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Wave transformation behind permeable breakwater

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Abstract— This research is designed to find out wave transmission coefficient Kt for three different models of pile breakwaters in coastal area. The selected breakwater models are: pile breakwater, horizontal rectangle strips fixed to piles, and horizontal c-channel strips fixed to piles. Experimental tests were conducted under perpendicular regular waves with various wave characteristics and pile breakwaters geometry. The considered dimensionless parameters are wave steepness Hi/gT^2, relative spacing between piles G/D, relative spacing between row of piles ¢ to ¢ S/D, relative spacing between strips C/W, and arrangement of strips A. The results depicted that Kt decreases with the increase of Hi/gT^2, S/D, and with the decrease of both G/D and C/W. The performance of model 1 was improved by adding horizontal c-channel strips with staggered arrangement and which resulted in decreasing Kt value by about 24.7 %. Empirical relations were derived by analyzing experimental data. This technique can be utilized to predict the performance of the selected models for different wave characteristics and models geometry. Also there are reasonable agreement between results of selected model and other previous similar studies.

Key words : transmission coefficient, pile breakwater, regular waves.

1 INTRODUCTION

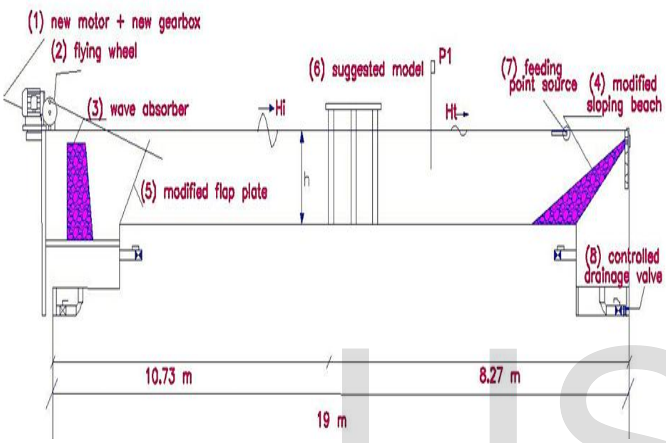
Pile breakwaters comprising of one or multiple rows of piles parallel to each other driven into seabed, are partially attenuate wave energy due to the turbulences and eddies created around piles. As turbulences and eddies increase, wave dissipation increases thus wave transmission decreases. The efficiency of any breakwater is determined by the amount of transmitted wave energy. The efficiency of pile breakwaters was studied by many researchers under regular waves; **Heikal et al., 2007**, **koraim, 2011** tested one row of vertical piles experimentally. **Elsharabasy et al., 2011** examined the hydrodynamic different types of breakwater performance experimentally. Pile breakwater tested in this study with different Hi/gT^2, h/L, G/D, S/D. The results revealed that Kt decreased with increasing Hi/gT^2, S/D and with decreasing G/D. **koftis et al., 2012** investigated multi row of staggered piles (2, 4, 6) in three cases (emerged, at water level, submerged case) to measure wave transmission coefficient Kt. Other researchers investigated the performance of pile breakwater under irregular waves such as; **Yoo et al., 2010** studied experimentally the hydrodynamic performance of three rows of vertical piles with staggered arrangement, **Nejadkazem and Gharabaghi, 2012** and **Nikoo et al., 2014** studied two rows of piles experimentally and numerically and investigated the effect of wave characteristics and model geometry such as G/D, S/D, and arrangement of piles A on its performance. In the current study, the experimental investigation are carried out to improve pile breakwaters efficiency by adding horizontal strips for increasing wave dissipation. Horizontal rectangle and c-channel strips fixed to piles are considered. Other previous researchers suggested solutions for improving pile breakwaters performance: **Laju et al., 2011** presented analytical solution based on Eigen function expansion method to estimate the behavior of single and double impermeable skirt breakwater supported with array of circular piles and experimental tests are carried out to valid from results. **Shih, 2012** conducted experimental tests on porous perpendicular pile breakwater with different wave characteristics and structure parameters such as pipe diameter (D) and pipe length(B) to estimate hydrodynamic performance of proposed breakwater. **Elsharnouby et al., 2012** proposed analytical solution to calculate transmission coefficient Kt of double porous curtain wall consisting of horizontal strips supported with a row of piles with different parameters like diameter of pipe D, vertical spacing between strips C, width of strips W and spacing between pile in row G. The results showed that the proposed breakwater in this study performed well where it can significantly decrease wave height and dissipate its energy. **Koraim, 2014**, and **Koraim et al., 2014** studied pipe suspended horizontal L-shaped or c-channel strips in terms of Kr, Kt, Kd theoretically and experimentally under perpendicular regular waves. The results showed that Kt decreased with increasing h/L (relative depth), dr/h (relative draft), D/h (relative diameter) and with decreasing εp (porosity of piles), εs (porosity of c or L strips). **Ibrahim et al.,2017** examined hydrodynamic efficiency of horizontal half pipe (H-shaped) and vertical half pipe (C-shaped) supported with pile with different porosity 56, 68 and 81% experimentally and numerically under regular waves. **Pereira et al., 2018** suggested reusing waste materials by examining the hydrodynamic performance for porous box type comprised of multi-scrapped pipes. The parameters like porosity ε, breakwater width B/L, and pipe length d/l (d is breakwater height, l is pipe length) were tested experimentally under perpendicular regular waves. From previous studies, it is concluded that porosity of these structures is the important parameter, that affect their performance.

