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Research Article

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Wave Run Up and Reflection on Tridimensional Virtual Breakwater

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Abstract

The paper provides some results of a new procedure (CAD and CFD) to analyze the hydrodynamic aspects of the interactions between virtual maritime emerged breakwaters and regular waves.

The structure is modeled into numerical domain, very much like the real world or the physical laboratory testing, by overlapping individual three-dimensional elements (Accropode™), and the computational grid is fitted so as to provide enough computational nodes within the flow paths.

Therefore 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 "porous media" approach.

For the results' validation, the numerical run-up and reflection effects were compared with some empirical formulas and some similar laboratory tests.

Keywords: VOF; Numerical simulation; Run up; Reflection; Rubble mound; Coarse grained

Introduction

Due to their interactions with complex natural system as the sea-beach, the emerged breakwaters are normally designed by making use of numerical or physical models, rather than by applying the simple formulas available in literature.

Until recently, the physical models in tank were the only way to investigate into some aspects which could not be evaluated by numerical modeling alone, such as the behavior of rubble mound breakwaters made up of stone or concrete blocks. Within such structures, the water flows through complex paths indoors the interstices, with a strongly non-steady regime, sometimes made even more complex by the presence of air.

So the designer, to obtain a valid support for the hydraulic and structural sizing (overtopping, run-up, reflection), in particular for the rocks stability, had until now only the possibility to realize the physical evidence in the laboratory.

The numerical approach, particularly for problems with a so complex geometry, had until recently the failure to provide not satisfactory information, due to the inadequate reproduction of the interaction phenomena as they happen in the reality.

The construction of the structure could not faithfully represent the geometry of a work made by overlapping single elements in layers (core, filter, armour) and furthermore there were major limitations on the calculation of the filtration motion.

The complexity of the fluid dynamics involved, which features strongly non stationary flow, free boundary, turbulence, interaction with solid transport and often complex geometry, has until recently hindered the direct application of Navier-Stokes integration within the rubble mound as a practical tool; current practice for tackling the problems of porous structure follows two different approaches.

The first and easiest one is based on the assumption that, even if the porous mound influences the global phenomenon because of its external shape, the flow within it does not bear an essential influence on the hydrodynamics. Hence, the mound is considered as a single waterproof block within the calculation domain, thus neglecting the effects of porosity. The equations therefore are discretizzate by finite differences on a mesh that has no calculation nodes inside the structure.

The second methodology, which is now becoming quite common, takes into account the influence of porosity by assuming that within the rubble mound the flow is purely viscous and can be treated by the classical "porous media" methodology.

Ofcourse, 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 second methodology ("porous media") only takes into account the influence of porosity on the fluid motion by assuming that, within the rubble mound, the equations are modified to treat the filtration motion (Darcy or Forchheimer, if the head loss is linear or quadratic respectively).

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.

Such an approach was reported in [1], later implemented in the COBRAS numerical code and finally perfected [2].

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 [2-10].

This approach 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.

The results obtained through these types of modeling are much more reliable, the better was the calibration of the model, which involves, however, great difficulties. In general, however, it is also possible to observe from figure 5, the porous medium model is ill-suited to the turbulent phenomena that occur inside the armour layer.

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For these reasons, in order to provide the designer with a numerical model more reliable for the purposes of the design and verification of seawalls, with a consequent containment of costs linked to numerous tank tests, the authors have realized this innovative numerical procedure [11].

Starting from these considerations, the recent advances in the computational technology of both fluid flow equations and the 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 the empty spaces delimited by the blocks into the calculation domain.

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, using the defined scheme, to assess the rock stability of the armour layer considering the hydrodynamic forces, such as happened in the laboratory tests.

Calculation Domain and Wave Attacks

To define a numerical breakwater such as the physical model or the real world in the beginning a virtual concrete block (Accropode™) and stone shapes have been designed (Figure 1).

Then this phase, the numerical reconstruction of the breakwater has been carried out by using a CAD procedure software system for modeling 3D geometries.

Considering that an higher depth would lead to a greater computational effort, it was decided not to go beyond the 6 m, which appears to be a preferred choice in many design schemes, while the length and the slope of the berm were taken from literature that allow a proper interaction with the incident waves.

