

EFFECT OF TANDEM BREAKWATER ON PRESSURE REDUCTION ON VERTICAL SEAWALL

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INTRODUCTION

There is an urgent need to develop methodologies to upgrade and retrofit existing coastal structures to retain their functionality in the scenario of changing climate. It is noticed that higher wave loads cause structural damage and increase wave overtopping rates, resulting in coastal flooding and inundation. Hard structures like seawalls can be reinforced by constructing a submerged breakwater in tandem with the seawall to adapt to the increased wave action due to climate change. Wave height attenuation, overtopping volume, and wave pressure or forces on structures are the important design parameters to be considered for the design of upgradation methods for coastal structures to withstand future climatic events. There are few works available in the literature focused on this direction. Some of the prominent works are brought out here. Dong et al. (2020) studied the performance of sea walls with four coastal retrofit structures like recurve walls, reef breakwater, diffraction pillars, and vegetation by conducting physical modeling experiments in the laboratory. In this study, the authors evaluated the performance of the retrofits by measuring overtopping volume and it is found that recurve wall is effective in mitigating overtopping volume. Srineash et al., (2020) investigated numerically the influence of a tandem reef breakwater on pressure reduction on a vertical sea wall. Anand et al., (2010) investigated the variations of dynamic pressure on the surface of curved seawall models placed over a bed slope of 1 in 30. Reddy and Neelamani (2005) studied experimentally the effect of low crested rubble mound breakwater in reducing wave forces on vertical seawall. Sasikumar et al., (2018) examined numerically the effect of submerged breakwater placed on seaward of the existing breakwater. In their work, the numerical analysis had carried out in REEF3D to find the optimum dimensions of rubble mound submerged breakwater based on the transmission coefficients measured and the also authors discussed the effect of relative submergence and relative width on transmission coefficients. In the present study, we focus on pressure reduction on seawall due to the presence of a submerged breakwater in tandem with the seawall. Numerical simulations were carried out using a CFD-based numerical tool REEF3D to understand the effect of a submerged breakwater on wave pressure reduction on the seawall. The work also includes a validation study where the numerical results based on the present work are compared with the experimental studies from the literature.

METHODOLOGY

In the present study, a CFD-based open-source numerical tool, REEF3D that solves the RANS equations along with the continuity equation is used to carry out the simulations involving the wave-structure interaction process. This numerical study is focused to

understand the pressure acting on the seawall for different conditions. This analysis of the hydrodynamic pressure exerted on the seawall is examined for different crest widths of breakwater placed in tandem with the seawall. Mesh convergence study and time step convergence study were conducted to fix the cell size and CFL criteria respectively. One mesh cell size is taken as the width of the numerical wave tank. Linear waves of intermediate type were generated by using the Dirichlet wave generation method. A 5th-order WENO scheme is employed to discretize the convection term of the RANS equations. 3rd order Runge-Kutta method is used for time discretization. The free surface was captured by the level set method.

VALIDATION

A 2D numerical wave tank of length 4.352m and 0.9m in height is generated in REEF3D. A water depth of 0.266m is used for the mesh refinement study. A linear wave of intermediate type of height $H = 0.1$ m and period $T=1.3s$ are generated using all the four mesh sizes ($\Delta x = 0.025, 0.01, 0.005$ m, and 0.0025 m), and the wave elevations recorded at a distance of 2.643 m. A mesh size of 0.01m is fixed considering both computational time and convergence of results. As the solution with CFL numbers 0.5 to 0.1 is seen to be almost constant and close to the theoretically expected value, in the present study a CFL of 0.1 is considered for better stability of the solution (Kamath 2012). The Validation of the numerical model was performed by comparing the wave elevation with measured wave elevations published by Didier et al., (2014) at a distance of 2.643 m from the wave generator and for a water depth $d=0.266$ m as shown in figure 1. Although numerical results overestimated the crest elevation in comparison to measured values, a considerable agreement is perceived between the experimental and numerical results. Figure 2 presents the numerical and experimental pressure time series at pressure probe P1. The complexity of wave interaction with the vertical wall was well captured by the numerical tool as there is good agreement between numerical and experimental data. From Figure 2 the maximum variation between the experiments and numerical simulations is noticed to correspond to maximum pressure observation. These discrepancies might be due to insufficient sampling frequency and other uncertainties associated with the measurements.

