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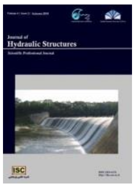

Modeling of Vertical Breakwater Wall under Bilateral Seawater Load

Masoud Abdolmaleki[1]
Hamdireza Kamalan[2]

Abstract

Floating breakwaters are widely used, recently. On this basis, numerous researches have been done on their bracing types and hydrodynamics recent times. In this study, stresses caused by induced waves have been numerically modeled. For this purpose, samples of floating breakwaters have been simulated in ANSYS software. First, AQWA tool in ANSYS finite element software has been utilized. Afterward, forces caused by the waves have been calculated utilizing this module of the software. Then, the results have been entered into the MECHANICAL module to enable fulfilling stress analysis. Next, concluding results of modeling have been verified through comparison with laboratory measurements. Finally, the stresses in the breakwater body have been estimated. The results show that induced waves with a period similar to the natural period of the structure causes the maximum stress. Besides, each period of waves causes different heights. The highest wave within a specific period causes the utmost stress.

Keywords: Numerical modeling, Seismic analysis, Breakwater wall, Bilateral interaction, Finite element method.

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1. Introduction

Beach is a dynamic and natural environment where water and land intersect each other. Nowadays, more than half of the world's population lives in the beaches. Also, many others accommodate beaches temporarily to visit, entertain, trade, providing services... About 20% of the citizens in Iran live in coastal provinces where around 3000 Km of coastline have [1]. Therefore, different activities in the coastline will impose environmental, social, and economical impacts, so there is a vital need for its statistics, information, and tools to enhance understanding and knowledge on existing phenomena and any changes taking place [2].

Erosion and undesirable deformation are the hazards that always threaten various industrial facilities, transportation, coastal tourism, natural habitats, and coastal roads. In these areas, the land has a unique economic value so that land development and also preventing marine

[1] Department of Civil Engineering, Roudehen Branch, Islamic Azad University, Roudehen, Iran
[2] Department of Civil Engineering, Pardis Branch, Islamic Azad University, Pardis, Iran. **(Corresponding author)**

transgression are extremely costly. Therefore, coastal management against erosion and undesirable deformations are vital [3].

Flexible structures are categorized among the most used and cheap shore protection structures. Also, their materials are mostly available. On the other hand, due to using natural materials, they are more adaptable to the environment and they are very common [4].

Coastal breakwaters are commonly used to protect shores against wave impact and erosion. Flexible quay wall is a newly introduced type of structure in which their components are two to ten times lighter than the traditional one, so they are much cheaper to be constructed and easier to be implemented. In addition, their maintenance costs are quiet less. As a result, flexible quay wall usually are defined as more economical option rather than traditional types of breakwaters [5].

Since constriction of breakwaters requires special infrastructure and its own construction procedure, usual seismic risk for common structures can to be applied for breakwaters. Therefore, design methods f these structures have been provided in special codes of practice. Defining the relationship between breakwater walls and earthquake has been the goal of several researches [6]. Some of these studies are summarized as follows.

Motta [7] has studied the theory of Columbus active earth-pressure for distance surcharge. Then, a closed form solution for estimating the activity coefficient, which determines the effect of soil weight and distance surcharge, has been calculated. Exploiting this solution allows economical design due to exact evaluation of the earth pressure based on the actual - site conditions. Fang et al [8] have investigated the variation of horizontal earth pressure behind a bulkhead through finite element method. Two different movements (i) rotation about a certain point beneath the bulkhead, and (ii) rotation about a certain point above the bulkhead have been considered. Numerical results and observed data have had a good correlation. The generation of earth pressure is influenced by the mode of bulkhead movement. Also, Coulomb's solution can provide exact figures for the intensity and distribution of active earth pressure in bulkheads under translational movement. Caltabiano et al. [9] have calculated the soil pressure on bulkhead in seismic conditions using pseudo-static analysis. They have developed a solution to improve Mononobe–Okabe method. This new solution considers the effects of the presence of the bulkhead as well.

Chen and Hung [10] used finite difference method to estimate the earthquake-induced hydrodynamic pressures of seawater and the pore water in seabed sediment on bulkheads. The dynamic response of a breakwater induced by constant ground acceleration has been studied. Then, the dynamic characteristics of the water–embankment–sediment have been are investigated thorough introducing four different earthquake-records. This study proves that seismic forces and hydrodynamics should be considered in breakwater designing in the seismic zones.

