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Numerical Investigation of Regular Waves Interaction with Submerged Breakwater

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Abstract— The protection of the Egyptian Tourist coasts is very important; Recently submerged breakwaters have been developed to overcome the drawbacks of fully protection breakwaters, these submerged breakwaters have minor influences of neighboring beaches and the coastal environment in which they support a more economical protection against waves and currents. For regular waves, a numerical model (FLOW 3D) is used to investigate the hydrodynamic performance of halfpipes submerged breakwater. Three different diameters of a precast in shape of halfpipe are investigated to determine the relative structure height that gives the maximum energy dissipation coefficient; thus, two halfpipes are used in horizontal positions (H shape) and in a vertical position (X shape). The models are investigated numerically to determine the reflection coefficient (Kr), the transmission coefficient (Kt) and the wave energy dissipation coefficient (Kd). The numerical results are compared with the experimental results of Rahman, M. et. al. (2013). The good agreement is achieved between them. Finally, the results of the numerical model are accepted and able to predict the hydrodynamic performance of halfpipes submerged breakwaters.

Index Terms—Numerical investigation, Regular Waves, Submerged breakwaters, Halfpipes submerged breakwaters, Reflection coefficient, Transmissions coefficient, Wave energy dissipation coefficient

1 INTRODUCTION

The Coastal protection process was always a challenging field for the engineers because of the included sophisticated natural operations, In the recent days the problem becomes more complicated as ensuring the aesthetic value for nature, the environmental details and water quality are important parameters included in the design of coastal projects.

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 contamination 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 to 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. For the sake of the protecting the coastal zone, the literature review was investigated that related to the efficiency of using submerged breakwater to decreasing the wave transmission. Many types of research were reviewed in this topic so most of the articles, published reports and publications were summarized, overviewed and analyzed. Observing that many researchers are involved in this field to investigate the interaction between waves and partially protection breakwater numerically and experimentally for a safe design. The hydraulic performance of perforated breakwaters had been investigated by theoretical and experimental models. Theoretical solutions had been developed on the basis of the boundary element method, reported by [1]. The Eigenfunction expansion method has been utilized as a numerical approach by [2], [3]and [4]. Numerical solutions for wave interaction with permeable breakwater, based on the Reynolds Averaged Navier-Stokes (RANS) equations with the Volume of Fluid (VOF) method have been used by [5]. In the recent past, many reports ([6],[7]and [8]) studied the submerged breakwater have appeared. The moral of the literature review to completely demonstrate the performance of characteristics for different types of submerged breakwater performed [9].

According to [10] the wave deformation for the multi-directional random waves which passing over impermeable submerged breakwater was studied. A comparison between reflection and transmission properties for different types of breakwaters is held by using numerical and experimental analysis for these breakwater types [9] Based on Reynolds-Averaged Navier-Stokes (RANS) equations a numerical study for investigating the performance of porous submerged breakwater under the attack of a solitary wave [11].

According to [12], Investigating the regular wave interaction with fixed submerged breakwater is performed numerically and experimentally where the numerical analysis is based on SOLA-VOF method. This model can simulate the velocity field of the water particle, VOF function F, water surface profile time series and the pressure around a breakwater. In this study, the regular waves interaction with submerged breakwaters from precast concrete in form of half pipes is investigated numerically by the Flow-3D program to focus on the reflection coefficient (K_r), the transmission coefficient (K_t) and the wave energy dissipation coefficient (K_d). The experimental results from (Rahman, M. A.and Womera, S. A. (2013)) [12] which carried out experimentally on rectangular submerged breakwaters are carried out numerically by (FLOW-3D) program to determine the efficiency of using this analysis program

2 NUMERICAL INVESTIGATION OF THE PRPPOSED BREAKWATER

This Section presents the theory of the (FLOW-3D) program and its method of execution where the simulation of the breakwater model is implemented to calculate the different coefficients governing this study including the reflection, transmission, and wave energy dissipation coefficients

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). As a matter of validation, this program was used in the numerical study of [13]and validated experimentally which showed a good apparent agreement in results. therefore, the marketable (CFD) has been used in the implementation of this research.