The scope of the current study is to improve pile breakwaters performance, and to investigate the influences of wave characteristics and pile breakwater configurations on Kt. Empirical relationships are developed through this study to predict Kt values for different cases.

2 Experimental setup

2.1 Wave flume

Developed wave flume is 19m long, 1m wide,1m deep and consist of flap wave generator that is generated perpendicular regular waves. Wave absorber is with slope 1:7 at the end of the flume and gravel screen filled is at the other end to prevent reflection and re-reflection waves from wave generator and wall of the flume. Wave flume is provided with feeding point source and controlled drainage valve to reach the desired water depth. The wave flume description is shown in figure (1).



Figure(1) : wave flume Description

2.2 Model scale

The geometrical scaling model can be primarily based on Froude scale. The current study was conducted in the laboratory for a constant water depth of 0.50 m, and wave period ranging from 0.75: 1.65 s. These ranges are corresponded to prototype to 5: 10 m water depth, and 2.9: 6.4 sec wave period. The selected experimental models are shown in plate 1.

2.3 Tested models

The current study look into three different models of breakwater and tested under constant water depth. Model 1 is consist of three row of vertical circular piles with constant diameter D= 0.033 m and with variable spacing between them ¢ to ¢ S=0.23, 0.28, 0.33 m. The spacing between piles in row (as called G) is also variable and G= 0.225, 0.254, 0.3 m. Model 2, model 3 is horizontal rectangle and c-channel strips respectively fixed to piles with dimensions; width b = 0.005 m (fixed) and height of strips W= 0.1, 0.15, 0.2 m (variable). The spacing between strips C are also variable, C = 0.0388, 0.0314, 0.0238 m. The arrangement of strips is also variable, parallel and staggered. The height of horizontal strips is (Hi max/2) above the water surface to reduce wave overtopping. In models 2, 3, the spacing between rows of piles ¢ to ¢ is constant, S= 0.33 m whether spacing between piles G is variable, G= 0.225, 0.254, 0.3 m. The models dimensions is clarified in figure (2).