So, reconstructed an inner shape of a breakwater (waterproof, including in it the core, filter and sea wall), on the facing slope an Accropode™ armour layer has been modeled, digitally reproduced by overlapping individual blocks, one by one, under the conditions of gravity, collision and friction, according to a real geometry. Then, given the good results obtained with this first model, the definition of the breakwater has been improved by introducing, with the same digital technique, the filter layer and the toe protection (Figure 2). Obviously the choice of introducing the filter layer and the toe protection is aimed at improving the capability of the model to reproduce the problem's physical reality.

Defined the virtual structures, the geometric implemented configurations were imported into the code FLOW-3D® [12] to evaluate the hydrodynamic interactions.

FLOW-3D® from Flow Science, Inc. has several distinguishing features enables highly accurate simulations for investigating the dynamic behavior of liquids and gases in a wide range of industrial applications and physical processes. Those are TruVOF, FAVOR™ and multi-block meshing. FLOW-3D uses special numerical methods to track the location of fluid and solid surfaces and to apply the proper dynamic boundary conditions at those surfaces. TruVOF incorporates major improvements beyond the original Volume of Fluid (VOF) method to increase the accuracy of boundary conditions and interface tracking [13]. FLOW-3D incorporates a special technique, known as the FAVOR™ (Fractional Area Volume Obstacle Representation) method, which is used to define general geometric regions within rectangular grids. This technique allows for the simplicity of structured gridding while maintaining a high level of accuracy in flow dynamics. FLOW-3D®'s multi-block meshing is designed to add even more flexibility and efficiency to the finite difference meshing technique, allowing users to efficiently capture complex flow domain sand a high level of detail required within the flow domain. The software is based on the Navier-Stokes equations and makes use of the Volume-of-Fluid (VOF) method to track the free surface. The flow is described by the general Navier-Stokes equations:

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_j}{\partial x_j} = \frac{1}{\rho}\frac{\partial \rho}{\partial x_i} + \upsilon \frac{\partial^2 u_i}{\partial x_j \partial x_j} + g_i \tag{2}$$

Where υ is the molecular viscosity, u_i is the ith component of the

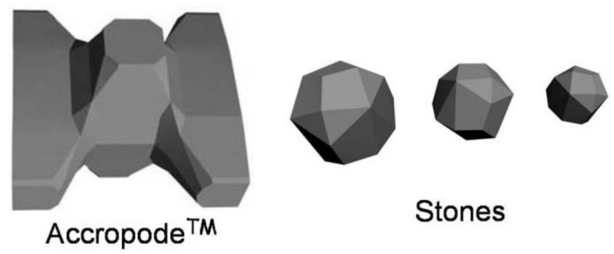

Figure 1: Virtual 3D models of stones and Accropode™

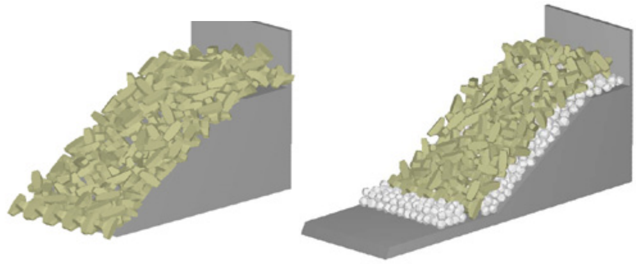

Figure 2: Virtual models of the breakwater (Bw 1 left, only armour layer and waterproof core – Bw 2 right, armour layer, filter layer, toe protection and waterproof core).

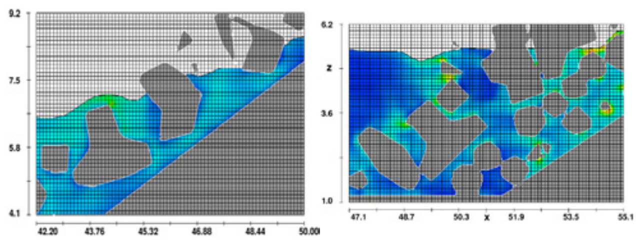

Figure 3: Snapshot of localized mesh (Bw 1 left, only armour layer and waterproof core – Bw 2 right, armour layer, filter layer, toe protection and waterproof core).

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instantaneous velocity in the pores, *p* the instantaneous effective pressure and g_i the *i*th component of the gravitational force.

The software has been well tested for coastal hydrodynamics problems, as shown in [14-16].

The simulations were carried out by integrating the RANS equations coupled with the RNG turbulence model on a numerical flume with a flat bottom. The numerical three-dimensional space is made up by two blocks of mesh, a general one in front of the breakwater and a localized one, with a finer grid, in the area of the breakwater where there is a more complex hydrodynamic and an adequate number of computing nodes within the flow paths is necessary in order to evaluate the filtration motion (Figure 3).