2.2 (FLOW-3D) numerical simulation

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.

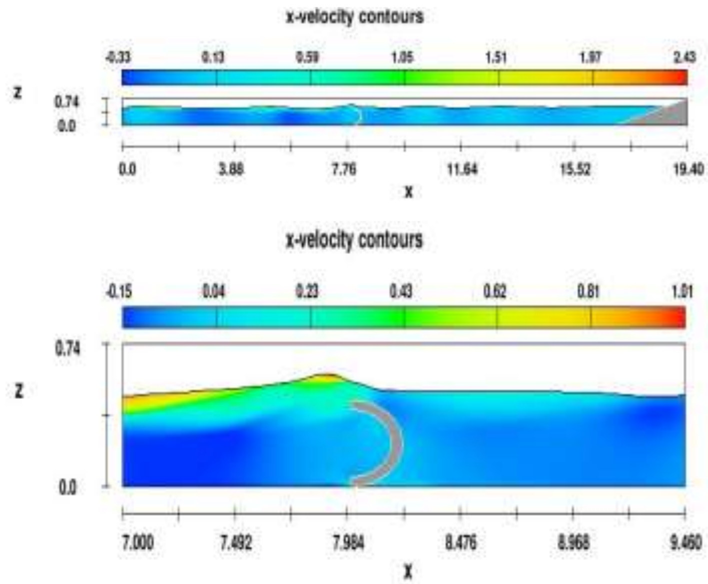

Fig. 1. Breakwater model in a Flow-3D program

2.3 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 wave energy dissipation coefficient (Kd) where the portion of the dissipated energy is shown. Finally, all the coefficients can be presented in equations forms as follows:

$K_r = \frac{Hr}{Hi}$ (ranging from 0 to 1) (1)

$K_t = \frac{Ht}{Hi}$ (ranging from 0 to 1) (2)

$K_d = \sqrt{1 - Kr^2 - Kt^2}$ [14] (3)

Where Hr is the reflected wave height, the Hi is the incident wave height and Ht is transmitted wave height.

2.4 Characteristics and Procedure of numerical Analysis model

The FLOW-3D program has been used in this study: to investigate the effect of regular waves characteristics and half pipes submerged breakwater systems on the breakwater efficiency, to validate numerical rectangular submerged breakwater results against laboratory results (Rahman, M. A.and Womera, S. A. (2013)) [12], thus a good agreement in results was apparent.

3 CHARACTERISTICS OF NUMERICAL ANALYSIS STUDY

3. 1 Wave Flume

To investigate the interaction between regular waves and 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).

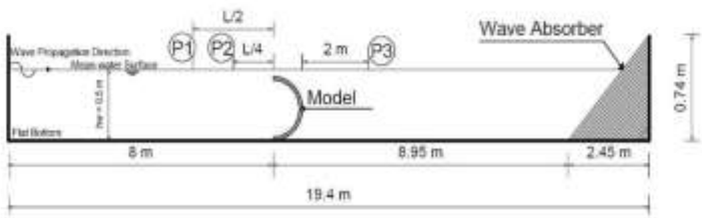

Fig. 2. Illustrative sketch for the wave flume details

3. 2 Waves

A set of run conditions are carried out by using five different regular wave periods(T) (1.2 sec, 1.4 sec, 1.5 sec, 1.8 sec, 2 sec), where the finish time of each run based on the wavelength (L) which varies according to the wave period.

3. 3 Tested Numerical Models

1- One half pipe fixed in vertical position with: Three different diameters (hs) (0.4 m, 0.45 m ,0.5 m), and relative structure height (hs/hw) (0.8 ,0.9 ,1), while the half pipe of 0.45 m diameter is tested in normal and inverse vertical positions as shown in figures (3, 4).