Plate (1): Proposed experimental models

2.4 Wave characteristics

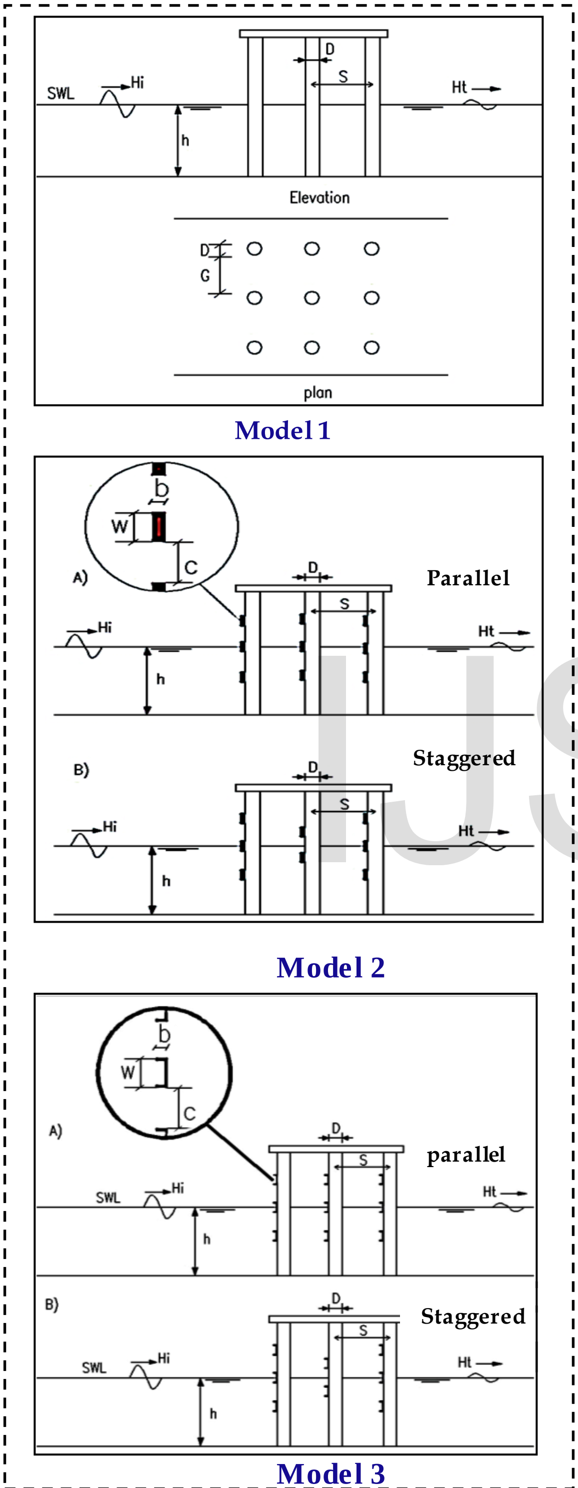
The experimental tests were conducted under perpendicular regular waves with wave period (T) ranging from 0.75: 1.65 s. These wave periods enhance wave length (L) ranging from 275 to 110 cm and incident wave height (Hi) varied from 4.38 to 10.77cm. A summary of wave characteristics are provided in table 1.

2.5 Run producers

Incident wave height, Hi was measured without models by utilizing Mobil camera to record video duration 30 to 60 sec of the wave with the most in mind the installation of the camera perpendicular in front of the selected vertical position to prevent any vacillation in the results. By using slow motion techniques of the recorded video on the computer program, the average wave height value can be obtained.
Behind pile breakwater models at distance 1 m was measured transmission wave height (Ht) at vertical specified position P1 in order to prevent the effect of turbulences re-

sulted from wave overtopping. Wave transmission coefficient Kt, can be calculated from the following ;

$$Kt = Ht / Hi \qquad (1)$$



Figure(2): Models dimensions.

Table 1: Wave characteristics:

Wave characteristics	Ranges
Wave period (T)sec	1.65 : 0.75
Wave height (H)cm	4.38: 10.77
Wave steepness Hi/gT^2	0.00164 : 0.01957
Wave Length (L)cm	275 : 110
relative depth (h/L)	0.18: 0.45
water depth Zone	Transition zone

2.6 Dimensional analysis

Dimensional analysis is performed to constitute dimensionally homogeneous relation by determination the relationship among various parameters related to the phenomena irrespectively the system of the units used. By applying dimensional analysis and deleting constant parameters, the following relation could be obtained:

$$Kt = f(Hi / gT^2, G / D, S / D, C / W, A) \qquad (2)$$

Where ; Hi/gT^2 : wave steepness, G/D: relative spacing between piles, S/D: relative spacing between row of piles ¢ to ¢, C/W: relative spacing between strips, andA : arrangement of strips.

2.7 Model conditions

The experimental models were studied with various wave periods, wave heights and pile breakwaters geometry. The conditions of the tested model are described in table 2. To achieve the objectives of this study, almost three hundred runs (300) were done to determine wave transmission coefficient Kt. Measurement of wave transmitted height values are achieved at distance 1m behind pile breakwater. The selected model is placed at distance 10.73 from wave generator.

Table 2: Model conditions:

S/D	G/D	C/W	A
6.897	8.996	4.385	Parallel or staggered
8.396	7.706	2.59	
9.895	6.747	1.693	

3 Results analysis and discussion:

The impacts of various wave characteristics and models geometry on the performance are analyzed in curves form. Kt values were plotted with various wave steepness $Hi/(gT^2)$ values, where g and T are gravitational acceleration and wave period, respectively. The trend line type for all curves is determined as second degree polynomial.

