Numerical Investigation of hydrodynamic Performance of Double Submerged Breakwaters

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Abstract—In terms of the importance of protecting Egyptian coastline, precast concrete half pipes submerged breakwater is a nature-conscious coastal protection work that prevents beach erosion and provides a safe and agreeable environment in the coastal areas. For linear waves, a numerical model (FLOW 3D) is used to investigate the hydrodynamic performance of separated half pipes submerged breakwater. Two different models are investigated to determine the best distance between separated half pipes submerged breakwaters. The models are investigated numerically to determine the transmission coefficient (Kt), the reflection coefficient (Kr) and the wave energy dissipation coefficient (Kd). The numerical results are compared with the experimental and numerical results of (Ibrahim, M., Ahmed, H., and Alall, M. A. (2017)) [8]. The good agreement is achieved between them. Finally, the results of the numerical model are accepted and able to predict the hydrodynamic performance of separated half pipes submerged breakwaters.

Index Terms—Numerical investigation, Linear Waves, Separated Half pipes submerged breakwaters, Reflection coefficient (K_r), Transmissions coefficient (K_t), Wave energy dissipation coefficient (K_d), Clear Distance(W).

1 INTRODUCTION

Submerged breakwaters distinguished by its submerged crests which result in avoiding the generation of reflected wave close to the shoreline classified as economic structure as this type is a control tool for the coastal erosion, support cheap measure for protecting beaches subjected to small or moderate waves, provide rapid installation for temporary off-shore works. In addition, it does not cause visual pollution of tourism coasts. Observing that, the fixed submerged breakwater is more effective in decreasing the wave-height and less subject to structural failure during destructive storms. All these advantage parameters lead to the popularity for its usage in the coastal protection however it has only disadvantage parameter with the navigation process. This disadvantage is not significant because such barriers are established near the shore, where navigation is limited on small boats. They can be overcome by establishing specific gaps for the passage of boats. With all these benefits, this type of breakwater utilizes to protect and install the beach. In addition to that, it is more suited for tourism coast where residential, environmental and recreational developments. The hydrodynamic efficiency of the submerged breakwaters is evaluated by testing the wave reflection, transmission and energy dissipation. Many experimental, numerical and theoretical studies were made for determining the hydrodynamic efficiency of the submerged breakwater. Since the pioneering study by **Jeffreys (1944) [9]** on the wave transmission due to the rectangular submerged breakwater several studies have been carried out. Dick and **Brebner (1968) [5]** presented theoretical and experimental studies for permeable and solid submerged structures. **Mei and Black (1969) [16]** studied surface piercing and bottom standing thick vertical barriers experimentally and theoretically. **Madsen (1974) [15]** produced simple solution for the reflection and the transmission coefficients. **Seelig (1980) [20]** obtained the most information about wave transmission, reflection, and energy dissipation by submerged breakwater from hydraulic model tests. **Abdul Khader and Rai (1980) [10]** investigated experimentally the damping action of impermeable, submerged breakwaters of various shapes (thin, rectangular, trapezoidal and triangular).**Abul-Azm (1993) [1]** examined the water-wave interaction with submerged breakwaters to determine the reflection and transmission coefficients a submerged breakwater extending from the sea bed until below the waterline the breakwaters are assumed to be rigid, thin and impermeable. **Lee and Liu (1995) [14]** solved mathematically the problem of wave interaction with a submerged porous breakwater. **Heikal and Attar (1997) [7]** examined experimentally and numerically the efficiency of vertical impermeable. **Hall and Seabrook, (1998) [6]** investigated experimentally the performance of permeable submerged breakwater to determine the effect of depth of submergence on the transmission coefficient .**Twu et al. (2001) [21]** studied theoretically the problem of wave transmission over rectangular and vertically stratified with multi-slice porous material by using the Eigen Function Expansion method.**Koraim (2002) [11]** investigated experimentally and theoretically the wave interaction with impermeable, submerged thin and thick breakwaters, rectangular and trapezoidal, on horizontal and sloping beaches. **Chiranjeevi Rambabu and Mani (2005) [19]** investigated numerically the performance of submerged breakwaters to determine the effect of depth of submergence, crest width, initial wave conditions and material properties on the transmission characteristics of the submerged breakwater. **Lee et al. (2007) [13]** studied the transformation of irregular waves propagating over a submerged breakwater .**Ahmed and Anwar (2011) [3]** investigated experimentally the efficiency of the submerged breakwater as shore protection structure .**Koraim and Rageh (2013) [12]** investigated he hydrodynamic efficiency of the vertical porous structures under regular waves by use of physical models. **Rahman and Silwati Al Womera (2013) [18]** investigated the interaction between regular waves and solid rectangular submerged breakwater experimentally and numerically based on the SOLA-VOF (Solution Algorithm-Volume of Fluid) method .**Rahman and Akter (2014) [17]** carried out an experimental investigation in a two-dimensional wave flume to investigate the effect of porosity on submerged and emerged fixed vertical porous breakwater .**Ibrahim, M.et al.(2017) [8]** Study experimentally and numerically the hydrodynamic performance of using half pipes as permeable breakwaters. **Ahmed, H. and Abo-Taha, M. (2019) [2]** investigated numerically the regular waves interaction with half pipes submerged breakwaters to determine the relative structure height that gives the maximum energy dissipation. In this study, the linear waves interaction with separated half pipes submerged breakwaters are investigated numerically by the Flow-3D program to focus on the transmission coefficient (Kt), the reflection coefficient (Kr) and the wave energy dissipation coefficient (Kd), thus selecting the best distance between separated half pipes submerged breakwaters. The experimental and numerical results of **(Ibrahim, M., Ahmed, H., and Alall, M. A. (2017)) [8]** are carried out numerically by (FLOW-3D) program in this study to determine the efficiency of using this analysis program.

