WAVE INTERACTION WITH SINGLE AND TWIN PONTOONS

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ABSTRACT

The hydrodynamic interaction of regular waves with floating breakwaters (FBs) in intermediate and deep water is examined experimentally. Two different FBs configurations are examined: (a) Single fixed FB and (b) twin fixed FB. The influence of incident wave characteristics and certain geometric characteristics, such as, breakwater width, breakwater draft and Gap between two pontoons on the efficiency of breakwaters is examined. This efficiency is presented as a function of the transmission and reflection coefficient. It was found that the transmission coefficient (K_t) decrease with increasing the relative breakwater draft, di/d, increasing the relative breakwater width B/d, and decreasing the relative gap between two pontoon (a/b).While, the reflection coefficient (K_r) increases with increasing the relative breakwater draft (d_i/d), the relative breakwater width B/d, and increasing the relative gap between two pontoon (a/b). In addition, no significant difference are observed between single and double pontoon when a/b=1.0 and d_i/d greater than 0.20 .By using nonlinear regression analysis, the equations were obtained to calculate the transmission coefficient, K_t, and reflection coefficient, K_r. Also, the proposed breakwater models are satisfactory compared with other previous works.

1. INTRODUCTION

The requirement of any harbor or marina is a water area free from attacking waves. In the coastal areas where natural protection from waves is not available, the development of a harbor requires an artificial protection for the creation of calm areas. For large harbours are required, large structures such as rubble mound breakwaters or vertical wall breakwater are used. However for small recreational harbours or fisheries harbours, and marinas at location where large littoral drift and onshore-off shore sediment movement exists, alternative types of breakwater such as piled structures or floating breakwaters are used. Such a structure cannot stop all the wave action. The incident wave is partially transmitted, partially reflected and partially dissipated. Energy is dissipated due to damping and friction and through the generation of eddies at the edges of the breakwater. Rectangular pontoon is known to be the most common and simplest design in the history of the floating breakwaters. It was reported that rectangular pontoons performed satisfactorily and gave high degree of wave attenuation than most of the existing types of floating breakwaters. Two types of mooring are typically used to restrain the floating breakwater motions, either piles or mooring lines. Floating breakwater anchored with chains or cables have some disadvantages such as large roll motion and secondary wave generation at the lee ward side of the structure due to sway motion. Therefore, in this research are placement of the mooring system with piles instead of mooring lines can be beneficial. Such system may overcome the problem of sway motion, which is prevented in this case by piles, and in addition the roll motion is limited due to the existence of the piles.