RESULTS AND DISCUSSIONS

A submerged breakwater with bottom width twice the crest width is placed in tandem with the seawall at a distance of $L_p=0.3L$ (L =Wavelength) from the starting of the slope (Reddy and Neelamani 2005) as shown in figure 3. Numerical Simulations were carried out for the submergence depth $d'=0.6H$ (H =incident wave height), for a relative water depth (d/L) = 0.11, and for different

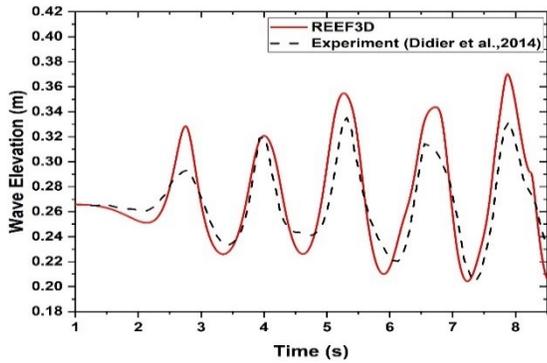


Figure 1 - Comparison of numerical Wave elevation with Experimental free surface at WG1

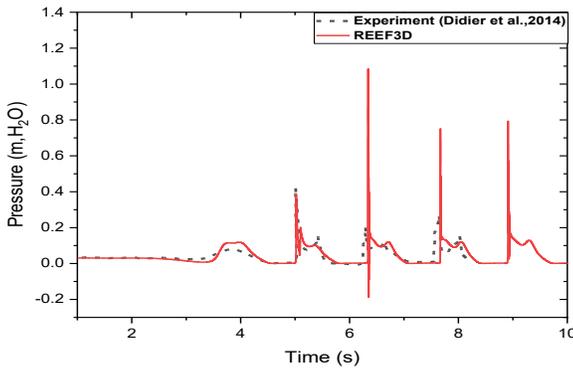


Figure 2 - Comparison of numerical Wave induced pressure with Experimental measurements at P1

crest widths of submerged breakwater vary from 0.1L to 0.4L. The simulations in the present study were carried out for a constant wave steepness of $H/L=0.0532$. The pressure records corresponding to different locations on the seawall were examined during the study. The location of the pressure probes was considered based on the experimental work of Didier et al., (2014). The pressure records were extracted from location P1, located 0.055m above the toe of the seawall. The remaining pressure probe locations were separated by an equidistance of 0.055m such that pressure sensor P6 at 0.511m above the toe of the seawall. This is also portrayed in figure 4. Regular waves of height 0.1m and period 1.3s were generated during the numerical study to find the wave-induced pressure acting on the seawall. The effect of the submerged breakwater on pressure reduction on the seawall was studied for four different crest widths $b= 0.1L, 0.2L, 0.3L,$ and $0.4L$. In Figure 6, these pressures are shown at different locations (P1, P2, and P3) in terms of non-dimensional pressure versus time (t/T). On examining the pressure time series portrayed in Figure 6, it can be noticed that P1 which is below the still water level, experiences the maximum dynamic pressure compared to the pressure probe above the water level. Further, during the numerical study, it was also observed that for certain conditions there was the absence of a trough in the pressure time series. This is due to the fact that the location of the pressure probe is above the still water level and this is subjected to only the crest of the wave. This is called as “intermittence effect” (Isaacson and Subbiah 1991;