2 NUMERICAL ANALYSIS FOR THE PROPOSED BREAKWATER

2.1 (FLOW-3D) program Theory

The investigation of the proposed breakwater achieved by numerical simulation by using the marketable (CFD) "Computational Fluid Dynamics" Code (FLOW-3D). Considering Coastal and maritime engineering, the proposed program has a developing rule where various applications are viable by its usage. The coding of this program is based on the finite volume theory in order to solve the three-dimensional Reynolds Averaged Navier Stokes (RANS) equations. Taking into account that the program is composed of many solid divisions, hydraulic and geometric boundary conditions is represented through this program as shown in figure (1). The numerical model is implemented by varying different parameters in this study in order to simulate the proposed breakwaters. The relation between the meshing method used in the analysis process versus the computational time, accuracy and precision are crucial where the 1 cm cell size is used for low frequencies and 0.5cm cell size is used for large frequencies. The wavelength affects the analyzing time so must be carefully selected to avoid any reflection from the wave paddle or the flume end.

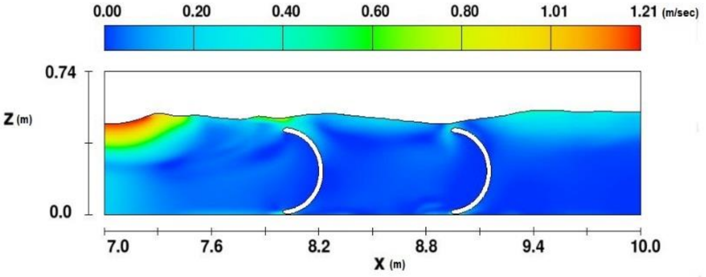


Fig. 1. Breakwater model in a Flow-3D program.

2.2 Governing Coefficients

Three coefficients governing this study are discussed. Firstly, the reflection coefficient (Kr) which indicates the amount of wave reflected from the barrier, Secondly the transmission coefficient (Kt) which presents the quantity of wave transmitted after the breakwater, Thirdly the energy dissipation coefficient (Kd)where the portion of the dissipated energy. The reflection coefficient (Kr) is estimated by measuring the maximum and the minimum wave heights (Hmax and Hmin) at upstream of the submerged breakwater. Incident wave height (Hi) and reflected wave height (Hr) are calculated as Hi=(Hmax+Hmin)/2 and Hr=(Hmax-Hmin)/2 respectively, where Hmax is the maximum wave height measured at antinodes while Hmin is minimum wave height measured at nodes., According to **Dean and Dalrymple [1991]. [4]**. The conventional method used to separate the measured wave train into its incident and reflected wave components. Two probes in flow -3D analyze for measuring maximum and minimum wave heights were placed at fixed distances of L/4 (at position P2) and L/2 (at position P1) from the breakwater, where L is the wavelength. knowing that the wavelength is varied according to the wave periods. At each position (L/4) antinode, and (L/2) node) data of water surface were collected. Where Kr is calculated according to the following equation:

Kr =Hr/Hi (ranging from 0 to 1) (1)

Where Hr is the reflected wave height, (Hi) is the incident wave height .Measuring the transmitted wave heights (Ht) using one probe in flow -3D analyze at position (P3) are performed, this position is located at a distance 2 m behind the submerged breakwater model (from the breakwater shore side), this position is for the sake of avoiding the turbulence effect resulting from the wave overtopping on the submerged breakwater also for minimizing the effect of the reflected waves from the wave absorber which is located at the end of the wave flume. Where (Kt) is calculated according to the following equation

$$Kt = Ht/Hi \qquad \text{(ranging from 0 to 1)} \qquad (2)$$

Where Ht is transmitted wave height.After calculating the values of Kr and Kt, the wave energy dissipation coefficient can be calculated

$$Kd = \sqrt{1 - Kr^2 - Kt^2} \quad \textbf{(Thornton and Calhoun 1972) [22]} \qquad (3)$$