2- Two half pipes with a diameter (0.45 m) are joined together in a horizontal position (H shape) and in vertical positions (X shape) as shown in figures (5,6)

Knowing that all the models are fixed at distance (8 m) in X-direction from the start of the wave flume.

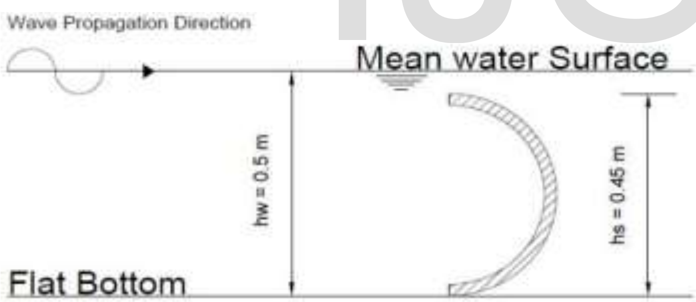

Fig. 3. One-half pipe fixed in a normal vertical position with 0.45 m diameter

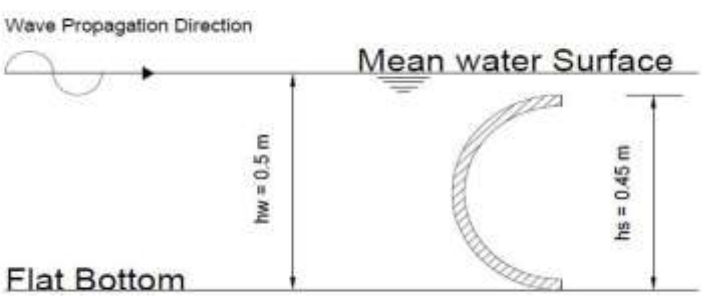

Fig. 4. One-half pipe fixed in an inverse vertical position with 0.45 m diameter

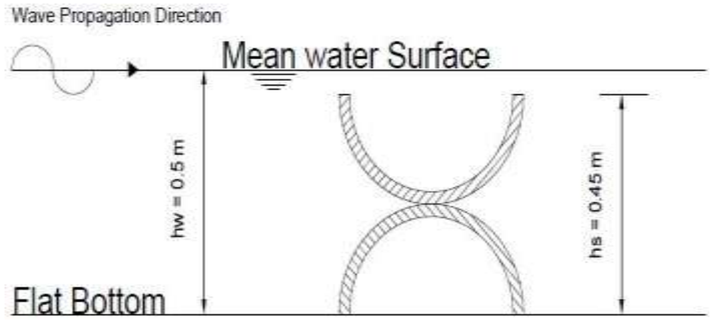

Fig. 5. Two half pipes are joined together in a horizontal position (H shape)

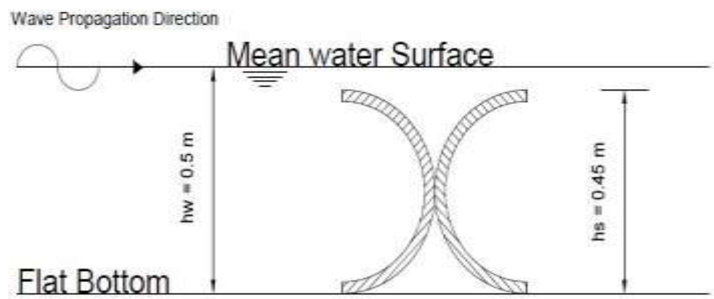

Fig.6. Two half pipes are joined together in a vertical position (X shape)

The numerical setup parameters for tested half pipes breakwaters shown are in table 1.

TABLE 1
THE NUMERICAL SETUP PARAMETERS FOR TESTED HALF PIPES BREAKWATERS.