2. LITERATURE REVIEW

Several configurations for the FBWs have been studied experimentally and theoretically by many of the investigators. **Tolba (1998)** studied experimentally and theoretically the performance of rectangular floating breakwaters. The suggested models were restrained model, limited roll motion model, heave motion model, and floating model connected with vertical plate.**Bhat (1998)** studied experimentally and numerically the hydrodynamic performance of a moored twin-pontoon floating breakwater made up of either rectangular or circular section pontoons.**Sonnasiraj et al. (1998)** studied experimentally and theoretically the behavior of a single pontoon-type floating breakwater with three different types of mooring configurations, mooring at water level, mooring, at base bottom and cross moored at base bottom level. **Koutandos et al. (2002)** presented numerically the efficiency of moored floating breakwaters using the finite-difference technique.**Neelamani and Rajendran (2002**)studied experimentally the behavior of partially submerged “T” type and “⊥“type breakwaters under regular and random waves.**Neelamani and Vedogiri (2002)**investigated the behavior of partially immersed twin vertical barriers and the water surface fluctuations in between the barriers under regular and random waves.**Briggs et al. (2002)** presented an integrated study of analytical, numerical, laboratory and field experiments for a floating breakwater with two legs in a “V“shape in plan view that provide a sheltered region from waves and currents.**Sundar et al. (2003)** studied experimentally the hydrodynamic performance characteristics of a floating pipe breakwater model.**Gunaydin and Kabdasli (2004)** studied experimentally the performance of solid and perforated U-type breakwaters under regular and irregular waves.**Gesraha (2004)** studied an analytical solution for the wave interaction of a floating flexible pontoon using eignfunction expansions method.**Usha and Gayathri (2005)** investigated analytically the wave reflection and transmission over a horizontal twin-plate structure based on the linear potential wave theory.**Loukogeorgaki and Angelides (2005)** studied theoretically the performance of a moored floating breakwater under the action of regular waves.**Koutandos et al. (2005)** examined experimentally Four different floating breakwaters configurations are; single fixed FB, heave motion FB, single fixed FB with attached front plate (impermeable and permeable), and double fixed FB**.Rageh et al. (2006)** studied experimentally the wave transmission through the floating breakwater which consists of one, two or three rows of spherical floating bodies having different diameter and draft. **Wang et al. (2006)** studied experimentally the performance of floating breakwater which consists of several horizontal plates under regular wave.**Chaiheng (2006)** studied experimentally the performance of the steeped- slope floating breakwater system.**Gunaydin and kabdasli (2007)** studied experimentally the performance of solid and perforated π-type breakwater under regular and irregular waves. **Hedge et al. (2008)** studied experimentally the forces in the moorings of horizontally interlaced, multi layered; moored floating pipe breakwaters**.Martinelli et al. (2008)** studied experimentally the behaviour of floating breakwater for different degrees of complexity (I- and J- shaped), and three obliquilities (0,30^0, 60^0).**Dong et al. (2008)** studied experimentally the wave transmission through three types of breakwater under regular waves with or without currents. Three types were the single box, the double box and the board net.**Rageh (2009)** studied experimentally the performance of floating breakwater which consists of floating body and partition walls with different configurations were installed vertically downward to enhance the strength of the structure.**Ozeren (2009)** studied experimentally and numerically the performance of the floating breakwater comprises single or multiple cylindrical sections with different mooringconfigurations.**Tsoukala and Moutzouris(2009)** investigated experimentally the wave transmission through flushing culverts.

3. EXPERIMENTAL WORK

3.1 Effect of surface tension, internal friction and boundary friction

Surface tension tends to increase the velocity of the propagation of surface waves. According to Hughes (1993), surface tension effects must be considered when wave periods are less than 0.35 sec and when water depth is less than 2 cm. the physical model tests in the present study were carried out on a constant water depth of 40 cm and with wave period greater than 0.35 sec, the effects of surface tension is considered negligible. Also, water waves are also attenuated by the internal friction and by viscous boundary layer friction caused by the water viscosity. According to (chanieug, 2006), the calculation showed that wave attenuation due to internal friction and boundary friction are very small and nearly negligible.

3.2. Model Scale

In according with the experimental facilities and instruments of the laboratory and the tested wave condition, we used a geometrical similar model scale 1:25 for the selection of models dimension and wave properties in the present study according to Froude scaling. Therefore studies are carried in the laboratory for a constant water depth of 0.4m, which corresponds to 10 m water depth in the prototype which is a suitable depth for suggested mooring system in this study.

3.3. Test Facility

Several experiments were carried out in a wave flume 15.10 m long, 1.0 m wide and 1.0 deep in the Irrigation and hydraulic laboratory of the faculty of Engineering, El-Mansoura University, Egypt. A flap type wave generator was used to displace the water in the flume to get the desired wave characteristics. This wave generator was installed at one end of the flume. Two wave absorber was used to prevent the reflection of wave from the far end of the flume to increase the efficiency of the wave experiments and to reduce the time required between runs while the water calm down. The first absorber was placed in the front of the wave generator. While, the other absorber has a 1:7 sloping beach installed at the end of the flume, the experiments were carried out with a constant water depth, (d) of 0.40m and with generator motions corresponding to regular wave trains with different nine wave periods T=0.62 , 0.66 , 0.74 , 0.80 , 0.90, 1.00, 1.06, 1.12 and 1.2 s.

3.4. Model details

The tested models were placed at the middle of the wave flume. The first model consists of a single box fabricated by using a hardwood of thickness (3) cm and it was fixed rigidly between the side walls of the wave flume. The other model consists of double-box includes two identical single boxes connected by rigid thin boards and has the same exterior dimension as the single-box system. The details of the tested breakwater models are shown in figure (1).