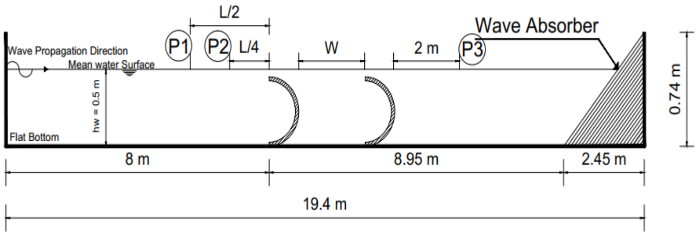
2.3 Characteristics of numerical analysis study

This section presents the details of tested numerical models . The numerical setup parameters for tested separated half pipes submerged breakwaters shown in table 1

Table 1: The numerical setup parameters for tested half pipes submerged breakwaters

Parameter	The ranges
Water Depth (hw) (m)	0.5
Wave periods (T) (sec)	1.2 to 2
Wave Length (L) (m)	2.05 to 4.1
Wave incident (Hi) (cm)	10.2 to 20.3
Breakwater Height (hs) (m)	0.45
Relative Structure height (hs/hw)	0.9
Clear Distance between to half pipes (W) (m)	0.5 to 2.05

To investigate the interaction between regular waves and separated half pipes submerged breakwater systems, a set of run conditions are carried out on rectangular cross-section wave flume (19.4 m long in X-direction , 0.1 m wide in Y-direction and 0.74 m deep in Z-direction) ,and in order to damp the transmitted wave, a wave absorber is installed at the end of the wave flume, keeping in consideration that the water depth is constant in this wave flume with value 0.5 m, all details of wave are shown in figure(2). Two separated half pipes with diameter 0.45 m, each is fixed in vertical position with clear distance (W) (0.25 L ,0.5 L, 0.75 L and 1.0 L), as shown in figures (3) where L is the wavelength. Knowing that all the models are fixed at distance 8 m in X-direction from the start of the wave flume.



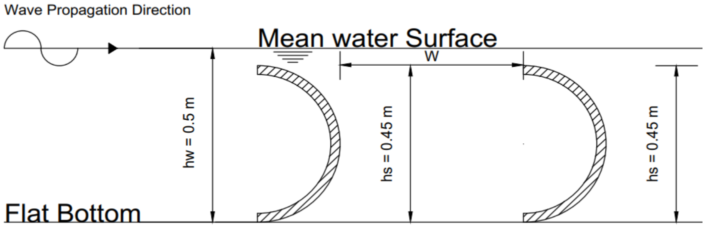


Fig. 2. Illustrative sketch for the wave flume details.

Fig.3. Two separated half pipes in a vertical position with a clear distance(w).

3 VERIFICATION OF NUMERICAL MODEL ANALYSIS

To validate the results of (FLOW-3D) program, the experimental and numerical results of (Ibrahim, M., Ahmed, H., and Alall, M. A. (2017)) [8]. are compared with the numerical (FLOW-3D) outcomes. As shown in figure (4), The model is two vertical half pipes joined together (C shape). The draft is a decimal multiple of the total depth. The lower part is permeable with a porosity 68 %. where Water Depth (h)=0.4m, Breakwater Draft (D) 0.1 m, Breakwater Width (B) 0.1 m and Pile diameter(d)=0.6 chart 1 presents the relationship between the different coefficients (kt, kr, kd) and h/L for different breakwater parameters (D/h=0.25, D/h=0.50). This chart shows that, the transmission coefficient (kt) decreases with the increasing h/L, the reflection coefficient (kr) increases with the increasing hw/L and the wave energy dissipation coefficient (kd) increases with the increasing h/L.This is may be attributed to, as the wave becomes short, the water particle velocity and acceleration suddenly change and the turbulence caused due to this sudden change causes a dissipation in the wave energy..It was observed there was a good agreement in results which reflects the efficiency of using this program in the numerical analysis simulation

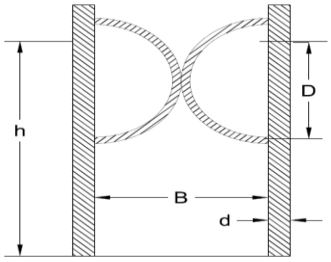


Fig.4. C- shape. [8]