The Overseas Coastal Area Development Institute of Japan [11] briefly describes the forces entering the breakwater walls. Green et al. [12] used the Mononobe-Okabe (M-O) method to determine the lateral force of a wall.

Ryul et al. [13] have proved that the magnitude of effective forces on breakwater wall during the earthquake and the phase relationship among their components (inertia force of the wall, lateral earth force, and water force) should be appropriately determined during designing of breakwater walls. On these bases, a model has been developed to assess the magnitude and the phase variation of the dynamic thrust on the rear of the quay wall. This model estimates the dynamic thrust through utilizing the force components calculated from existing equations.

Wharf breakwater located in Kushiro port during earthquake in 1993 in Japan was damaged incredibly. This wall was located in a high potential of liquefaction area. The breakwater wall was a simulated using numerical method. Results demonstrate good correlations between estimation and observed data during earthquake for horizontal and vertical deformations of top of the wall. The obtained results from different numerical simulations and measurements indicate that liquefaction has a destructive effect on breakwater behavior during earthquake [14].

Yong et al [15] have run a series of centrifuge model tests to investigate the seismic response of a caisson-type quay wall system, and the liquefaction and deformation characteristics of the saturated non-cohesion embankment. These models have been developed through nonlinear solid-fluid-phase finite element program. Results show that the dynamic properties and permeability of embankment material have extremely important role in stating seismic performance of a breakwater wall system. Dewoolkar et al. [16] have investigated the static and seismic behavior of a breakwater wall with a liquidated backfill during earthquake. A series of centrifugal tests has been performed and the acceleration has been measured statically on the wall and the embankment.

Recently, genetic programming (GP) models have been developed to evaluate the stability of breakwater walls with more correct estimations [18].

Shape of the breakwater has an important role. Newly, studies are conducted to investigate the optimal shape and layout of quay walls. A new configuration of floating breakwater containing rigid cylinders and flexible mesh cage has been introduced to reduce long and high wave. The introduced breakwater has had an improved performance than the traditional ones which equipped with double pontoons and the box floating bulkhead. The reason that wave transmission is dramatically decreased by the mesh cage with the walls [17]. Also, a stepped-slope floating breakwater has been developed as an efficient anti-reflection quay wall and wave attenuator [19]. Besides, the performance of floating breakwater in four forms of pontoon, catamaran, curved pontoon and curved catamaran has been investigated [20].

This study aims to analyze behavior of vertical breakwater under high altitude waves to investigate important parameters for designing breakwater walls. Breakwaters have been considered in two versions (i) with crown, and (2) without crown to investigate on the effects of geometry against high altitude waves.

2.Experimental Procedure

ANSYS version 18.2 has been used in this study to simulate vertical breakwater wall with crown under lateral seawater load and seismic load. Navier-Stokes, conservation of mass, and conservation of energy are the three fundamental equations in ANSYS. This software needs the physical figure of the object which is defined through a number of rectangular cubic cells.

The first step in this study has been to define the problem conditions such as shape of the breakwater, surrounding area, and induced forces. Next, simulation has been performed. As a boundary condition, hydrostatic force of seawater is applied to the breakwater wall. Then, earthquake created waves which has a different force on the breakwater wall. The difference between maximum horizontal pressure caused by wave and seawater hydrostatic pressure defines the net value of pressure introduced to the vertical breakwater. In this way, wave pressure distribution profile is easily drawn.

This method can be a suitable approach to calculate wave pressure profiles with precise accuracy at the elevation of the structure. Initial design of the structure can be done based on this approach, which would be much easier and cheaper than laboratory modeling. After that, the structural stability of the vertical breakwater has been analyzed. Safety factor against slippage and overturning have been estimated by applying some needed calculation on the software output forces.

It is notable that this research discusses geometrical modeling of vertical breakwater wall under lateral seawater and seismic load. On this basis, two scenarios of Caisson breakwaters (with and without crown) have been simulated and analyzed. Both scenarios have been analyzed under three different wave height modes.

Figure 1 demonstrates the geometry and dimensions of the vertical breakwater structure and its rock mass bed in scenario 1. It is notable that this geometry is based on Tsujio et al [21] study, because there would be a need for verification with the observed data.