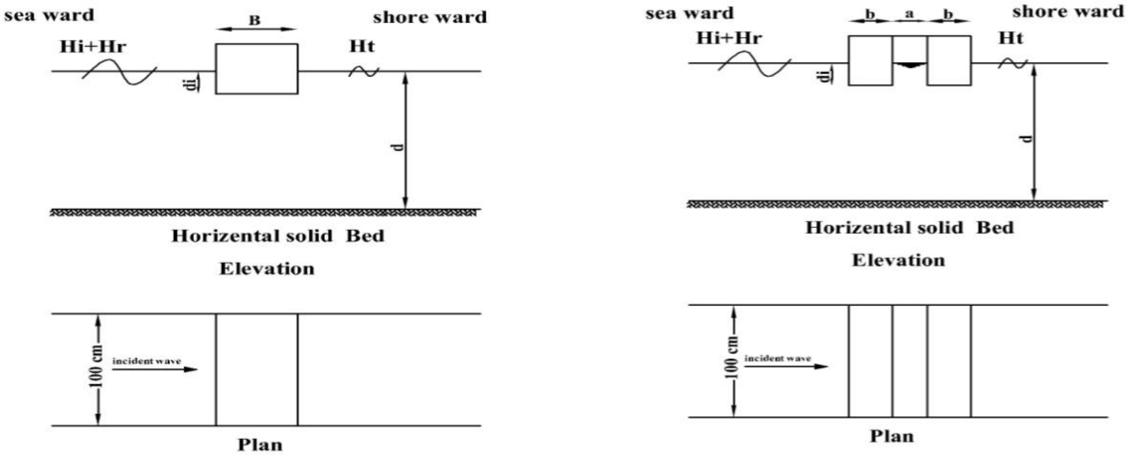


Fig.1.Details of the tested breakwater models.

3.5. EXPERIMENTAL CONDITIONS

The experimental setup details and the dimensions of the breakwater models are shown in Table (1) and table (2).

Table (4.1): Experimental setup parameters for single fixed floating breakwater.

Parameter	**Ranges**	**Notes**
Water Depth (cm)	40	at the breakwater site
Water period (T) (sec)	0.62, 0.66, 0.74, 0.80, 0.9, 1.0, 1.06, 1.12, 1.2	
Wave Length (L) (cm)	60 to 200	at the breakwater site
Breakwater width (B) (cm)	15,20,25,30	
Depth of immersion (di) (cm)	4,8 and 12 cm	

Table (4.2): Experimental setup parameters for double fixed floating breakwater.

Parameter	Ranges	Notes
Water Depth (cm)	40	at the breakwater
Water period (T) (sec)	0.62, 0.66, 0.74, 0.80, 0.9, 1.0, 1.06, 1.12, 1.2	
Wave Length (L) (cm)	60 to 200	at the breakwater
Breakwater width (b) (cm)	5	
Distance between breakwater (a) (cm)	5, 10 and 15	
Depth of immersion (di)(cm)	4, 8 and 12	

3.6. INSTRUMENTATION

3.6.1. Measuring Means

Vertical scales with accuracy of 1.0 mm fixed along the Perspex part used to measure the wave characteristics. Two vertical scales were positioned in front of the breakwater model (wave generator side) at different locations according to Goda and Suzuki (1976). While, one vertical scale was selected the behind of the breakwater model (wave absorber side) to measure the transmitted waves. The wave characteristics were recorded by using digital camera (auto focus 5 mega pixel) connected to a personal computer was used for analyze the wave data by using computer program.