As for the wave motion, have been simulated 14 regular wave attacks, various periods, for the Breakwater Bw 1, while 18 regular wave attacks, various periods, have been simulated for the Breakwater Bw 2.

Preliminary Model Validation

Initially, the analysis of results was addressed to test the mesh capability to best represent the wave-structure interaction phenomena and the motion inside the blocks.

Thus, some snapshots of the turbulent kinetic energy are plotted, considering the central section of the flume (Figure 4a) and some 3D configurations of the free surface (Figure 4b).

It is possible to notice, how the used mesh allows to properly estimate the variation of the hydrodynamic quantities inside the flow paths and along the boundary of the individual solid element of the armour. This condition is most visible in the 3D reconstruction of the free surface (Figure 4b) where the effects of waves on the breakwater can be seen with more detail.

Among the flow paths inside the blocks turbulent kinetic energy is developed, due to a high Reynolds number motion which influences the wave profile evolution at the breakwater, giving a different shape from the classic one obtained with the "porous media" model, which generally fails to reconstruct the turbulence effects inside the permeable layer (Figure 5).

In order to have a preliminary validation, the results obtained through the numerical model was compared with empirical literature formulas and with physical data derived from laboratory tests.

The hydraulic parameters chosen to carry out this validation's procedure were the "run up" and the reflection coefficient "Kr". For the comparison a double approach was implemented.

In the first one the parameters of a linear regression was used. On the Cartesian reference system: points on the graph have the following coordinates:

$$P \equiv \left(X_{fk}; Y_{nk}\right) \tag{3}$$

X_{fk} = k_{-th} parameter calculated by the literature formula;

Y_{nk} = k_{-th} parameter calculated by the numerical simulation;

To evaluate the empirical formulas parameter (X_{fk}), in the equation were used the values of wave's height determined at the toe structure by the method proposed by Goda and Suzuki (method of two probes) [17], that allows to separate the incident wave conditions on the structure from those reflected [18].

In the following tables are showed the values of wave height obtained by the method of two probes at the toe structure for the Bw 1 and Bw 2:

An example of the linear regression lines with the intercept at the origin obtained is shown in the figure 6.

The slope of the straight line "α" was compared with the perfect

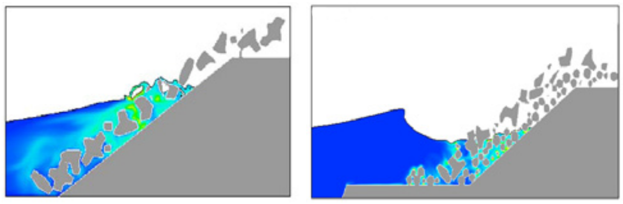

Figure 4a: 2D-Results Turbulent Kinetic Energy (Bw 1 left - Bw 2 right, In Bw 2 greater dissipation of turbulent energy between filter layer and armour layer).

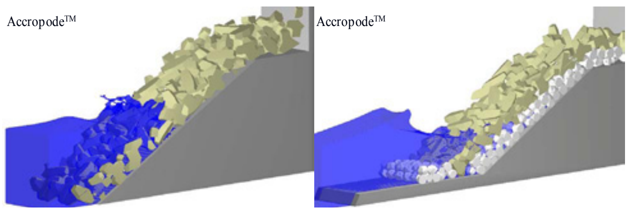

Figure 4b: 3D-Results Free surface evolution (Bw 1 left - Bw 2 right).

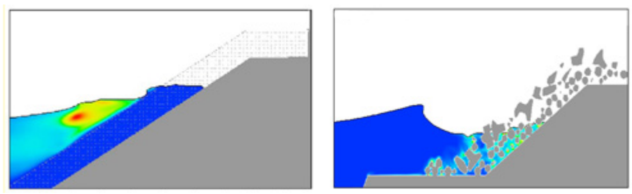

Figure 5: 2D-Comparison between turbulent energy in the "porous media" model, absence of turbulent energy in armour layer (left) and 3D reconstruction of armour layer, where, instead, the turbulent energy is faithfully reproduced the physical reality (right).

