor elements. Some of the results are summarized in the following images (Fig. 3), where the evolution of some hydraulic parameters along a two-dimensional section of the 3D domain are represented. The 3-D reconstruction of the free surface can be appreciated in (Fig. 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 – Overtopping) connected with the hydrodynamics of the wave-structure interaction phenomenon have been analyzed and the results compared with available experimental data.

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, encouraging evidence that physically meaningful results can be obtained.

Finally, we started to study the stability of armor units, with the GMO (General Moving Object) model of the FLOW-3D, using two approaches. The first approach evaluates the forces generated only by the pressure acting on the armor layer (Accropode), located at the middle section of the calculation domain.

In the second approach, the full motion equations are considered, so the previously considered elements have been imported without motion in the calculation domain, as heavy objects. During the calculation the hydraulic forces (pressure and shear stresses) on the individual elements are evaluated and then, after the simulation, compared with the weight of blocks.

If the force is greater than weight a warning to that block is assigned because the stability is due only to the interlocking force. In the pictures an example of the hydraulic forces versus time with the weight of the colored armor block is showed (Fig. 5).

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 could be analyzed numerically.

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

Conclusions

A method utilizing Navier-Stokes-based numerical simulation to provide an accurate representation of the interactions between a maritime structure, either submerged or emerged, and fluid motion has been demonstrated. Simulations 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.

The results show that the procedure provides a detailed picture of the fluid motion within the paths among the blocks, thereby offering a more accurate simulation than the conventional seeping flow methods. There are no limitations on the possibilities of simulating the structure, both submerged and emerged, in all its relevant parts (filter, core and toe).

Figure 5