3.6.2 Wave Height Measurement

The water level variation which is resulted from the wave-structure interaction was recorded by using digital camera (auto focus 5 mega pixel). The camera zoom was adjusted exactly perpendicular to the linear scale on the glass flume side at each recording positions. The used camera was fixed on vertical stand to avoid the variations of the vedio shots. The recording time for each run is about 2.5 the time required for a generated wave to travel from wave generator to the recording position. By using a slow motion technique (e.g. codec) which divides the second into thirty fractions, the recording waves taken by the camera can by analyzed and then, the wave elevation with the time can be drawn. The vertical distance between the heights and the lowest elevation represents the incident wave height (Hi), In case of the absence of the model. While, to measure the reflected (Hr) wave heights, two recording positions (P2 and P1) were determined in front of the breakwater model (wave generator side) at distances 0.2L and 0.45L respectively. This is according to the two point method of Goda and Suzuki (1976) (the distance between the two positions ranging from 0.05-0.45L). These two vertical scales were positioned to meet maximum and minimum of standing wave envelop. After recording the water surface elevations at two vertical scales by using the camera, the following relationship were used as follow:

Hmax= max wave height at the antinodes =max crest level-min through level (1)

Hmin= min wave height at the nodes = min crest level-max through level (2)

Where;

$$H_{max} = H_i + H_r \quad (3)$$

$$H_{min} = H_i - H_r \quad (4)$$

The reflection coefficient (Kr) is the ratio of reflected and incident wave height, therefore

$$K_r = H_r / H_i \quad (5)$$

Depending on the equations (3), (4), (5)

$$K_r = \frac{H_{\max} - H_{\min}}{H_{\max} + H_{\min}} \quad (6)$$

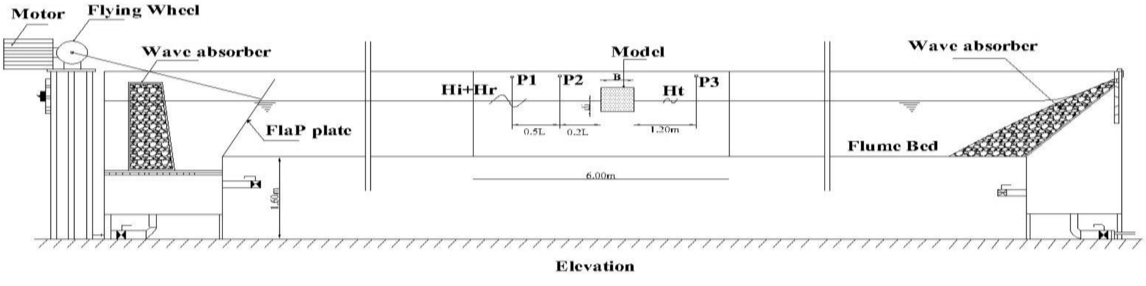
Hence, the significant reflected wave height is computed using the relationship as follow:

$$H_r = K_r * H_i \quad (7)$$

Also, to measure the transmitted wave heights (Ht), one recording position (Ps) was positioned behind the breakwater model at a distance (1.2m) according to (chaiheng 2006). The data were analyzed as shown in equation (8) and the average of those wave heights was taken to be transmitted waves.

Ht = transmitted wave height = max crest level-min through level. (8)

The details of wave flume, position of the tested breakwater model and location of wave recording are shown in Figure 2.



3.7. Reflection, Transmission, and Energy Dissipation coefficient

The reflection (Kr) coefficient can be estimated from the above-mentioned equation (5). While, the transmission coefficient (Kt) can be estimated from the experimental data as follow:

$$K_t = H_t / H_i \quad (9)$$

In practice, when the wave reaches the structure, some of the wave energy dissipated by the structure it self. This dissipation part of the wave energy can be estimated as a function of the reflection and transmission coefficients as given by Reddy and Neelamanit (1992):

$$KL = \sqrt{1 - K_t^2 - K_r^2} \qquad (10)$$

In which KL is the wave energy dissipation coefficient.