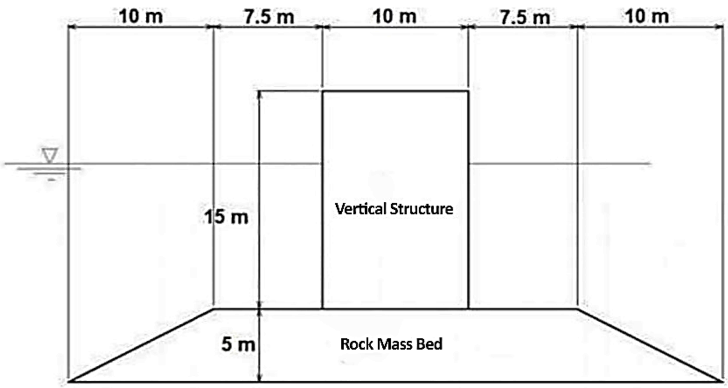

Figure 1.Geometry of Vertical Breakwater Structures with Rock Mass bed

It is noteworthy that the case with the crown structure (scenario 2) is similar to figure 1 but a rectangular structure with length of 5m and height of 4m is added on top of the vertical structure, which is shown in Figure 2. In this figure, the overall geometry of the investigated network is also presented along with the breakwater positioning in the model.

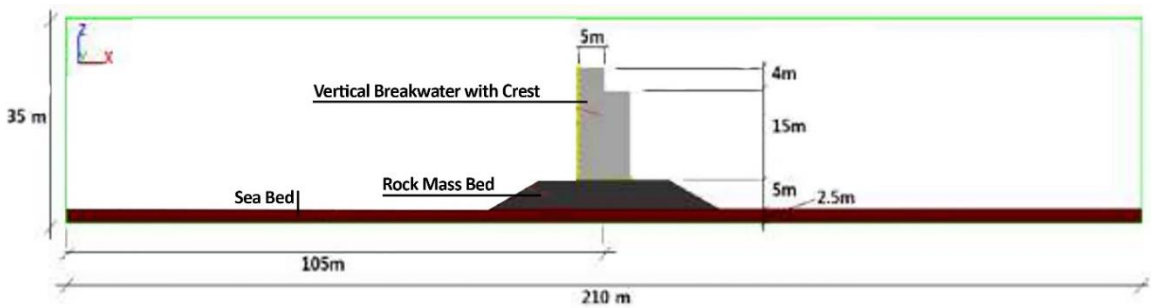

Figure 2. Model domain and geometry of the breakwater with crown

In this study, water has been used as the single fluid. Also, RNG and Darcy porous medium model have been applied to analyze turbulence and rock bed, respectively. The vertical breakwater wall has been considered as a rigid structure. Besides, its density has been expected to be 2000 kg/m3, which is suitable for concrete Caisson breakwaters. This figure is used to calculate the stability analysis calculations. In addition, friction coefficient between the vertical concrete structure and the rock mass bed has been considered between 0.5 and 0.6 in different studies, while it has been assumed as 0.5 in this study.

Boundary conditions of the scenarios can be defined as follows:

- wall boundary condition for the two sides of this model,

- symmetry boundary condition for the end of the model,
- pressure boundary condition with zero flow for the vertical direction at the top and bottom, and
- wave generator for the horizontal direction of the canal entrance.

In this research, a solitary wave model has been applied to simulate the tsunami wave. A solitary wave defines as a non-oscillating nonlinear wave, which has a crest but no trough. On the other words, this kind of wave is completely above the seawater free level.
Similar to all other nonlinear waves, in ANSYS, it is assumed that the solitary wave is in a tank with flat bottom and enters the computational domain at the mesh border. The depth of water in the tank is represented by a constant "d". The height of the wave, "H", is measured vertically from the seawater level to the crest. There may be a flow, so its velocity component is displayed with "U". Figure 3 illustrates the solitary wave definition in the software.