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3.1 Model 1

The transmission coefficient Kt is plotted with Hi/(gT^2) values with different G/D at S/D= 6.879, 8.396, 9.895 and are showed in figure 3 (a, b and c). The results find that Kt decreases when Hi/(gT^2) increases. The reason for this is when wave steepness increases, wave velocity and acceleration increases, when the wave collides with pile breakwater, wave velocity and acceleration varied suddenly and create turbulence resulted in increasing wave dissipation and decreasing wave transmission. It is noted that at G/D=6.747 and S/D= 9.895 when wave steepness Hi/(gT^2) increases from 0.002 to 0.02, Kt decreases from 0.976 to 0.88. At small values of Hi/(gT^2) where waves are long, there is not remarkable differences in Kt values but when Hi/(gT^2) increases where waves become shorter, the differences in results of Kt values increase. In these figures, the effect of variation G/D, S/D in studied range on Kt is examined and the results declared that in general, Kt decreases with decreasing G/D but the difference is not great. The range of G/D in this study is not sufficient to make remarkable change in Kt. Kt decreases with increasing S/D except at G/D=6.747, Kt decreases with increasing S/D until S/D=8.396 and then increases with increasing S/D. Case in point, at G/D = 6.747, Kt decreases from 0.975 to 0.878, from 0.966 to 0.875, from 0.974 to 0.876 with rising wave steepness Hi/(gT^2) from 0.002 to 0.02 for S/D = 6.897, 8.395, 9.895 respectively. The performance of breakwater is not satisfied where the lowest value of Kt is 0.875.

3.2 Model 2

Figure (4) clarified the relationship between transmission coefficient Kt and Hi/(gT^2) for different G/D and C/W at S/D= 9.895 for parallel and staggered rectangle strips. The results reveal that Kt decreases with increasing Hi/(gT^2) and with decreasing G/D and C/W for parallel and staggered arrangement. The reason of this is when C/W decrease, area that supposed to wave across from it also decrease thus turbulences increase and Kt decreases. The performance of piles is improved by adding horizontal strips and decreased Kt value by about 13.83 %. Form comparison between parallel and staggered arrangement of horizontal rectangle strips, it is noted that the efficiency of this selected model is improved at staggered arrangement. The effect of arrangement increases with increasing Hi/(gT^2) and with decreasing C/W. As Hi/(gT^2) rise from 0.002 to 0.02, Kt decreases from 0.991 to 0.804, 0.98 to 0.793, 0.971 to 0.780 for parallel arrangement and from 0.982 to 0.793, 0.972 to 0.779, 0.966 to 0.760 for staggered arrangement at C/W= 3.885, 2.09, 1.193. Staggered arrangement reduce Kt by about 2.4 % for G/D=6.747, C/W=2.59 and Hi/(gT^2) =0.02 than parallel arrangement. The best value of Kt is 0.754 that achieved at small C/W and G/D for staggered arrangement.