Parameter	The ranges	Notes
Water Depth (hw) (m)	0.5	at the breakwater sit
Wave periods (T) (sec)	1.2 to 2	
Wave Length (L) (m)	2.05 to 4.1	at the breakwater sit
Wave incident (Hi) (cm)	10.2 to 20.3	
Breakwater Height (hs) (m)	0.4 to 0.5	
Relative Structure height (hs/hw)	0.8 to 1	Dimensionless

4 THE PROCEDURE OF GOVERNING COEFFICIENTS CALCULATIONS

1-The reflection coefficient (K_r) is estimated by measuring the maximum and the minimum wave heights (Hmax and Hmin) at upstream of the submerged breakwater. Incident wave height (H_i) and reflected wave height (H_r) are calculated as H_i=(Hmax+Hmin)/2 and H_r= (Hmax-H min.)/2 respectively, where Hmax is the maximum wave height measured at antinodes while H min is minimum wave height measured at nodes., According to [15], The conventional method used to separate the measured wave train into its incident and reflected wave components. Two wave gauges required 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 equation (1).

2-Measuring the transmitted wave heights (Ht) using wave gauge 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 equation (2).

3-After calculating the values of Kr and Kt, the wave energy dissipation coefficient can be calculated as shown in equation (3).

5 VERIFICATION OF NUMERICAL MODEL ANALYSIS

To validate the results of the present study which using numerical code (FLOW-3D), a comparison with experimental results of Rahman, M. et. al. (2013) [12] that performed at the hydraulics and River engineering laboratory of Bangladesh University of Engineering and technology are carried out. As shown in figure 7 ,rectangular submerged breakwater models of 0.76 m length in Y-direction ,1 m width in X-direction and three different heights of 0.3 m , 0.35 m ,and 0.4 m in Z-direction fixed in the wave flume ,having dimensions of 21.3 m long ,0.76 m wide and 0.74 m deep, with constant water depth 0.5 m ,were tested at five different regular wave periods (T) (1.5 sec ,1.6 sec ,1.7 sec ,1.8 sec and 2 sec), therefore fifteen different experimental run conditions (Rahman, M. et. al. (2013) [12] are tested, then performed in this numerical study for the sake of validation process. The results are presented clearly in the chart 1 and table 2. It was observed there is a good agreement in results which reflects the efficiency of using this program in the numerical analysis simulation.

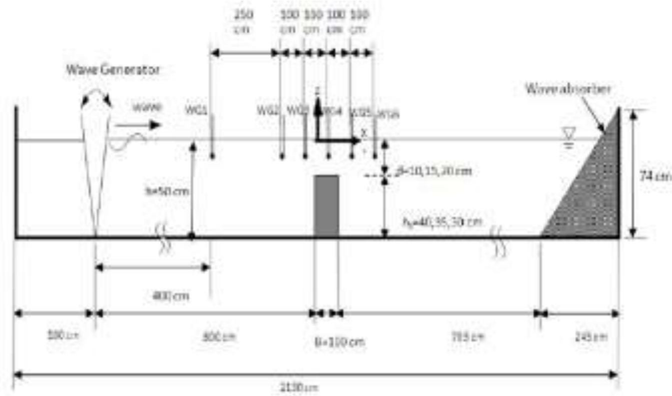

Fig. 7. Details of the experimental setup of Rahman, M. et. al. (2013) [12]

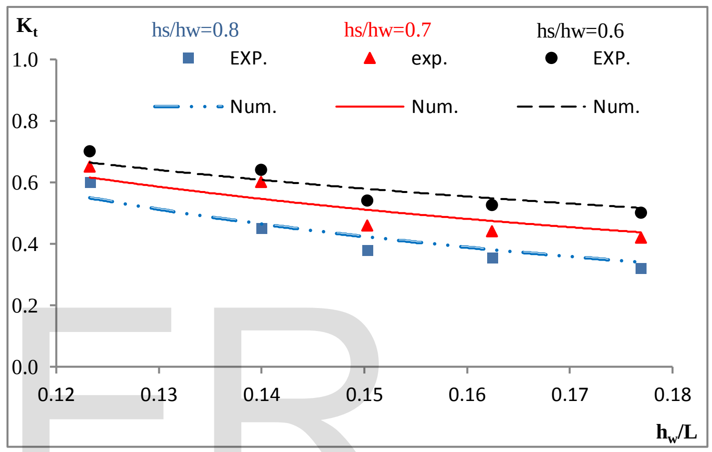

Chart 1. Comparison between experimental results of Rahman, et. al., (2013) [12] and the results of the present study at various of (hs/hw) for rectangular submerged breakwater.