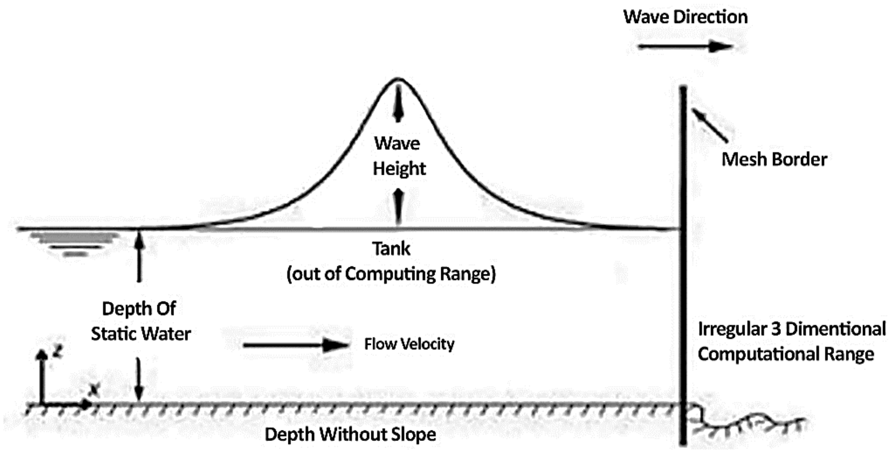

Figure 3. Definition of single wave specifications in ANSYS

FlUID220 and SHELL281 elements have been used for the analyses. First, shell element is pre-stressed through nonlinear static analysis applying large deformation. Besides, the seismic amplitude is 0.2 by 0.2 by 0.2 cubic meters and a prototype dimensioned reinforced concrete with thickness of 0.1m is assumed to be located at x=0.2m. Also, the dimensions of the breakwater are 0.1 by 0.2 by 0.2 cubic meters. In addition, the boundary conditions of the breakwater are Ux=-1, Uy=0 and Uz=0. Moreover, at page x=0, the boundary condition Ux=0 and Uz=0 is applied at surface defined as x=0, similarly, the boundary conditions Uy=0 and Uz=0 at y=0 surface.

3. Results

As it has been mentioned, two scenarios of vertical breakwater have been analyzed with crown of 2 and 7m impacted by solitary wave each in three modes of input wave height 5d up to 15 m. Since, the horizontal pressure caused by the wave is incredibly important parameter, it should be analyzed carefully.
Pressure and elevation of the pressure gauges in meters have been indicated on horizontal and vertical axis, respectively. It should be noted that the vertical breakwater bottom level is 7.5 meters and it has risen up to a level of 26.5 meters. This indicates that the total height of vertical

breakwater with its own crown is 24 meters. Also, the height of the completed breakwater is 22.5 m in scenarios without crown.
Figure 4 illustrates the modeling of the breakwater wall in ANSYS. As this figure shows at a glance, water sounds both sides of the breakwater wall at deferent elevations. Besides, figure 5 shows the breakwater wall networking. Since ANSYS is numerical analysis software, there is a need for dividing all geometry to small meshes, those shape are square.

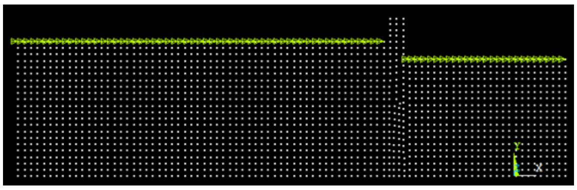

Figure 4. Modeling breakwater wall in ANSYS

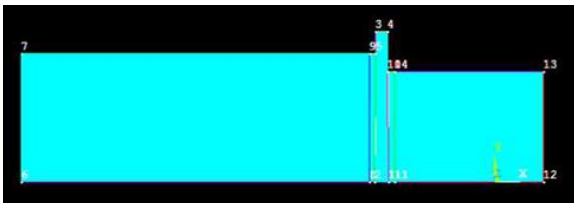

Figure 5. Interaction of fluid forces imposed to the breakwater

Given that there is a force to the breakwater wall due to induced wave and water pressure, the fluid around the wall must also be considered. On the other words, interaction between wave and the structure should be considered in the numerical analyses. The compressive force applied to the breakwater along with its direction has been shown in figure 6. Figure 7 demonstrates displacement and deformation of breakwater wall under waster and seismic loads.