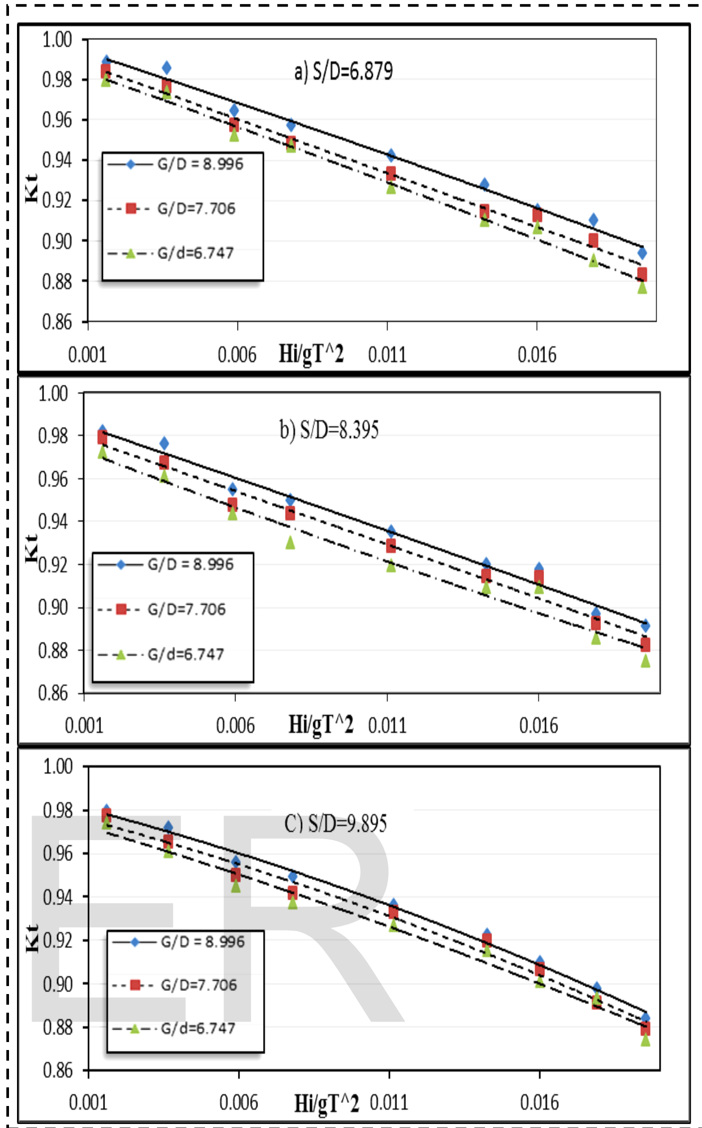

Figure (3):The relationship between transmission coefficient Kt and wave steepness Hi/(gT^2) for different G/D.

3.3 Model 3:

The relationship between transmission coefficient Kt and wave steepness Hi/(gT^2) for different G/D and C/W at S/D= 9.895 are displayed in figure (5) for parallel and staggered c-channel strips. The results depict that Kt decreases with increasing Hi/(gT^2) and with decreasing G/D and C/W for parallel and staggered arrangement. It is found that at S/D= 9.985, G/D= 7.706, parallel arrangement, Kt decreases from 0.976 to 0.739, from 0.974 to 0.792 and from 0.972 to 0.766 as Hi/(gT^2) increases from 0.002 to 0.02 at C/W=3.885, 2.09, 1.193 respectively. The performance of piles is greatly improved by adding c-channel strips and decreased Kt value by about 24.7 %. The results of parallel and staggered arrangement of horizontal c-channel strips were compared, and it is found that staggered arrangement enhance less Kt values than parallel arrangement. The effect of arrangement increases with arising Hi/(gT^2) and with decreasing C/W. For example, at G/D=8.996 and C/W=3.885, Kt decreases from 0.978 to 0.769 and from 0.975

to 0.766 but as C/W decreases to 1.193, Kt decreases from 0.975 to 0.713 and from 0.97 to 0.699 with increasing $Hi/(gT^2)$ from 0.002 to 0.02 for parallel and staggered arrangement respectively. The best value of Kt is 0.659 that can be achieved for staggered arrangement at small value of C/W and G/D.