TABLE 2
COMPARISON BETWEEN VALUES OF (KT) IN EXPERIMENTAL OF RAHMAN, M. ET. AL. (2013) [12] AND THE RESULTS OF THE PRESENT STUDY AT VARIOUS OF (HS/HW) FOR RECTANGULAR SUBMERGED BREAKWATER

	Kt				
T (sec)	1.5	1.6	1.7	1.8	2
hs/hw=0.8 (Exp.)	0.320	0.355	0.380	0.450	0.600
hs/hw=0.8 (Num.)	0.340	0.376	0.422	0.480	0.540
hs/hw=0.7 (Exp.)	0.420	0.440	0.460	0.600	0.650
hs/hw=0.7 (Num.)	0.440	0.467	0.507	0.560	0.610
hs/hw=0.6 (Exp.)	0.500	0.526	0.540	0.640	0.700
hs/hw=0.6 (Num.)	0.520	0.541	0.575	0.620	0.660

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6 NUMERICAL RESULTS AND DISCUSION

By using (FLOW-3D) program the hydrodynamic efficiency of using various systems of half pipes are demonstrated as a function of reflection coefficient (K_r), transmission coefficient (K_t) and the wave energy dissipation coefficient, taking into consideration the effect of structure parameters and different regular waves on the interaction between these waves and submerged breakwaters.

By investigation of one half-pipe fixed in a vertical position with three different diameters (0.4 m, 0.45 m, 0.5 m), with relative structure height (hs/hw = 0.8, 0.9, 1) respectively. The results indicates that increasing the diameter of half pipes (increasing the relative structure height) increases the reflection coefficient and decreases the transmission coefficient while the wave energy dissipation coefficient increases gradually until reaching its optimum value at 0.45 m in diameter (relative structure height = 0.9) then it decreases gradually as shown in the chart (2) ,so it was concluded that the 0.45 m pipe in diameter (relative structure height hs/hw=0.9) will be used in the following cases. The first case is a comparison study between one-half pipe fixed vertically with normal position versus inverse position, its results shown that the hydrodynamic efficiency of half pipe in normal position is better than the half pipe in inverse position as shown in the chart (3). The second case is a comparison between two half pipes are joined together in a horizontal position (H shape) and in a vertical position (X shape), it's results shown that the hydrodynamic efficiency of X shape is better than H shape as shown in the chart (4).observing that in each of all the previous cases the transmission coefficient decreases with increasing the relative wavelength (hw/L), while the reflection coefficient (K_r) and the wave energy dissipation coefficient directly proportional to the relative wavelength.

