# NUMERICAL ANALYSIS OF PERFORMANCE OF WAVEBREAKERS EXPOSED TO REGULAR WAVES IN STATIC AND FLOATING CONFIGURATION

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## ABSTRACT

The study of wavebreakers is an important field of research in maritime and coastal engineering. These devices are widely in use for a number of applications; among the others, they are used for protection of harbors, marina, offshore petroleum platforms or other kinds of marine infrastructure from the action of waves and storms. The big impact of their use on the economy and industrial progress of a country gives these infrastructures a very important role Sadeghi(2008). They are also employed for reduction of coastal erosion, which in recent years has particularly intensified due to anthropogenic activities Van(2011). Also, they may be used as Wave Energy Conversion (WEC) systems, devices that convert the energy of the waves in zero-emission electric energy. In particular, the integration of different types of clean energy devices (for example the WECs with floating wind turbines, platforms and the wavebreakers) is crucial to reduce the total Levelised Cost of Energy (LCoE). The operation principle of a wavebreaker consists in reflection of the incident wave and dissipation of a fraction of the wave energy through the formation of a swirling and dissipative fluid motion. As a result, the wave energy transmitted behind the body, is a small portion of the energy of the incident wave. Here we focus on floating wavebreakers (FB) which represent a subset of the general class of wavebreakers and are used in a number of situations. The key parameter to be quantified in the analysis of wavebreakers is the transmission coefficient, defined as the ration between the height of the wave transmitted behind the obstacle and that of the incident wave.

Macagno(1954) developed a formula to assess the transmission coefficient for a rectangular, fixed and infinitely long wavebreaker with a draft d and subject to the action of regular waves. The use of this formula is restricted to the rectangular box-type wavebreaker, and has intrinsic limitations like the fact that if the draft is equal to the depth of the water column the transmission coefficient is not zero.

In the seminal work of Wiegel(1960) the Author formulated the theory for the study of the wavebreaker performance, quantified through the analysis of the wave transmission past a vertical wave barriers. He compared his analytical solution with experimental data finding a good agreement between theory and experiments. The "Wiegel theory" has been widely adopted for design and innovation in the coastal engineering field. Recently, Bollmann(1996) proposed a modified power transmission theory that takes into account the effect of partial wave reflection and obtained a lower transmission coefficient compared to the Wiegel theory. In addition, these theories do not take into account the influence of the FB oscillation which produces a significant impact on the wave's energy reflection and dissipation.

Starting from the Macagno(1954) formula, Ruol(2013) developed an empirical formulations for the estimation of the transmission coefficient for an inverted Pi-shape and anchored floating wavebreaker subject to the action of irregular waves. In particular they introduced a nondimensional parameter, the ratio between the incident wave period and the FB natural period in order to consider the dynamic behavior of the wavebreaker itself.

In numerical studies, the potential flow theory has been traditionally used, because of its own efficiency and versatility to afford problems of propagation of water waves and interaction with bodies. For example, Zheng(2004) used the potential theory to develop an analytical method to analyze radiation and diffraction of a wave incident over a rectangular FB. Yang(2015) used the potential flow theory in conjunction with experiments to calculate the coefficients of reflection and transmission for a rectangular and a Pi-shape FB.

Recently the numerical solution of the Unsteady Reynolds Averaged Navier Stokes (URANS) equations in conjunction with the Volume Of Fluid (VOF) method is becoming more and more popular for the study of propagation of water waves. This methodology is suited to model the interfacial flow between the two fluids (air and water) and, once used in conjunction with a turbulence model, is able to reproduce the dissipative behavior of the flow after the passage of the wave under the FB.

There are some important numerical experiments that adopt this methodology, to evaluate the impact of the wavebreaker shape on its own performance. Recently, Zhang(2018) used URANS to evaluate the performance of a fixed L type and of a rectangular FB.

In the present paper we study the behavior of two wavebreakers, a rectangular one and a Pi-shape one respectively. The study is carried out numerically, using the URANS methodology discussed above. First we analyze the problem of static wavebreakers and we compare our results with those obtained with the Wiegel(1960) theory and with the modified power transmission theory

of Bollmann(1996). Successively we extend the analysis to the floating configuration, in which the body is free to move along the vertical direction in response to the action of the waves. In the floating configuration the motion of the body is coupled with the fluid dynamics field, through a monolithic explicit solver. We analyze the response of the wavebreakers in terms of reflection and transmission coefficients and also, discuss how the floating configuration behaves compared to the fixed one. In our study we focus on the case of regular wave systems.

Initially, we investigated the generation and propagation of the wave systems and compared numerical results with the available analytical data. We found a good agreement, with error within 5.8 %.

Afterward, we considered the presence of the wavebreaker, fixed in space, and we evaluated the transmission coefficient and compared our numerical results with those obtained with the classical formula of Wiegel and with the modified Wiegel formula. The agreement was in general satisfactory.

We found that the Pi-shape wavebreaker is less reflective and more transmissive and dissipative than the rectangular one, which appears more efficient than the former. In fact, we found that in this situation, wave reflection plays a role much more significant than energy dissipation.

Successively, we performed the analysis of the response of the floating wavebreaker. We recorded the FB heave displacement and we compared our results with those of analytical theory finding a general satisfactory agreement. In particular we found that using the hydrodynamic coefficients obtained by numerical free decay tests allows to obtain accurate evaluation of the heavy motion of the structure when excited by monochromatic waves in a range of frequencies around the resonant one.

We also measured the reflected and transmitted waves and calculated the corresponding coefficients. Additionally, by using the energy balance equation and taking into account the energy absorbed by the body motion, we determined the dissipation coefficient associated to turbulence and wave radiation from the body motion.

Finally we compared our numerical results with those of the Ruol et Al. empirical formulation for the transmission coefficient. We found a good agreement with the Ruol at Al. formula when the wavebreaker is in the resonance region. The disagreement found in off-resonance conditions may be due the fact that the empirical formulation refers to moored systems in irregular sea, conditions substantially different from those herein discussed.

We found that the motion of the FB has a significant effect on transmission, reflection and dissipation. In particular, when the wavebreaker is free to move in the vertical direction, a larger amount of the wave energy is transmitted downstream compared to the static case. We found that for the low frequency waves (higher waves heights) the movement of the body follows the free surface pattern so that the wavebreaker is unable to absorb or reflect a significant amount of wave energy and, also, the dissipation due to turbulence is small. On the other hand, moving towards the resonance region produces a larger amplitude of the body oscillation and shift of phase, resulting in an higher absorption of energy due to the body motion and a greater generation of turbulent structures. Furthermore, we found that the hydrodynamic behaviour of the rectangular and the Pi-shaped wavebreakers is similar. In fact, in this condition, the efficiency of the wavebreaker seems to be strictly related to its own ability to reflect some of the wave energy, rather than to the dissipation of energy due to turbulence and body motion.

A future analysis should focus on the effect of the mooring system on the oscillatory motion of the FB and the presence of irregular wave systems.

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