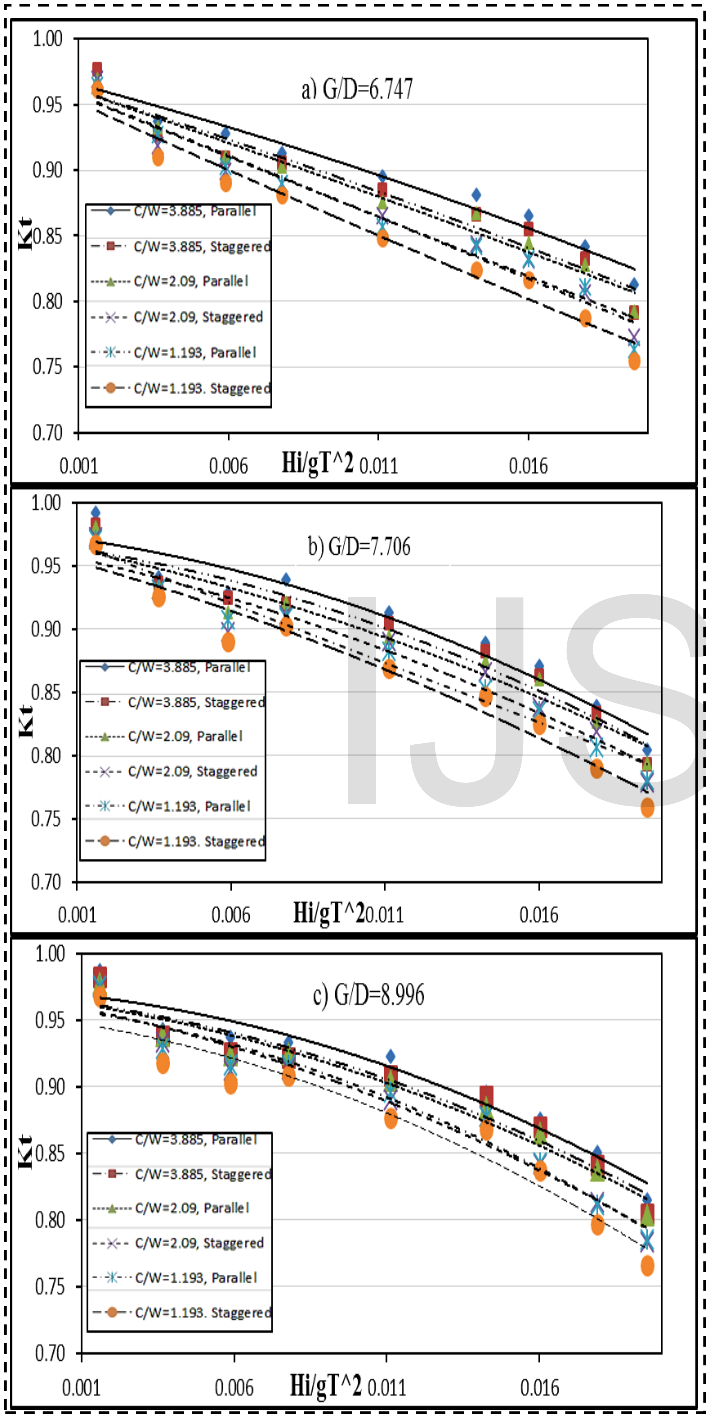

Figure (4): The relationship between transmission coefficient Kt and wave steepness $Hi/(gT^2)$ for different C/W and arrangement at S/D= 9.895 for rectangle strips.