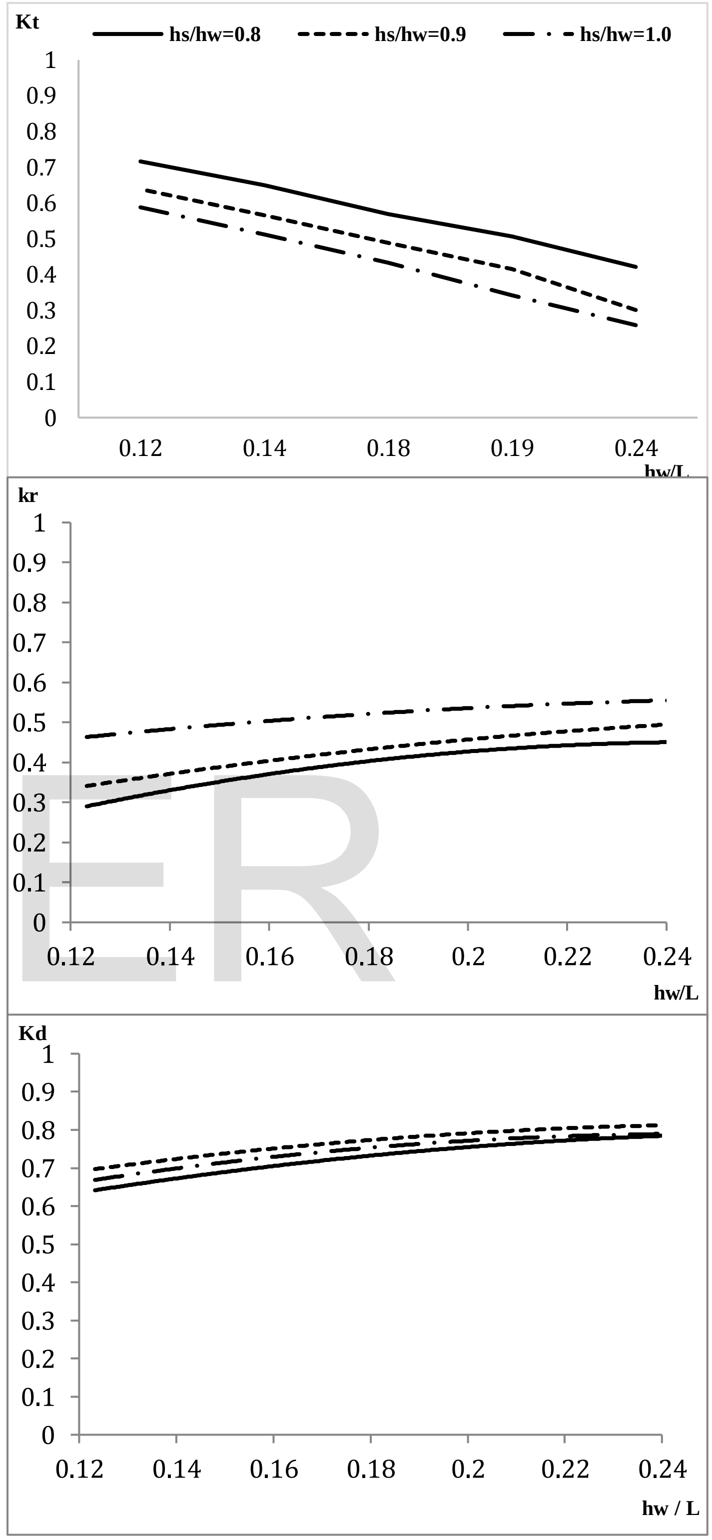

Chart 2. The relationship between the different hydrodynamic coefficients (kt, kr, kd) and hw/L for different breakwater parameters (hs/hw=0.8, 0.9 and 1.0)

