COMPARISON BETWEEN A PERCHED BEACH AND AN ARTIFICIAL REEF IN TERMS OF WAVE ATTENUATION

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ABSTRACT
In the present work, numerical models of a perched beach (PB) and an artificial reef (AR) are used in order to assess their effectiveness as environment-friendly coastal protection methods. The comparison is based on the results of wave attenuation and velocity field. The methodology is based on large-eddy simulations of the developing two-phase (water/air) flow induced by wave propagation. The results of the free-surface elevation indicate that the PB reduces slightly the wave height, whereas the reef diminishes it almost completely.

INTRODUCTION
Coastal erosion and inundation pose a major threat for coastal regions worldwide. Due to climate variability and extreme meteorological events, these phenomena are expected to intensify and potentially damage sensitive coastal ecosystems. It is urgent to design both effective and sustainable protection measures, resilient to extreme events. The sustainable development of coastal areas includes the use of environmental-friendly and low-cost protection solutions, like the concept of a perched beach (PB). Nature-based solutions (NBS) have also gained significant attention recently. NBS are effective and low-cost coastal protection methods inspired by nature, e.g., an artificial reef (AR).
A PB includes a nourished area consisting of well-sorted sand and a submerged sill. The role of the nourished area is to form a wider beach profile, and the role of the submerged sill is to reduce the required volume of the nourishment material, to stabilize the nourished bed profile, and ultimately prolong the lifespan of the PB (Moreno et al., 2018). On the other hand, ARs are submerged structures placed on the seabed to mimic functions of natural reefs. Their presence repairs and improves the coastal habitat while increasing the fishery production, which is achieved by modifying the local hydrodynamic conditions (Zhang et al., 2021). Moreover, it is proposed that apart from environmental enhancement they can also offer wave protection functioning as submerged bars (Srisuwan and Rattanamanee, 2015). In the present study, a numerical analysis is performed using an in-house Large Eddy Simulation (LES) hydrodynamic model, to examine and compare the effect of these methods on wave attenuation and induced velocity field.

METHODOLOGY
The governing equations of the fluid motion are the continuity equation and the Navier-Stokes equations modified to model flow in porous media. The porous medium approach is used to model the flow inside the porous medium in the case of the AR. To this purpose, an equivalent porosity, n_{eq}, is utilized which depends on the volume ratio (the ratio of the actual volume of the reef to the facility volume). The boundary conditions on the seabed, as well as the PB and the AR are imposed using the Immersed Boundary method (Dimas and Chalmoukis, 2020) where a Cartesian grid is used, and it is not necessary for boundaries to coincide with grid lines. The location of the water-air interface is tracked using the level-set method that introduces a scalar variable φ, which is the perpendicular signed distance from the location of the interface. The free-surface evolution is computed by an advection equation. A two-stage time scheme is followed for the temporal discretization of the Navier-Stokes equations. First, an intermediate velocity field is computed utilizing a 2nd order Adams-Bashforth scheme, and the final velocity field is computed in the second stage. The solution is based on the dynamic pressure correction, which is obtained by solving a Poisson equation, so that the continuity equation is satisfied at the end of the numerical time-step. Finally, 2nd order central finite differences are used for the spatial discretization, on a staggered Cartesian grid. Detailed information regarding the used in-house hydrodynamic model and its validation are provided in Chalmoukis et al., (2023).

NUMERICAL SETUP
A sketch of the computational domain with the AR is presented in Figure 1; no PB figure is presented due to space limitations. The region downstream from the wavemaker has constant water depth for two wavelengths, to allow waves to fully develop before reaching the beach. The beach slope is 1/15. The AR comprises two rows of cubic units with frame structure (Wang et al., 2022) with a principal dimension of 1.5 m and a volume ratio of 0.35 (n_{eq} = 0.65). Concerning the PB geometry, a sill of 3 m width and 0.5 m height was placed also at a water depth of d_s = 3 m to bound the sediment in the nourished bed. For the simulations, lengths are non-dimensionalized using the water depth, d_s at the toe of the PB sill and the AR, and velocities with $(gd_s)^{1/2}$.
To simulate wave propagation, incident second-order regular waves of specific height and period are generated by a numerical piston-type wavemaker at the left boundary of the computational domain. In terms of the flow model, a zero Neumann boundary condition for pressure is imposed on the bottom and on both streamwise boundaries of the computational domain, and a Dirichlet-type condition is implemented at the top computational boundary. Accordingly, the velocity boundary conditions are zero Neumann on the bottom and right boundaries. At the wave generation boundary, a Dirichlet-type condition is implemented for the streamwise velocity to be consistent with the harmonic wave generation.
A uniform spatial discretization is used in the horizontal directions, whereas a non-uniform resolution is applied in

the vertical direction; finer at the water and coarser at the air. The numerical time-step is selected so both the convective (CFL) and diffusive (VSL) conditions are satisfied.