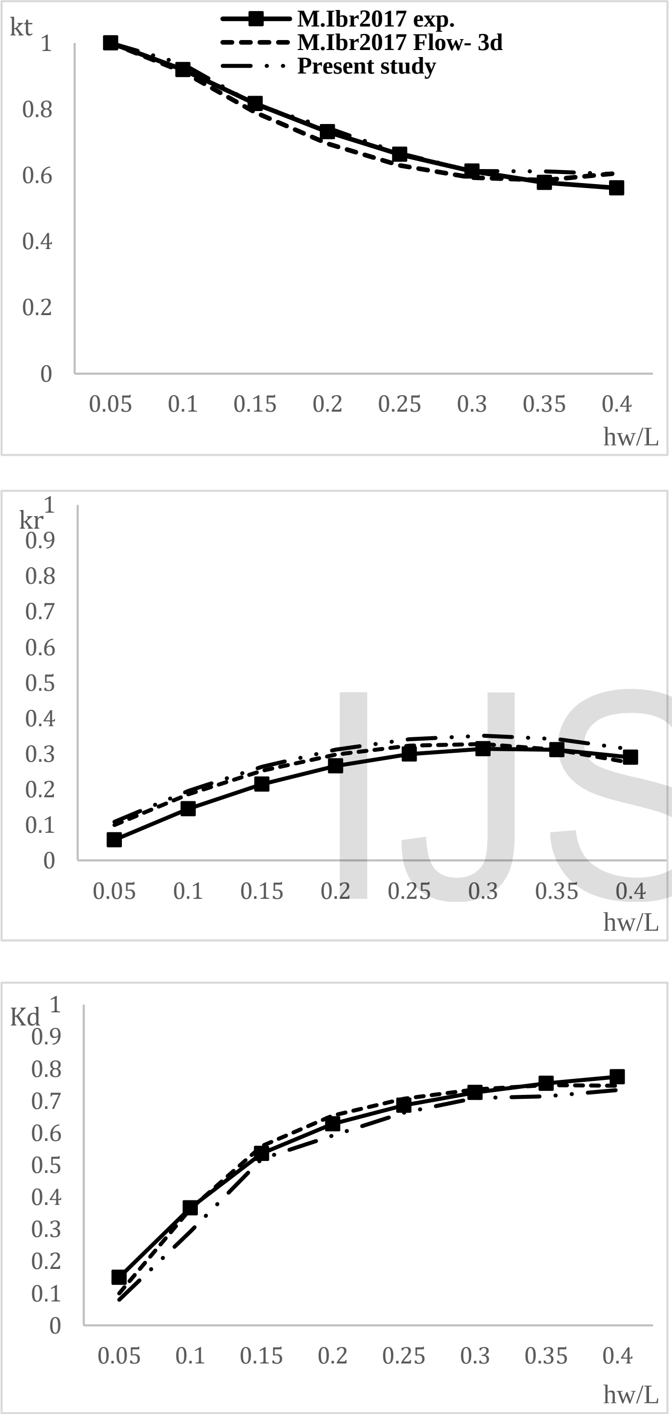


Chart 1. Comparison between experimental (Ibrahim, M., Ahmed, H., and Alall, M. A. (2017)) [8] and results of numerical present study

4 NUMERICAL RESULTS AND DISCUSSION

By using (FLOW-3D) program the hydrodynamic efficiency of using various systems of separated half pipes are demonstrated as a function of reflection coefficient (Kr), transmission coefficient (Kt) and the wave energy dissipation coefficient (Kd), taking into consideration the effect of structure parameters and different regular waves on the interaction between these waves and submerged breakwaters.Chart 2 presents the relationship between the different hydrodynamic coefficients (kt, kr, kd) and hw/L for two vertical separated half pipes with clear distance 0.25 L with relative structure height (hs/hw=0.9). This chart shows that, for the increasing hw/L from 0.12 to 0.25, the transmission coefficient (kt) decreases with the increasing hw/L (kt decreased from 0.434 to 0.187). the reflection coefficient (kr) increases with the increasing hw/L (kr increased from 0.416 to 0.506) and the wave energy dissipation coefficient (kd) increases with the increasing hw/L (kd increased from 0.799 to 0.824). This is may be attributed to, as the wave becomes short, the water particle velocity and acceleration suddenly change and the turbulence caused due to this sudden change causes a dissipation in the wave energy.Chart 2 presents also the relationship between the different hydrodynamic coefficients (kt, kr, kd) and hw/L for two vertical separated half pipes with clear distance 0.50 L with relative structure height (hs/hw=0.9). This chart shows that, for the increasing hw/L from 0.12 to 0.25, the transmission coefficient (kt) decreases with the increasing hw/L (kt decreased from 0.542 to 0.253). the reflection coefficient (kr) increases with the increasing hw/L (kr increased from 0.403 to 0.491) and the wave energy dissipation coefficient (kd) increases with the increasing hw/L (kd increased from 0.737 to 0.834). This is may be attributed to, as the wave becomes short, the water particle velocity and acceleration suddenly change and the turbulence caused due to this sudden change causes a dissipation in the wave energy.Chart 4.6 presents that the hydrodynamic efficiency of two vertical separated half pipes with clear distance 0.25 L is better than the other with a clear distance= 0.50 L as 0.25L case gives the transmission coefficient less by average value
=8.33%. and gives wave energy dissipation coefficient more by average value =3.4%.