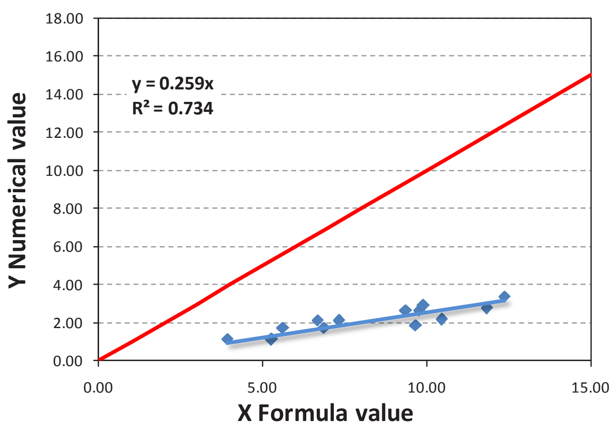

Figure 6: Example of physical - numerical correlation.

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agreement α=1. Therefore, through the difference |1-α| it was possible to quantify the distortion of the numerical model, in reference to the empirical formulas and, consequently, to the physical tests used to construct them; through the R^2, that measures the fitting of the correlation, instead, has checked the reliability of the numerical model in reproducing, systematically and not randomly, the processes of the wave motion's slope on the external face of the breakwater; also in this case the optimal condition is obtained for R^2 =1.

In the second one, the mean error was implemented:

$$\text{Meanerror} = \frac{1}{n}\sum_{k=1}^{n}\frac{X_{fk}}{Y_{nk}} \qquad (4)$$

Where the symbols have the same meaning as given above. This parameter was introduced in order to have an extra measure of goodness of the correlation and then a further check of reliability of the proposed procedure. Once again, the perfect agreement consists of the mean error value of 1.

Run-up Validation

The evaluation of the wave motion's slope along the external face of the breakwater (run-up) has great importance in the design of marine works. This phenomenon heavily influences the choice of design summit share the work, especially in order to limit overtopping events.

To a validation of the proposed methodology, despite the use of simulations with regular wave motion, it was deemed appropriate to make a comparison between the run up values' obtained by some equations in the literature [19] and those obtained by the numerical tests carried out. It is specified that this choice is mainly due to the unavailability of laboratory tests with which to make a comparison, also the formulas of literature, being based on tank tests, they give a first estimate of the adaptation of the proposed model to physical reality .

As will be showed in the following, for the reflection coefficient, such a comparison was made also with the results of empirical evidence collected in explanatory graphs (Figures 10a,b,c,d) by Prof. Zanuttigh (University of Bologna). In the formulas, for empirical values, have been used the geometrical features of the implemented structure and the wave conditions shown in table 1. The numerical values, instead, based on the proposed definitions for the Run up 2%, 10%, medium, significant, were evaluated processing the time series (Figure 7a) obtained by frames of the wave motion's slope (Figure 7b) along the armour layer of the structure.

An example of correlation between equation and numerical run up is shown in figure 8, while the results for two virtual breakwaters was summarized in table 2.

As can be seen from the analysis of the three parameters introduced, the numerical data shows a good array with the formulas of Aces (1975) and Losada & Curto (1981), the correlation is not ideal, however, for Mase (1989) and Hunt (1959). For the latter, in fact, the parameter 1- α is very different from zero %, showing an high distortion.

This fact leads us to think, then, that there is no correlation between the physical modeling, used for the formulation of the equations, and the numerical one.

However, it is easily seen that there is a systematic, not random,

Table 1: Wave characteristics at toe breakwater for two structures.

ID SIMULATION	Bw1		Bw2	
	T (s)	Hi (m)	T (s)	Hi (m)
NS1	4,20	1,246	3,43	0,631
NS2	5,25	1,453	4,28	1,024
NS3	6,30	1,714	5,15	0,749
NS4	4,85	1,935	4,20	1,365
NS5	6,06	2,102	5,25	1,083
NS6	5,42	2,186	6,30	1,288
NS7	6,78	2,744	4,85	1,631
NS8	8,14	2,032	6,00	1,525
NS9	5,69	2,385	7,28	2,403
NS10	7,11	2,717	5,42	2,116
NS11	8,54	2,163	6,78	1,794
NS12	6,42	3,423	8,14	2,824
NS13	8,03	3,128	5,69	1,870
NS14	9,63	2,374	7,11	2,295
NS15			8,54	2,966
NS16			6,42	2,473
NS17			8,03	2,858
NS18			9,63	2,251