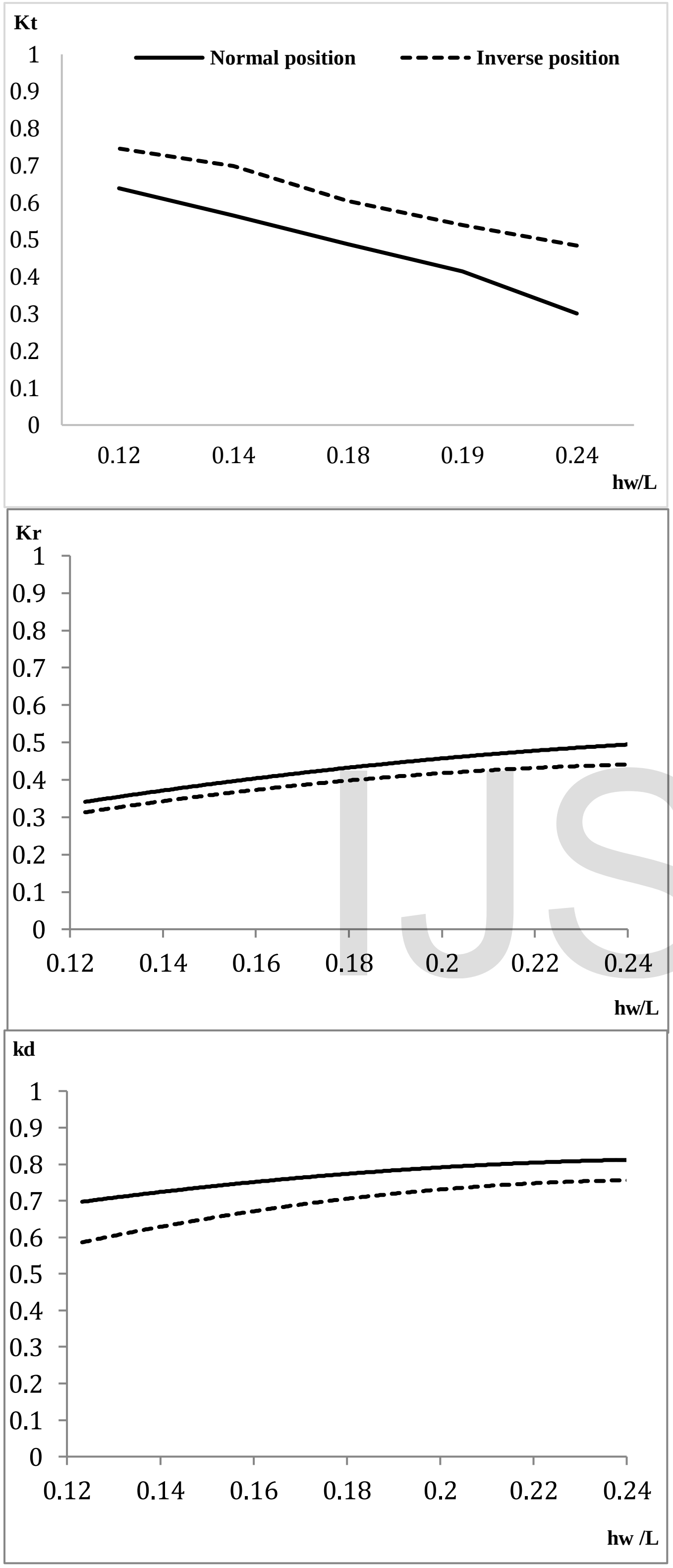

Chart 3. The relationship between the different hydrodynamic coefficients (kt, kr, kd) and hw/L for one-half pipe fixed vertically with normal position versus inverse position with relative structure height (hs/hw = 0.9)