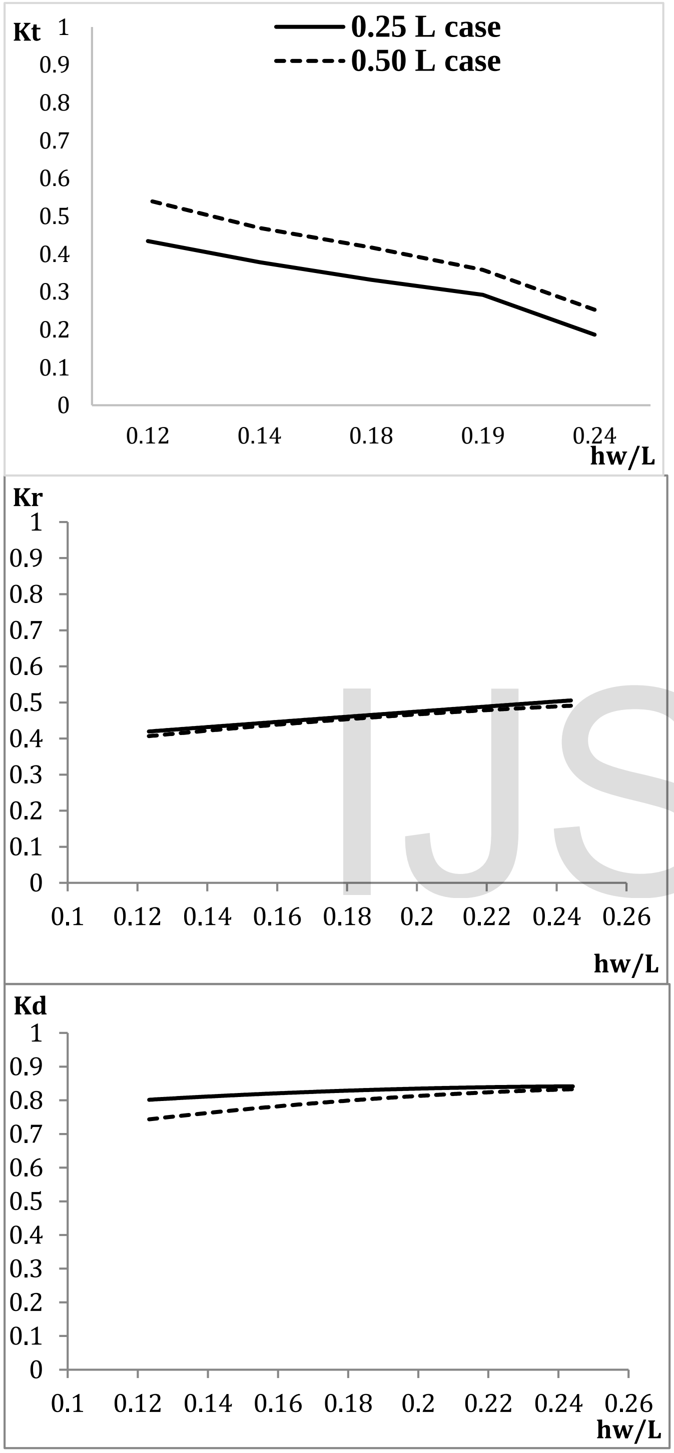


Chart 2. The relationship between the different hydrodynamic coefficients (kt, kr, kd) and hw/L for (0.25 L case) versus (0.50 L case) with relative structure height (hs/hw=0.9)