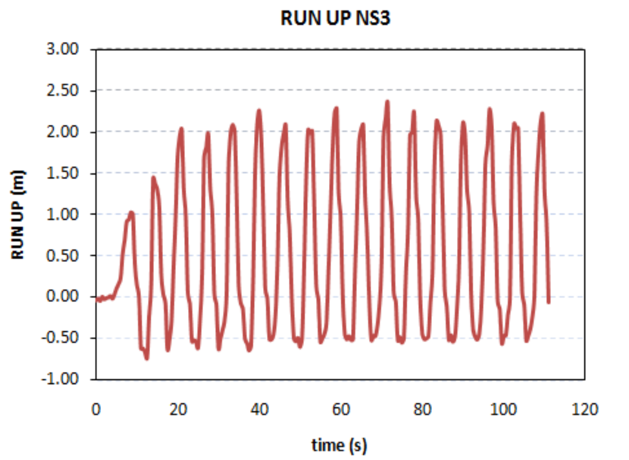

Figure 7a: Run-up time series evolution.

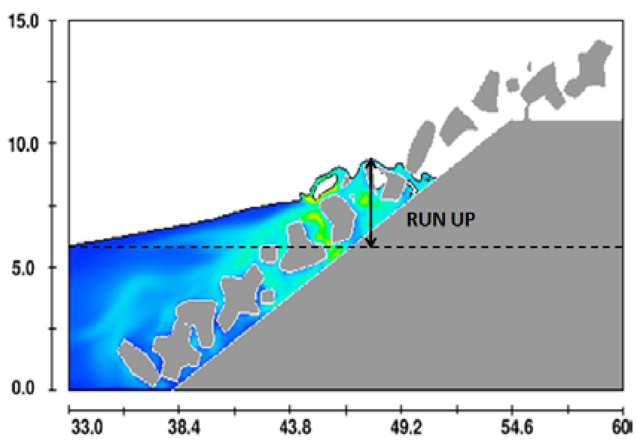

Figure 7b: Example of wave motion's frame.

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differences between the numerical and physical values, confirmed by the R^2, which is always quite high.

The above analysis leads to say that the numerical model implemented correctly interprets the phenomenon studied, even when the parameter α is very far from the unity. In fact, the value of the slope of the linear regression is affected by a distortion due to the virtual structure's characteristics. With regard to these characteristics in fact, it is seen that the Breakwater 1, where there is only the armour layer, while the filter layer and the core are represented as a single solid waterproof, presents a great mean error for all formulas. So, as was expected, the BW2, with reference to the mean error only, more correctly interprets the empirical data, the numerical models implemented for the two structures (BW1 and BW2) prove a similar distortion.

Reflection Validation

The effects due to wave reflection near a maritime structure are very important from engineering standpoint, especially for the consequences which may result in erosion at the toe, in movements of armour blocks, in reduced structure's functionality.

For these reasons, over the years, many studies have been developed with the aim to characterize the phenomenon and the parameters that most affect it [20,21]. These studies led to the formulation of the reflection coefficient defined as the ratio between the reflected and incident wave height.

Based on experimental tests, several equations have been defined, according to the geometrical characteristics of the structure and the waves, to quantify this parameter in order to classify the structure behavior, both if it is waterproof (K_r=1) or porous (K_r<1).

Therefore, in order to analyze the behavior of the procedure, especially on the reproduction of the phenomena of motion that are generated within the armour layer's interstices of a rubble mound, comparisons were made between the values of Kr obtained through the application of some empirical formulas, [19,22-29], and the numerical ones obtained from the processing of simulation results.

The first ones were always determined by the geometrical characteristics of the structure and of the wave motion shown in table 1. The latter, instead, on the basis of the technique of separation of the incident wave from the reflected one proposed by Goda and Suzuki [17], (method of two probes), and from them the reflection coefficient.

An example of correlation between equation and numerical Kr is shown in figure 9, while the results for two virtual breakwaters was summarized in table 3.

Is immediate to observe that the numerical results obtained for the reflection coefficient give rise to correlations slightly different from those obtained for the Run-up, these correlations can still be considered satisfactory for the reasons that we going to illustrate.

As the reflection coefficients obtained through the empirical formulas of Battjes [23] and Gimenez - Curto [24] the parameters (α and mean error) indicate a poor correlation, probably due to the obsolescence of the methods used to derive the equations, the values of α and the mean error obtained for the other authors suggest that the adaptation of the numerical model, compared with the experimental ones used for the formulations of the relationships, is correct. It is also possible to observe how the Bw 2, is closer to physical reality, showing the results statistically more correct, in particular, if one considers the distortion and the average error, it is immediate to observe that the structure 2 best interprets the empirical evidence, this confirms the good ability of the model to reproduce the hydrodynamic phenomena that take place, as well as the energy dissipation due to the filter layer.