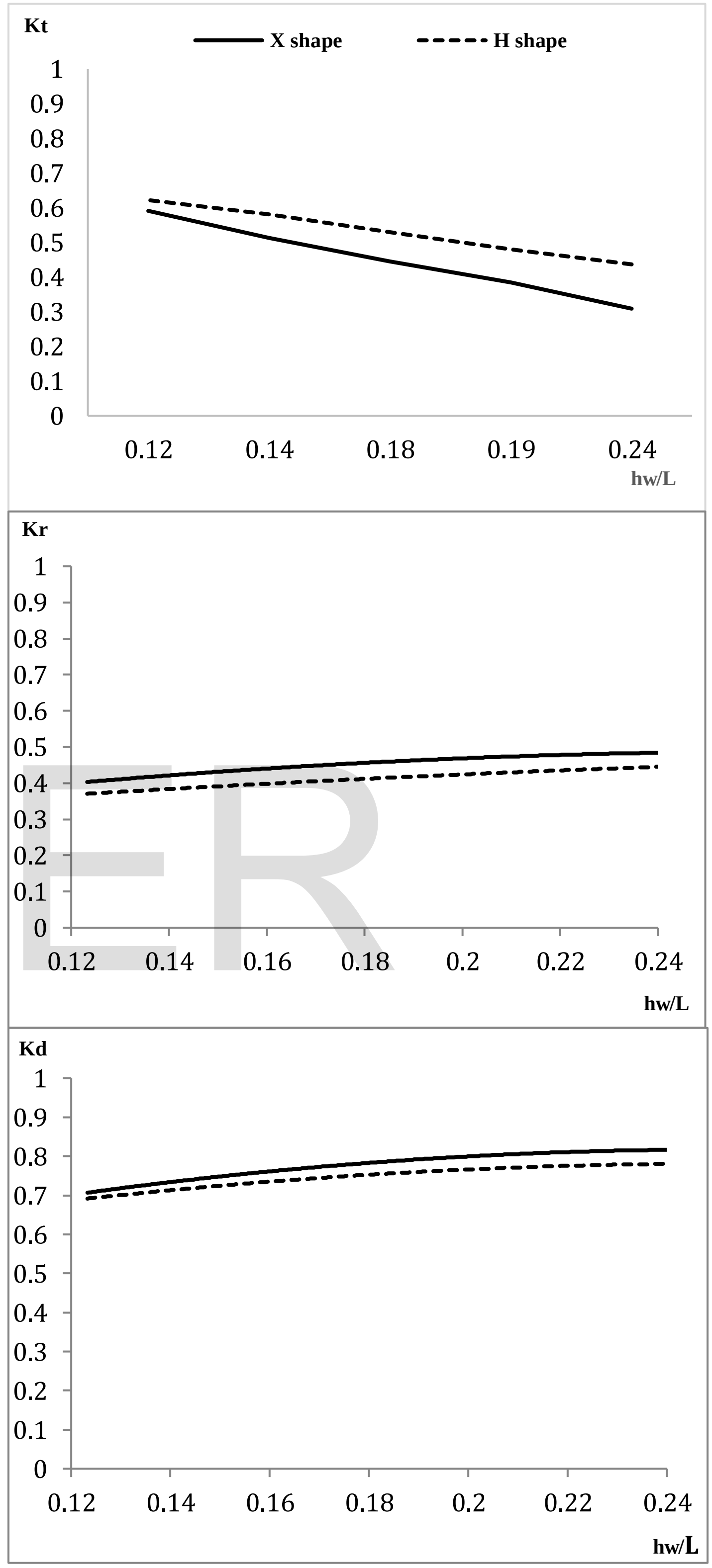

Chart 4. The relationship between the different hydrodynamic coefficients (kt, kr, kd) and hw/L for (X shape) versus (H shape) with relative structure height(hs/hw=0.9)

7 CONCLUSIONS

Precast concrete 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, the interaction between regular waves and fixed submerged breakwaters has been investigated numerically thus the conclusions from the present research is investigated observing that increasing the relative structure height increases the reflection coefficient and decreases the transmission coefficient while the wave energy dissipation coefficient increases gradually until reaching its optimum value at relative structure height = 0.9 then it decreases gradually. For the same diameter, the hydrodynamic efficiency of half pipe in normal position is better than the half pipe in inverse position as a half pipe in normal position gives transmission coefficient less by average value= 13.3% and gives wave energy dissipation coefficient more by average value =7.9%. The hydrodynamic efficiency of two half pipes, joined together in a vertical position X shape is better than that of two half pipes joined together in horizontal position H shape as (X shape) gives transmission coefficient less by average value =8.2%. and gives wave energy dissipation coefficient more by average value =2.7%. Keeping in consideration that the experimental results from (Rahman, M. et. al. (2013)) [12] which carried out experimentally on rectangular submerged breakwaters are carried out numerically by (FLOW-3D) program which showed a good agreement in results where the average difference between them during fifteen run conditions =3.18 % which ensures the efficiency of using this analysis program.

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