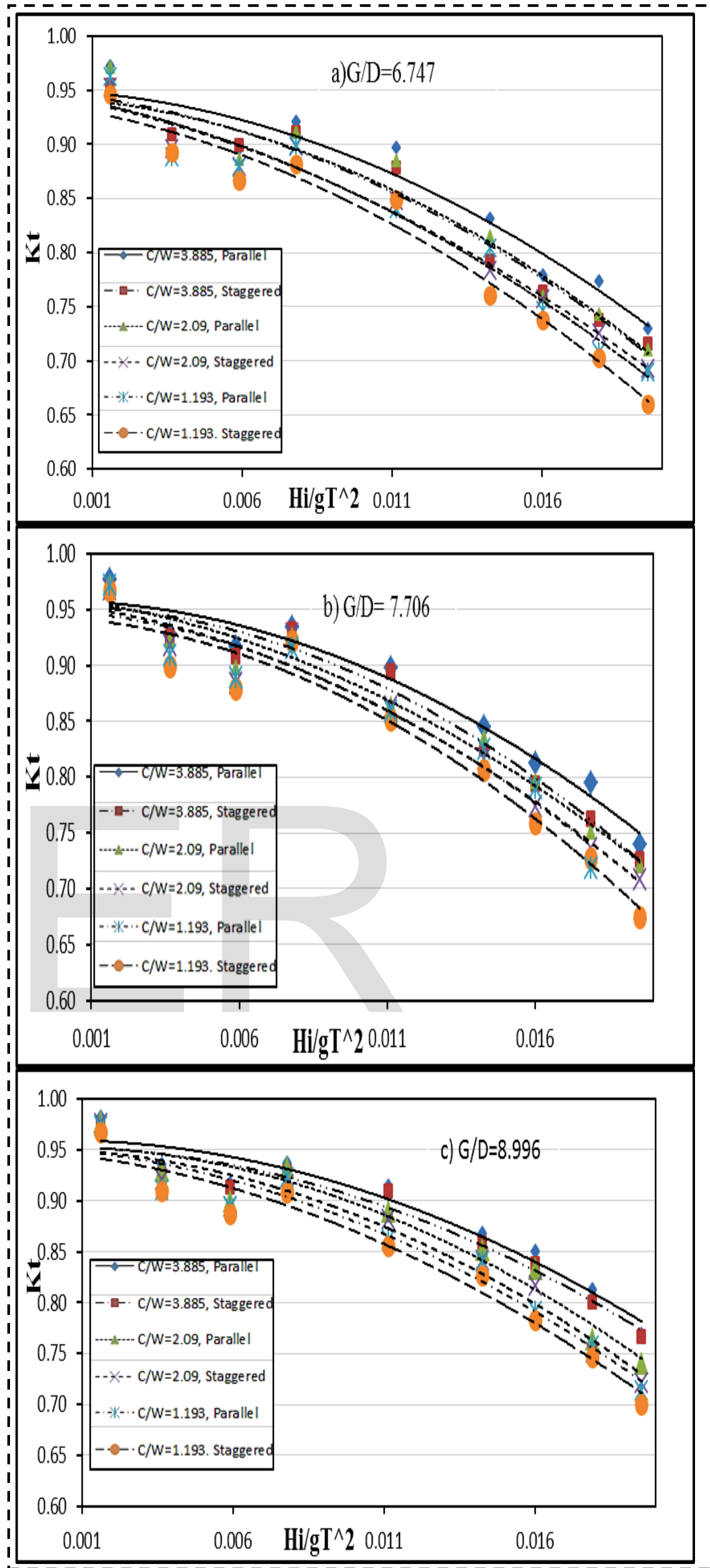

Figure (5): The relationship between transmission coefficient Kt and wave steepness $Hi/(gT^2)$ for different C/W and arrangement at S/D= 9.895 for c-channel strips.

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3.4 Empirical Relations

Empirical relations were represented by analyzing experimental data. This technique is utilized to predict the performance the selected models for various wave characteristics and models geometry. Statistical Package for the Social Sciences (SPSS) program was used for analyzing the results. The dimensionless parameters are investigated to estimate simple linear empirical relations to predict transmission coefficient for each model. The Empirical relations for each model are showed in Table 3:

Table 3 : Empirical Linear relations:

Model no.	Kt (linear expression)	R^2
1	$Kt = 0.959 - 5.01\frac{Hi}{gT^2} - 0.002\frac{S}{D} + 0.005\frac{G}{D}$	0.9774
2	Parallel $Kt = 0.91 - 8.46\frac{Hi}{gT^2} + 0.006\frac{G}{D} + 0.009\frac{C}{W}$	0.938
	Staggered $Kt = 0.89 - 8.85\frac{Hi}{gT^2} + 0.007\frac{G}{D} + 0.01\frac{C}{W}$	0.927
3	Parallel $Kt = 0.864 - 12.35\frac{Hi}{gT^2} + 0.012\frac{G}{D} + 0.012\frac{C}{W}$	0.911
	Staggered $Kt = 0.861 - 13.05\frac{Hi}{gT^2} + 0.015\frac{G}{D} + 0.011\frac{C}{W}$	0.937

The analyzed results are distributed on line with angle 45^0 to assess the agreement with observed and estimated Kt. The figure (6) appeared that the correlation between the results is acceptable.

3.5 Verification with other experiments and theories

Figure 7 presents a comparison between the results of model 3 (the best efficiency) with S/D=9.986, G/D=6.747, C/W= 1.193 and staggered arrangement, and those obtained by other previous studies. The figure shows that, kt decreases with the increase of Hi/gT^2 for all the results and there is high scatter in the performance of the different compared models. This can be due to the difference in the models conditions and cross sections shapes.