5 VELOCITY DISTRIBUTION

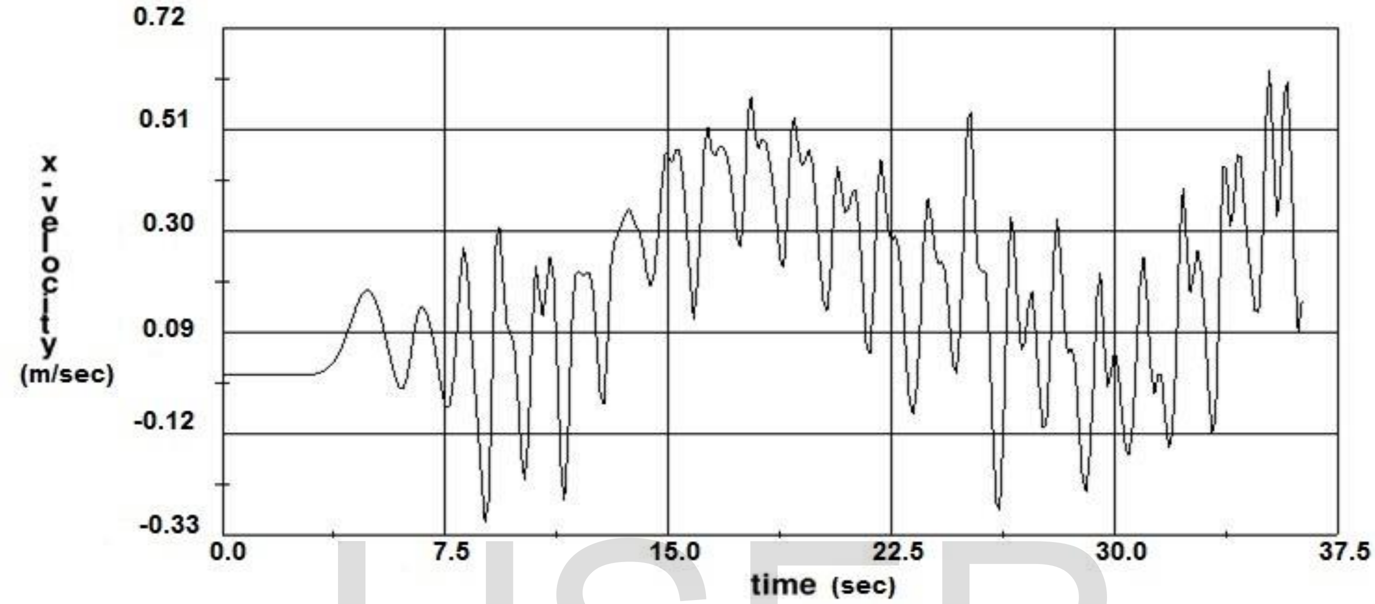
This section presents the velocity distribution in the vicinity of the proposed innovative breakwaters. The numerical model was implemented to detect the velocity field and the velocity vectors in the vicinity of the barriers. This was achieved to indicate how energy was dissipated.

Figure 5 presents the distribution of velocity at different probes for half pipes submerged breakwater (0.25 L case) at T=1.50 sec and hi=0.14 m. The velocity in X direction is very high in front of the barrier and very low behind it, where a part of wave energy is banned, another part is transmitted and the rest part is dissipated. The wave becomes short, the water particle velocity and acceleration suddenly change and the turbulence caused due to this sudden change causes a dissipation in the wave energy.

Figure 6 presents the velocity vector and velocity field for half pipes submerged breakwater (0.25 L case), provided by FLOW-3D, for time increment of 0.15 sec of wave period 1.50 sec. The higher velocities were observed at the wave crests around the half pipes as a vortex as presented by the velocity vectors. The vortex is may be attributed to the presence of the obstacle, which causes contraction of moving wave.

Figure 9 presents the comparison between the maximum velocity magnitude for different cases of half pipes submerged breakwaters of Ahmed, H. and Abo-Taha, M. (2019) [2]. and (0.25 L) case in this study, provided by FLOW-3D, for time increment of 0.15 sec of wave period 1.50 sec, where the minimum velocity magnitude is observed by using 0.25 L case (increasing the wave energy dissipation).