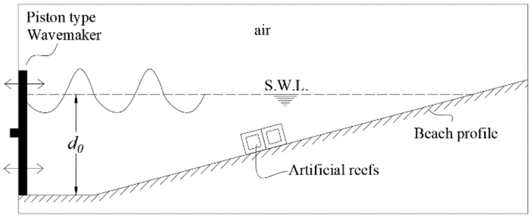

Figure 1 - Sketch of the configuration of the computational domain with an AR.

RESULTS

The objective of the present work is to examine the effect of the two coastal protection methods on wave attenuation. The height of the incident wave is H = 1.3 m, and its period is T = 4.1 s. The phase-averaged envelope of the free-surface elevation is presented in Figure 2 for all studied cases. In NP_1.3, the wave propagation over the unprotected beach is shown. The PB seems to affect the wave but not so significantly as the reef. The reef reflects a lot of the wave energy and imposes the wave breaking more offshore, possibly due to its height.

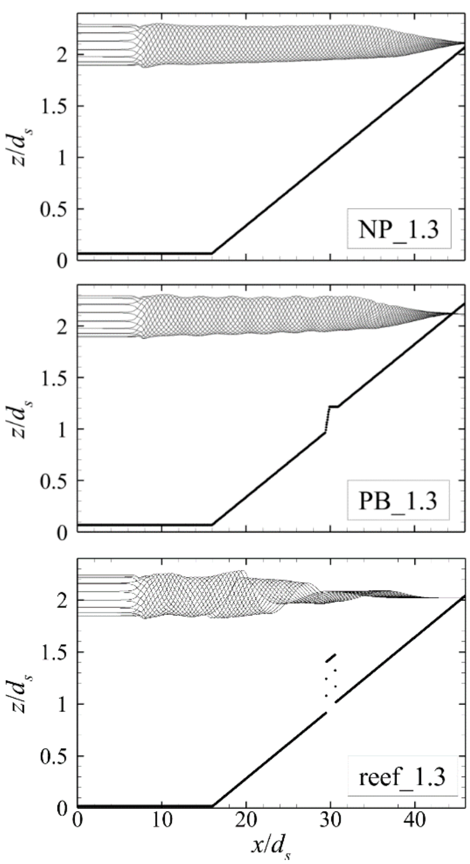

Figure 2 - Phase-averaged envelope of the free-surface elevation over beach: (a) unprotected, (b) with a PB, and (c) with an AR.

The surrounding flow field is strongly affected by the AR presence (Figure 3). Seawards, an upwelling area is formed, which functions in favor of the vertical water circulation, the improvement of the water quality and the enhancement of biodiversity. Shorewards, a milder hydrodynamic flow field is formed, known as the wake region, which is a flow recirculation area characterized by a complex field of eddies. The wake region provides habitat and shelter, which makes it an ideal location for the safe reproduction of sea organisms (Zhang et al., 2021).

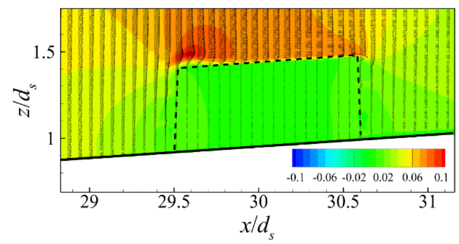

Figure 3 - Instantaneous streamwise velocity contours and velocity magnitude (arrows) in the vicinity of the AR.

CONCLUSIONS

An in-house numerical model was applied to study the effect of two environmental-friendly protection methods on wave attenuation. The flow field has been resolved by means of LES, and the porous medium approach was utilized to model the presence of the AR in the specific case. According to the results, the AR causes stronger wave attenuation in comparison to the PB.

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REFERENCES

Chalmoukis, Leftheriotis, Dimas (2023): Large-eddy simulation of wave attenuation and breaking on a beach with coastal vegetation modelled as porous medium, J Mar. Sci. Eng., MDPI, vol. 11, 519.

Dimas, Chalmoukis (2020): An adaptation of the immersed boundary method for turbulent flows over three-dimensional coastal/fluvial beds, Appl. Math. Model., ELSEVIER, vol. 88, pp. 905-915.

Moreno, Negro, Garrote, Muñoz-Pérez, López, Esteban (2018): An engineering method for the preliminary functional design of perched beaches. Theoretical approach, J of Coast. Res., Sp. Is. 85, 1-5.

Srisuwan, Rattanamanee (2015): Modeling of Seadome as artificial reefs for coastal wave attenuation, Ocean Eng., ELSEVIER, vol. 103, pp. 198-210.

Wang, Nie, Zhang, Zhu, Xie, Liang, Jiang (2022): Numerical simulation study on the influence of artificial reefs on the instantaneous collision with seabed based on the explicit finite element method, Ocean Eng., ELSEVIER, vol. 261, 112169.

Zhang, Zhu, Liang, Sun, Nie, Wang, Xie, Jiang (2021): Numerical Study of Efficiency Indices to Evaluate the Effect of Layout Mode of Artificial Reef Unit on Flow Field, J Mar. Sci. Eng., MDPI, vol. 10, 1827.