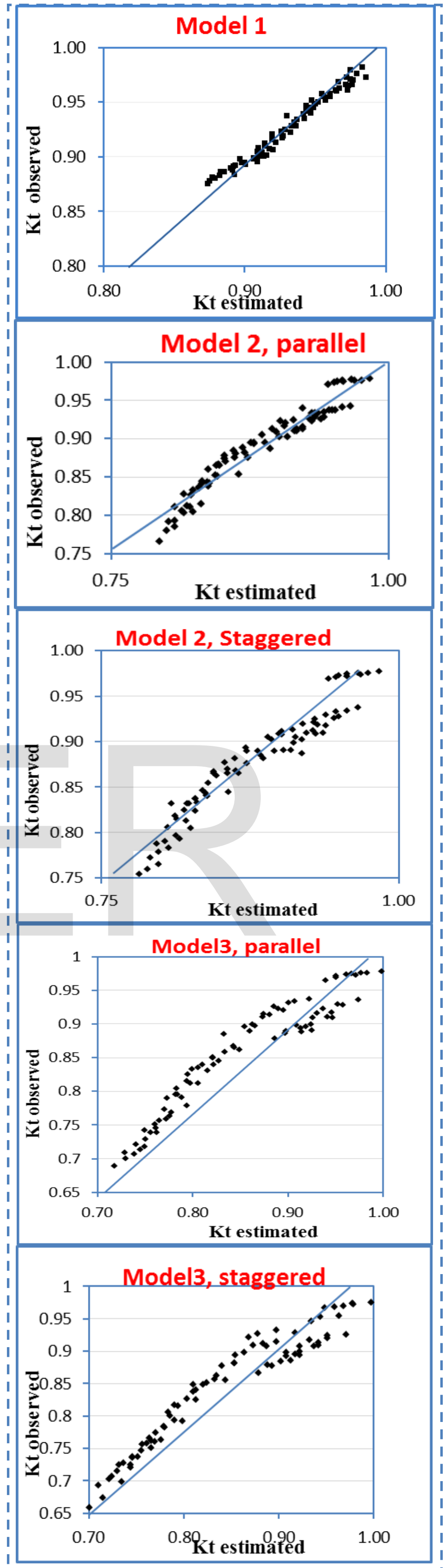

Figure 6: The acceptance between observed and estimated results for present suggested models.

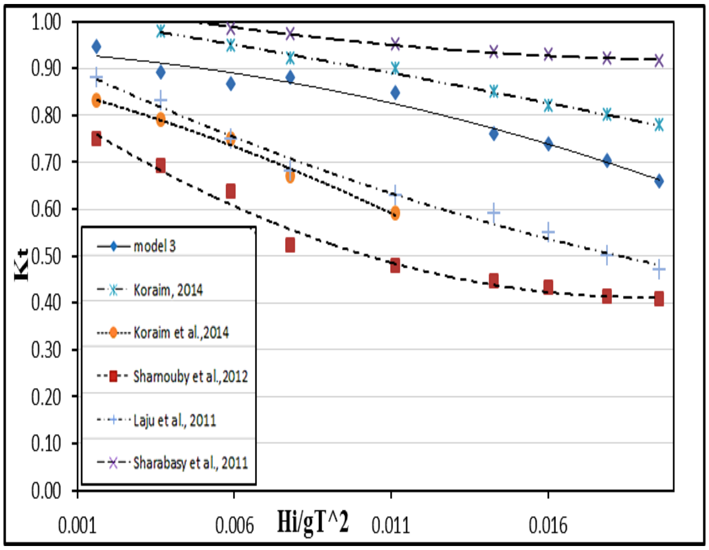

Figure 7: Comparison between the performance of the present different models and other types investigated by different authors.

4. Conclusions and Recommendations:

The present study looked into the performance of three different models of pile breakwater experimentally under regular waves in intermediate water depth by evaluating transmission coefficient Kt. Three models suggested: pile breakwater, horizontal rectangle strips fixed to piles, and horizontal c-channel strips fixed to piles. The following conclusions can be drawn:

- In general, the results revealed that Kt decreases with increasing Hi/gT^2, S/D, and with decreasing both of G/D and C/W.
- For model 1, its efficiency wasn't satisfied where the lowest value of transmission coefficient, Kt was 0.875 so horizontal strips for model 2 and 3 was used to improve its performance.
- For model 2, 3, Kt decreases with increasing Hi/gT^2 and with decreasing G/D, C/W for different arrangement A (parallel or staggered). The performance of model 1 was improved by utilizing horizontal rectangle and c-channel strips to reach Kt value by about 0.754, 0.659 respectively.
- Model 3 with staggered arrangement can be reduced Kt value by about 24.7% so it provides the best efficiency among three models. It prefer when the water depth increases because of its low construction cost. It can also be quickly and easily adjusted according to any possible environmental changing.

List of symbols

L: Wave length
T: Wave period
Hi: Incident wave height
Ht: Transmitted wave height
Kt: Transmission coefficient
h: Water depth
D: Diameter of piles
G: Spacing between piles
S: Spacing between rows of piles ¢ to ¢
C: Spacing between strips
W: Height of strips
b: width of strips
A: Arrangement of strips

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