Probe at i=10.0, j=0.05, k=0.49



Probe at i=7.00, j=0.05, k=0.49

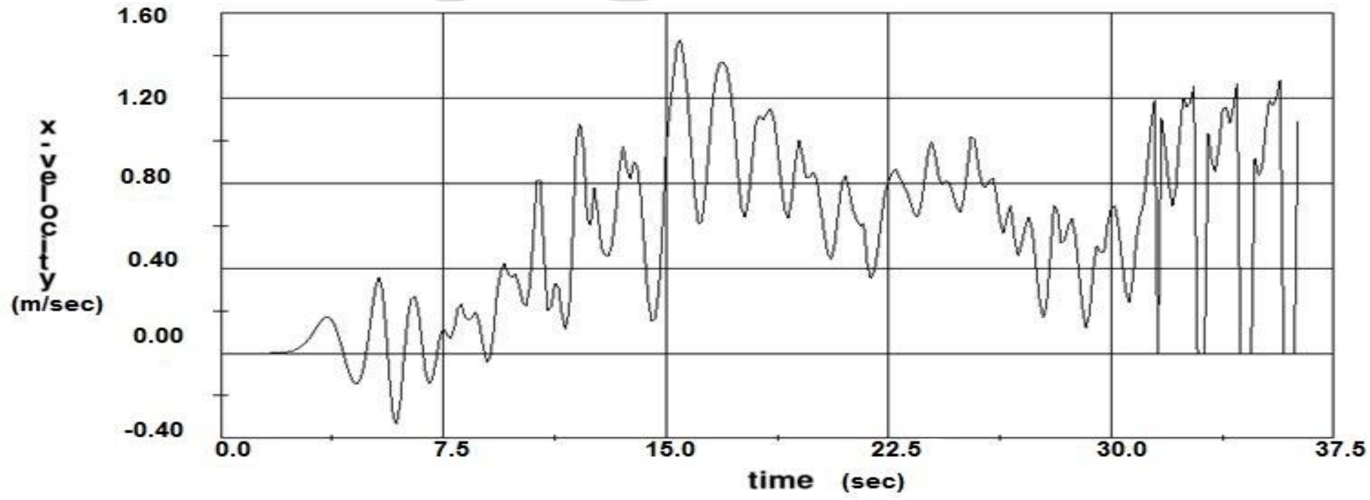


Fig. 5. The distribution of velocity at different probes for half pipes submerged breakwater (0.25 L case) at T=1.50 sec and hi=0.14 m.