For extra confirmation of this view, a further comparison was made of the numerical data with the experimental work proposed by Zanuttigh and Van der Meer (2006) [29] developed to define a new

Table 2: Run up validation.

Author	Formula	Slope α		Distortion |1-α|		R^2		Mean Error	
		Bw 1	Bw 2	Bw 1	Bw 2	Bw 1	Bw 2	Bw 1	Bw 2
Hunt (1959)	$\frac{R}{H_i}=\frac{\tan \hat{a}}{\sqrt{\frac{H_i}{L_0}}}$	0,26	0,30	74,10	69,70	0,73	0,79	3,84	3,18
Aces (1975)	$R=H_i\left(\frac{a\xi}{1+b\xi}\right)$ a = 0,956 b = 0,398	0,69	0,74	31,50	26,50	0,83	.73	1,49	1,27
Losada & Curto (1981)	$\frac{R_u}{H}=A\left[1-\exp(-B\xi)\right]$ A = 1,322 B = 0,966	0,76	0,75	24,30	25,30	0,75	.65	1,34	1,17
Mase (1989)	$\frac{R_{2\%}}{H_0}=1.86\cdot\xi^{0.71}$	0,30	0,30	70,10	70,30	0,56	0,07	3,31	2,62
	$\frac{R_{1/3}}{H_0}=1.38\cdot\xi^{0.70}$	0,28	0,30	71,80	70,00	0,83	0,42	3,58	2,62
	$\frac{R_{1/10}}{H_0}=1.70\cdot\xi^{0.71}$	0,29	0,28	71,40	72,10	0,80	0,04	3,49	2,76
	$\frac{R_{medio}}{H_0}=0.88\,\xi^{0.69}$	0,16	0,14	83,90	86,20	0,79	0,34	7,25	6,77

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Table 3: Kr validation.

AUTHOR	FORMULA	Slope α		Distortion |1-α| (%)		R^2		Mean Error	
		Bw 1	Bw 2	Bw 1	Bw 2	Bw 1	Bw 2	Bw 1	Bw 2
Battjes (1974)	$Kr = 0.1\varepsilon^2$	0,27	0,33	73,20	67,50	0,11	0,42	3,42	2,87
GimenezCurto (1979)	$Kr = \frac{1}{2} - \frac{\exp(-0.125\varepsilon)}{2}$	2,27	1,98	126,50	98,30	0,54	0,68	0,47	0,50
Ahrens Seeling (1981)	$\frac{R_u}{H} = A\left[1 - \exp(-B\xi)\right]$	1,05	0,93	5,20	7,30	0,50	0,76	1,01	1,08
Buerger et al. (1988)	$\frac{R_{2\%}}{H_0} = 1.86 \cdot \xi^{0.71}$	1,33	1,15	32,50	14,50	0,57	0,63	0,79	0,86
Postma (1989)	$Kr = 0{,}125\varepsilon^{0{,}73}$	1,29	1,13	28,80	13,20	0,53	0,70	0,82	0,88
Van Der Meer (1992)	$Kr = 0.07(P^{-0.08} + \varepsilon)$	1,24	1,09	23,70	8,90	0,53	0,70	0,85	0,91
Hughes & Fowler (1995)	$Kr = \frac{1}{1 + 7{,}1\varepsilon^{0{,}8}}$	1,07	1,00	6,50	0,10	0,60	0,72	1,00	0,99
Zanuttigh e Van Der Meer (2006)	$Kr = tgh\left(0{,}12\varepsilon^{0{,}87}\right)$	1,17	1,02	17,00	2,30	0,55	0,67	0,90	0,97

empirical formula, based on a substantial number of tank tests carried out in a scale model or prototype.

In the graphics shown in Figures 10, that represent different synthesis of physical data obtained in the hydrodynamic study of rubble mound's filter behavior made with different geometry and materials, the values of Kr have been reported depending on the number of Irribarren.

The alignment between the numerical and empirical data is optimal in all simulations investigated, in fact the reflection coefficients determined by the development of the virtual model are always understood within the cloud of experimental data.