Mallayachari and Sundar 1995; Anand et al., 2010). When a submerged breakwater of width 0.4L is placed in tandem with the seawall, the dynamic pressure is noticed to reduce by 6 times and the peak pressures at P1 and P2 were observed to be reduced drastically for all crest widths. However, the same was not observed at P3 for crest width corresponding to 0.1L. On interpreting Figure 6(c), it is witnessed that the magnitude of wave pressure at P3 is higher for the case involving submerged breakwater of crest width 0.1L in comparison with the other cases. Further, it is also insightful to notice that the pressure observed at P3 is higher in comparison with the case where no submerged breakwater was placed in tandem with the seawall. This is considered to be an important observation that portrays that placing a tandem structure may not always result in pressure reduction in the leeside protected structure. This might be due to shoaling over the reef, standing wave formation near the seawall and other complex hydrodynamic processes during the wave structure interaction and this needs further investigation. Figure 5 portrays the velocity contours of wave propagation over submerged breakwater. From the Figure 5, it is observed that the magnitude of horizontal velocity is higher than wave celerity. This could result in wave breaking in the vicinity of the submerged breakwater as perceived from Figure 5. It is to be noted that the present observation pertains to a pool length of 0.3L, which leads to an increase in water level in the vicinity of the seawall as depicted in Figure 5. This could be a reason for the increase in hydrodynamic pressure at P3; although submerged breakwater is placed in tandem with the seawall. Hence, this necessitates an extensive investigation focused to understand the hydrodynamics associated with the tandem submerged structures especially the effect of the submergence depth and the influence of pool lengths. This would help us to design the tandem submerged structures that are economically viable and functional to withstand the increased wave loads due to climate change impacts.

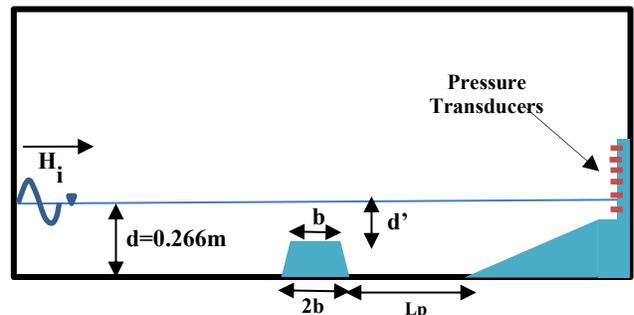


Figure 3 - Numerical Wave tank with seawall and submerged breakwater

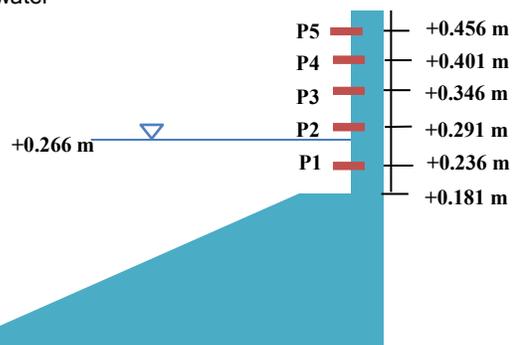


Figure 4 - Location of Pressure Probes

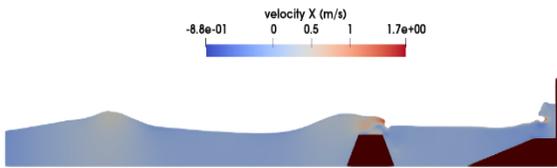


Figure 5 - Wave transmission over submerged breakwater of crest width 0.1L in REEF3D at $t/T=3.23$