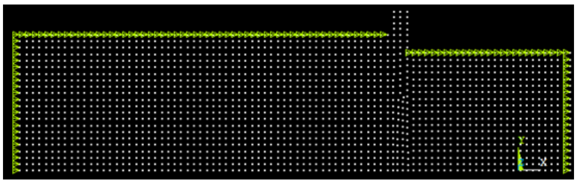

Figure 6. Compressive force applied to the breakwater

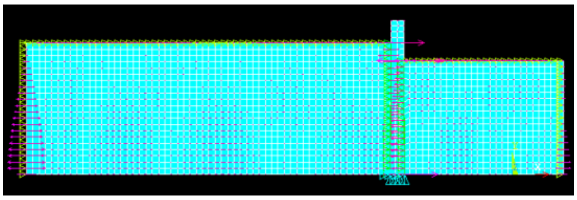

Figure 7. Breakwater displacement under water and earthquake loads

The manmade accelerogram applied as earthquake is shown in Figure 8.

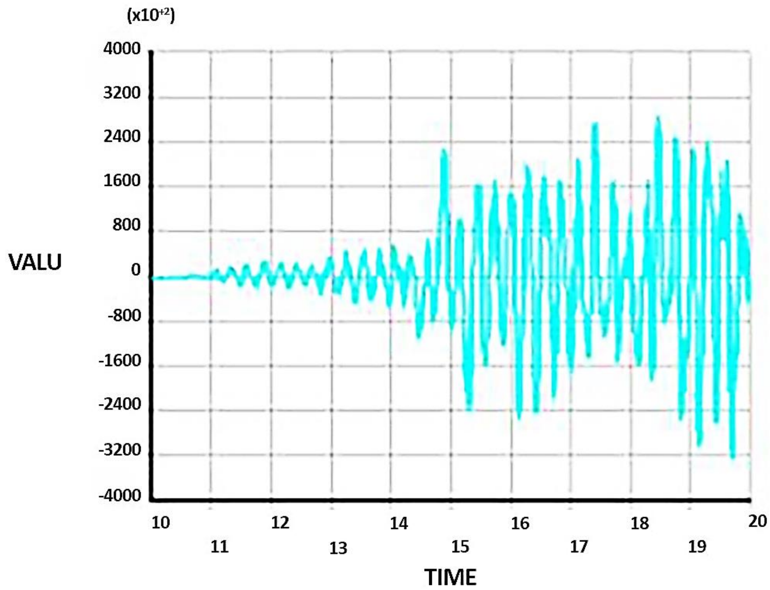

Figure 8.Mapping acceleration applied to earthquake load

4. Discussion

By analyzing the overall displacement of the vertical breakwater wall it is investigated that there is a significant displacement is at the tenth second and its value is equal to 4.56×10^{-5} meters. More importantly, vertical breakwater displacement at the 20th second shows higher value is higher than the 10th second equal to 2.441×10^{-3} m.

Displacement, maximum stress and minimum stress can be obtained by modal graph. Counters of modal graph in this study show that maximum compressive stress of the analyzed breakwater wall is 7125MPa. It is notable that minimum compressive stress is 6033MPa. Also, it is in the seawater side. In short, stress in the front side of breakwater wall is compressive. Meanwhile, maximum tensile stress and minimum compressive stress are 0.44 and 43MPa, respectively. Comparison of these results with the overall displacement and stress shows that the stress and displacement have more values in other directions.

5. Conclusion

Coastal engineering is by far the most important branches of engineering science around the world. Coping with high altitude waves such as tsunami requires more precise investigations, which needs coastal engineering knowledge. Also, it requires more stable and secure infrastructures. Nowadays, usage of vertical breakwater walls is considered as a common protection strategy against sea waves in most countries. On this basis, more accurate studies of these breakwater walls against high altitude waves can facilitate usage of these structures. In this study, two scenarios of vertical breakwater wall have been numerically analyzed utilizing ANSYS commercial software, because this software is a proper option for calculating and analyzing them.

Results show that breakwater wall with crown resist against higher pressure and horizontal force than the one without crown. The maximum displacement at the top of the structure is 4.56 x 10-5m and also the highest level of stress on this breakwater is 7125MPa. Moreover, minimum compressive stress is equal to 6003MPa, which happens on the seawater side.

The modeling results have demonstrated that the maximum stress (both normal and shear ones) occurs under the solitary waves which their period is equal to one of the natural periods of the breakwater structure. It was also observed that higher altitude waves introduce higher values of stress, linearly. So the most important consideration for designing breakwater walls is designing against (i) an iduced wave with a period equal to one of the natural periods of the structure, and (ii) the highest possible wave height at that period.

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