Especially it can be seen, on average, the reflection coefficients obtained for the Bw 1 (14 simulations) are greater than those obtained for the Bw 2 (18 simulations), of course due to the absence of the filter layer in the first structure.

This result, obtained for the reflection coefficient, together with that obtained for the Run-up, suggests that the described methodology could be used successfully to analyze the phenomena of interaction between a rubble mound and the wave motion.

Ofcourse, as proposed should be considered only as a preliminary basis of a study yet to be explored.

Conclusions

In the present paper the results of a new numerical approach to model the filtration motion inside an emerged breakwater, have been presented.

Generally, from the numerical point of view, the porous media model is used to consider the voids inside the structure, but it is not always appropriate, however, to represent the real phenomena, especially when the layer has a random flow paths.

Instead in this case, the structure was modeled as it happens in the real construction, by overlapping individual 3D elements; the numerical grid has been fitted such to have some computational nodes within the voids so to directly assess the filtration phenomena inside the breakwater.

As shown by the obtained results, the implemented procedure, based on CAD and numerical techniques, in this case computational fluid dynamics software which uses the VOF algorithm (FLOW-3D®), helps to optimally evaluate the hydrodynamic parameters.

Future

Recently, the authors are testing the numerical procedure implemented with random waves, on a virtual Breakwater with armour layer in Accropode™, Core-loc™ and Xbloc®.

Also, with the proposed methodology it could be possible to structure a numerical analysis to evaluate the armour stability [30].

The stability of the armour layer, filter layer and toe protection blocks, until now, has been investigated using laboratory tests in channel or basin. Using well established techniques, it has been possible to analyze the movement of individual elements providing an assessment of the potential damage of the structure [31].

This procedure was made precisely with the intent to fill as much as possible this gap between the numerical model and physical one, and then to build a numerical approach which can be used to unambiguously identify, as in the laboratory tests, which block of the breakwater is under a potential damage action.

With the available technology and the proposed methodology it could be possible to structure a numerical analysis similar to that used in the laboratory test, by evaluating the potential movement of the blocks and therefore the damage. Unfortunately, now, the hypothesis

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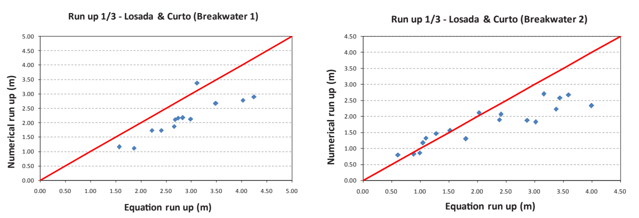

Figure 8: Example of correlation between equation and numerical run up.

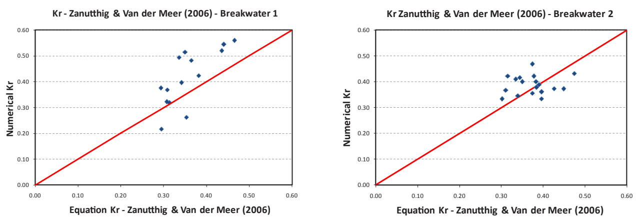

Figure 9: Example of correlation between equation and numerical Kr.

is not feasible because of the computational time that would be very high.

For this reason, and considering not essential in the numerical field to assess the block's path of displacement, we propose a simplified procedure based on the engineering concept of the safety advantage.

Considering the numerical conformation of the breakwater under the wave attack, it was possible to quantify the time evolution of the total hydrodynamic action over a single block (pressure and stress), then the resultant of all forces that can cause instability. Comparing this action with the rock weight it is possible to define the stability of the single element.

Indeed, if this solicitation exceed the one which gives the stability (block's weight), then that element is in a potential damage state as its balance within the breakwater would be guaranteed only by the interlocking forces, which are smaller than its own weight. This makes it possible, therefore, to have not only a check on the block's size but also an identification of the elements that can be subjected to any damage caused by extreme hydrodynamic action.