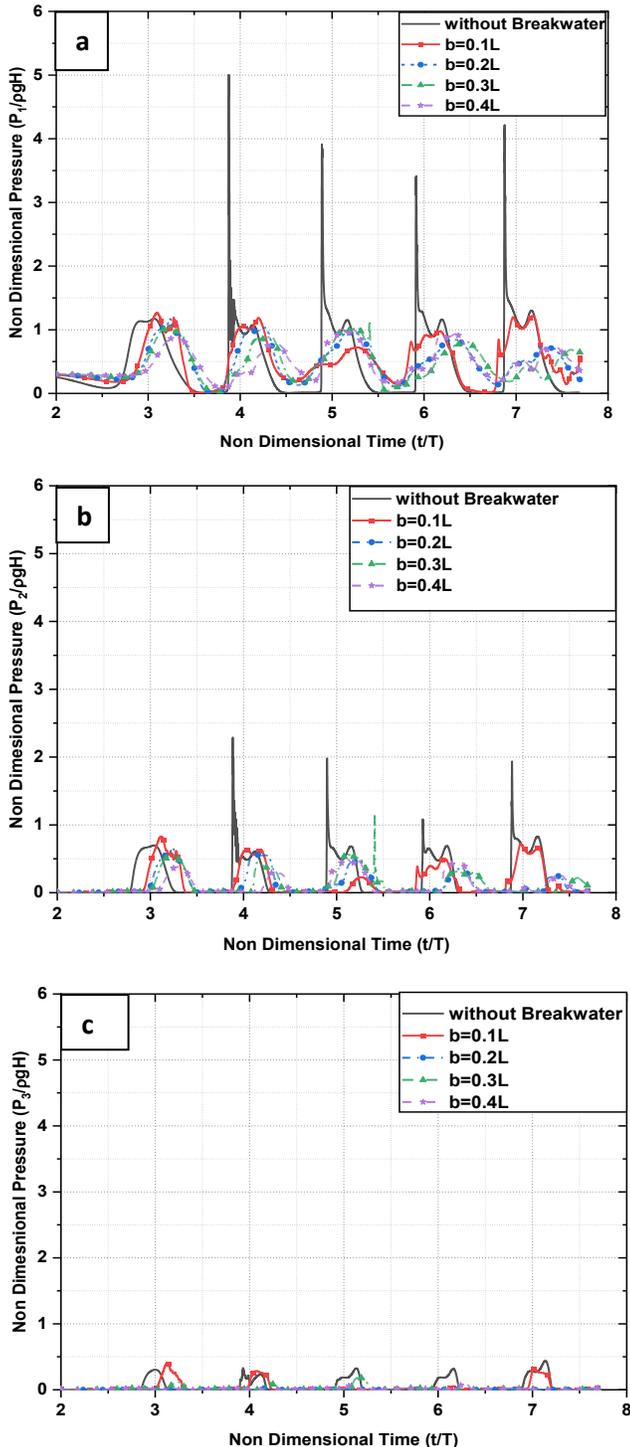


Figure 6 - Comparison of wave pressure on seawall with and without breakwater (a) at P1, (b) at P2 and (c) at P3

Overall the wave pressure at P1 on the seawall was reduced by 74.61%, 76.51%, and 77% for crest widths 0.1L, 0.2L, and 0.3L respectively. Around 80% reduction in maximum wave pressure on the seawall is observed for the submerged breakwater of crest width 0.4L. The measurements from the other pressure transducers P4, P5, and P6 show that there is a significant reduction in pressure acting on seawall due to the inclusion of submerged breakwater as the waves can't reach the probe locations completely and in turn, a low magnitude of pressure was observed. From the results, it is observed that maximum pressure reduction is observed for breakwater with crest width $b=0.4L$. The increase in crest width causes an increase in the reduction of pressure acting on the seawall. Further increase in crest width may result in negligible pressure reduction and may be uneconomical. In the future, one can study the maximum crest width of the tandem breakwater to attain of the maximum pressure reduction with minimum cost of construction. The present work has focused on pressure reduction due to submerged breakwaters under the action of regular waves. Based on the observation from the present work, it is noticed that a lot of research is still required to better understand the wave structure interaction of tandem effects of submerged breakwaters. In particular, it is essential to understand the effect of crest width and the resulting hydrodynamic pressure reduction on the leeside structures and the related overtopping rates.

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