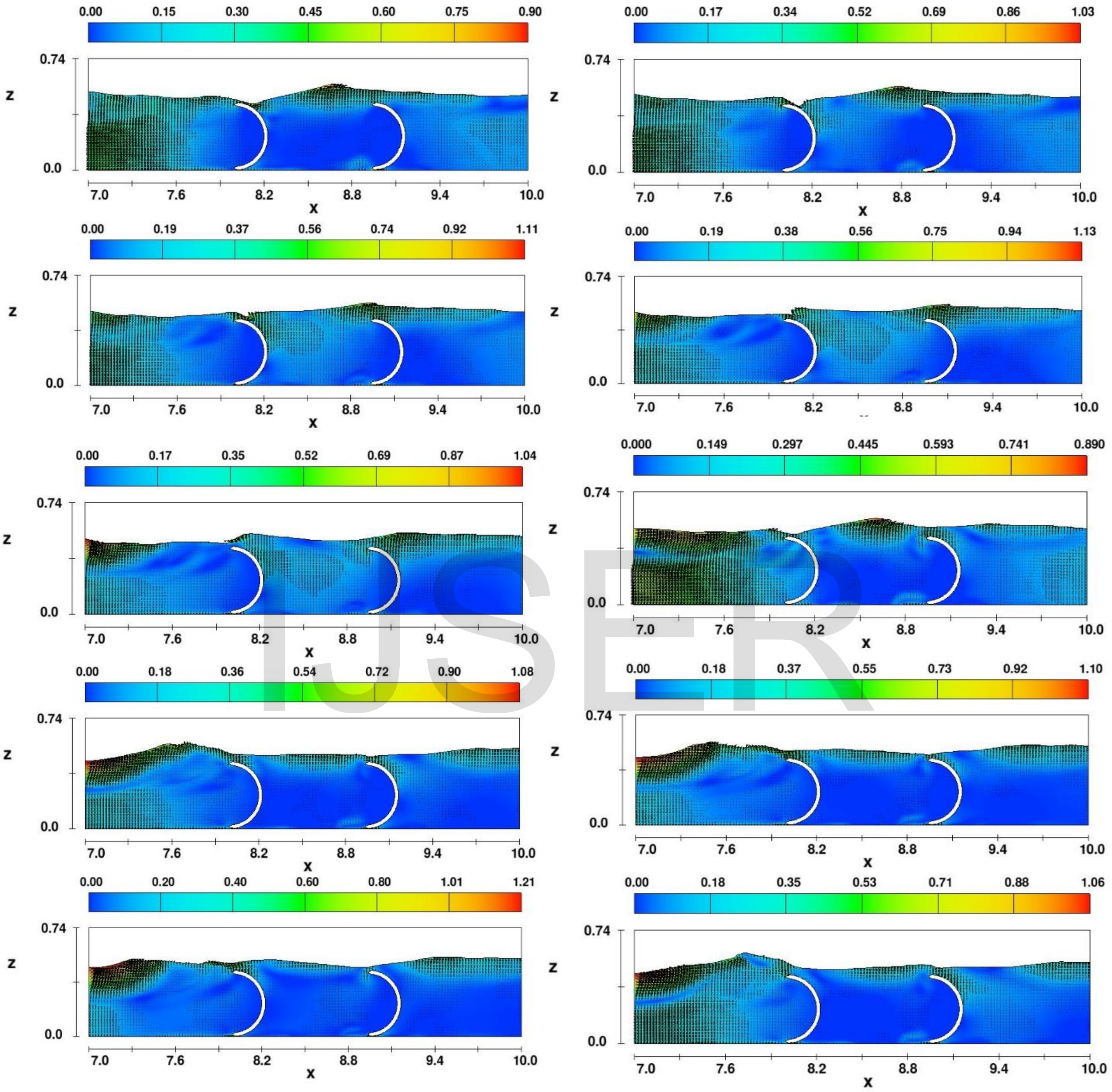


Fig. 6. Velocity vector and velocity field for half pipes submerged breakwater (0.25 L case), provided by FLOW-3D, for time increment of 0.15 sec of wave period 1.50 sec.

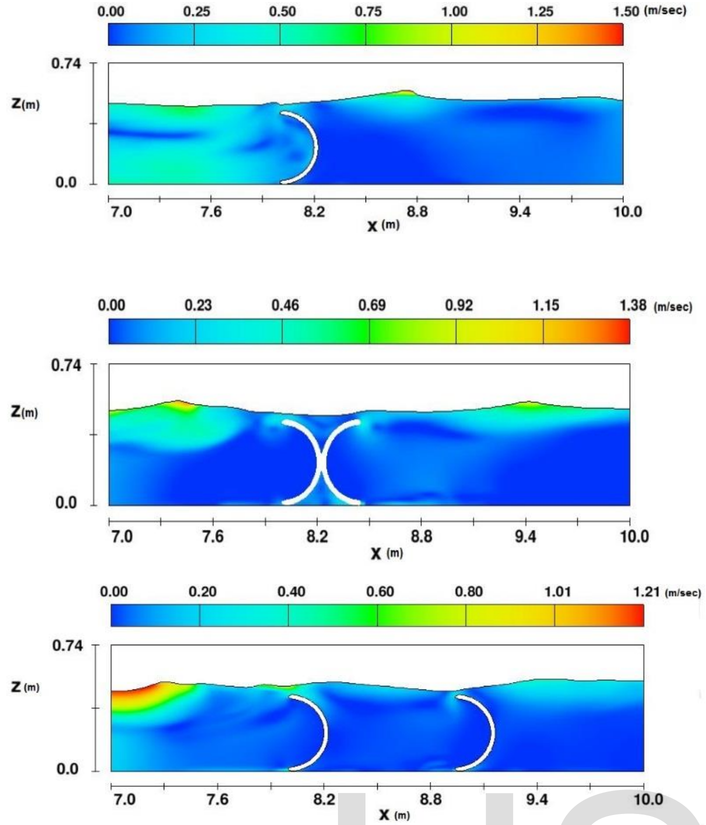


Fig.7.The comparison between the maximum velocity magnitude for different cases of half pipes submerged breakwaters of Ahmed, H. and Abo-Taha, M. (2019) [2]. and (0.25 L) case in this study, for time increment of 0.15 sec of wave period 1.50 sec.

6 CONCLUSIONS

Submerged breakwater is a nature-conscious coastal protection work that prevents beach erosion and provides a safe and agreeable environment in the coastal areas. In this research work, numerical studies are carried out to investigate the performance of half pipes type submerged breakwater. A set of run conditions are carried out at 0.50 m still water depth with different systems of fixed half pipes submerged breakwaters for different wave periods (from T =1.2 sec to T =2.0 sec) in the same wave flume. For more run conditions, water surface elevations are collected at three different locations both in front of and behind the breakwater. Thus, the conclusions from the present research observing that: -

- The experimental and numerical results of **(Ibrahim, M., Ahmed, H., and Alall, M. A. (2017)) [8]**. are compared with the numerical (FLOW-3D) outcomes. A good agreement was apparent, where the results indicated the applicability of the numerical model to reproduce most of the important features of the interaction.
- The hydrodynamic efficiency of two vertical separated half pipes with clear distance 0.25 L is better than the other with a clear distance= 0.5 L as 0.25L case gives the transmission coefficient (kt) less by average value =8.33%. and gives wave energy dissipation coefficient (kd)more by average value =3.4%.
- The velocity in X direction is very high in front of the barrier and very low behind it, where a part of wave energy is banned, another part is transmitted and the rest part is dissipated. The wave becomes short, the water particle velocity and acceleration suddenly change and the turbulence caused due to this sudden change causes a dissipation in the wave energy

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