An example is shown in the figures below where the comparison

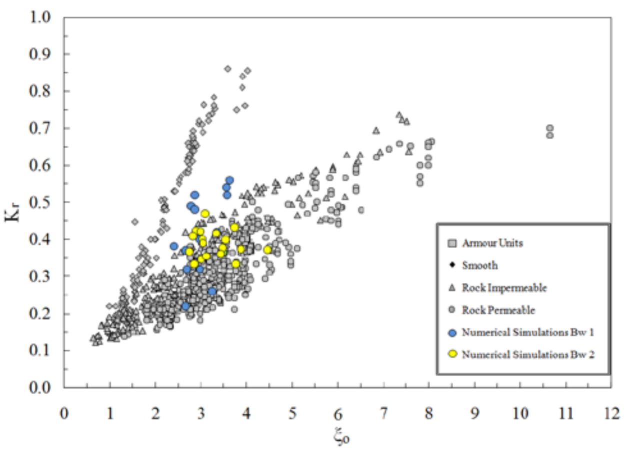

Figure 10a: K_r vs physical data (Zanuttigh and Van der Meer, 2006) for breakwater scheme (Accropode™).

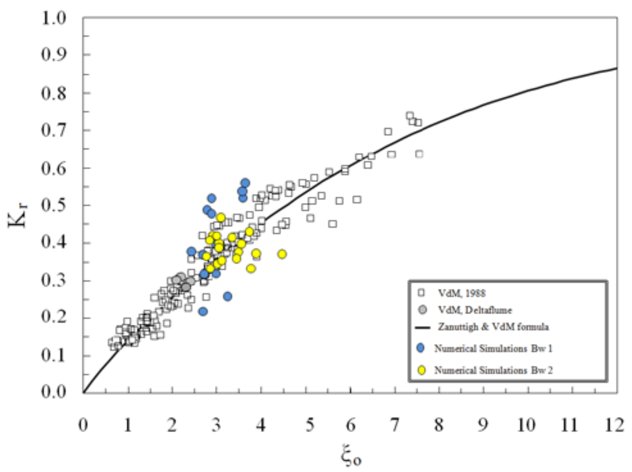

Figure 10c: K_r vs physical data (Zanuttigh and Van der Meer, 2006) for breakwater scheme (Accropode™).

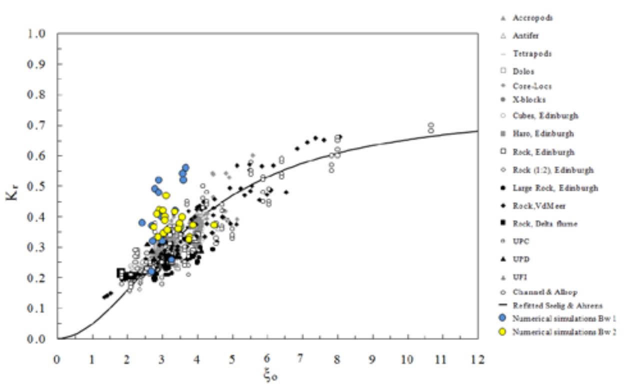

Figure 10b: K_r vs physical data (Zanuttigh and Van der Meer, 2006) for breakwater scheme (Accropode™).

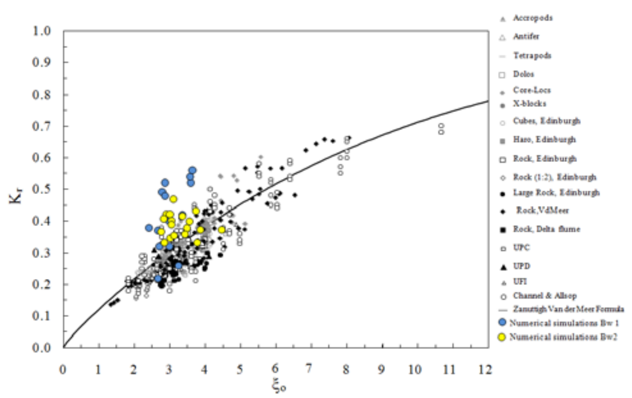

Figure 10d: K_r vs physical data (Zanuttigh and Van der Meer, 2006) for breakwater scheme (Accropode™).

doi:http://dx.doi.org/10.4172/2325-9647.1000101

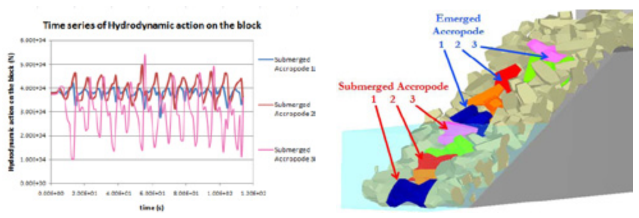

Figure 11: Comparison between the hydrodynamic force and the weight of the armour blocks.

between the hydrodynamic force and the weight of the armour blocks for the elements below the average sea level (Figure 11).

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