4. EXPERIMENTAL RESULTS AND ANALYSIS

Many parameters affecting the breakwater performance and studied such as the wave length, (L), the wave period, (T), The Wave Height, (H_i), The breakwater width (In case of Single pontoon), (B), The breakwater width (Incase of Twin Pontoon), (b), the Gap between twin Pontoon, (a), the breakwater draft, (d_i)and the water depth(d). the analysis presents the efficiency of the breakwater in the form of relationships between transmission, reflection, and energy dissipation coefficients (K_t,K_r,K_L) and the dimensionless parameters represent the wave and structure characteristics as in the following equation:

$$K_t,\ Kr \text{ and } K_L = f\ (B/d,\ d_i/d,\ a/b,\ H_i/L,\ d/L) \qquad (11)$$

Using the above dimensionless parameters, Non-linear regression analysis was carried out using SPSS13 (SPSS Inc, 2004) software. Empirical equations for estimating the transmission and the reflection coefficients are developed as follows:

For single fixed pontoon

$$Kt=0.001(di/d)^{-2.106}+0.779(d/L)^{0.412}-2.904(Hi/L)^{0.531}+0.526(B/d)^{-0.308}. \qquad R2=0.956 \qquad (12)$$

$$Kr=-0.000028(di/d)^{-3.325}+1.382(d/L)^{-0.006}-0.23(Hi/L)^{-0.39}+6.237(B/d)^{18.87}. \qquad R2=0.884 \qquad (13)$$

For double fixed pontoon

$$Kt=0.686(di/d)^{-0.169}+14.042(d/L)^{17.57}-1.938(Hi/L)^{0.354}+0.334(a/b)^{0.271}. \qquad R2=0.917 \qquad (14)$$

$$Kr=-0.024(di/d)^{-0.741}-1.02(d/L)^{6.16}-23.372(Hi/L)^{-0.012}+24.859(a/b)^{0.003}. \qquad R2=0.992 \qquad (15)$$

Fig.3 shows sample of data at the three wave recording positions P1,P2,P3 for the case of an incident wave with frequency f=2.5HZ (T=1.20sec) at the breadth of floating breakwater model of 30cm and relative draft di/d=0.30.Fig3a, and Fig3b shows the sample of data for previous case at the two vertical scales of the standing wave, the two vertical scales were installed in front of the model (P1andP2).It is clear in the figure that in the period between 0.0 and 5.0sec, the wave travel from the wave generator side to the position of two measuring points. In the period between 5.0 and 9.0sec, the incident wave passes the two measuring points and reflects from the upward face of the model and the standing wave begin to build its shape. in the period between 9.00 and 12.0sec, some disturbances take- place for the standing wave, after that the standing wave tends to be stable which is the period of the time between 12.0 and 21.0sec. This period is the suitable time for analysis and gives the exact values of the reflection coefficient, Kr. Subsequently, the shape of the standing wave changes due to the new reflection of the standing wave from the wave generator. Also, fig.3c shows the sample of the data at the one vertical scale of transmitted wave for the previous example (f=2.5HZ, D/d=0.30, B=30cm), the one vertical scale was installed behind the model (P3).It is clear in the figure that is period between 0.0 to 8.0sec, the wave travel from the wave generator side and passes the structure until it reaches the vertical scale. in the period between 9.00to12.00 sec, some disturbance take place for the transmitted wave, after that the wave seems to be very stable which is the period of the time between 12.00 sec to 20.0sec this period is the suitable time for analysis and gives the exact values of the transmissions coefficient ,Kt. subsequently, in the period greater than 20.0sec ,the wave shape changes due to the reflection of the standing waves from the wave generator and the partial reflection of the transmitted wave from end of the flume .

Fig.4 shows the effect of the relative breakwater draft (di/d) and dimensionless wave steepness (Hi/L) on the transmission coefficient (Kt), for changing the relative breakwater width (B/d) from 0.375 to 0.75. the model was tested according to two types of the incident wave , the one is flat waves (lower values of Hi/L) and the other is steeper waves (greater values of Hi/L).it is seen from the results that the transmission coefficient decreases as wave steepness (Hi/L) increases or when the values goes from flat to steeper waves . For example, the Kt decreases from 0.756 to 0.217 when wave steepness equal 0.026 and 0.1955, respectively. This trend of reduction of Kt can be explained as follows, under a certain height wave action, with the decreasing of the period, the wave length increasing, and the same of the wave steepness. Thus, the surface wave is easy to break up, so the transmission coefficient decreases. Finally, the diminishing values of Kt with increasing of (Hi/L) are observed. Therefore, the overall performance indicates that flat waves (lower values of Hi/L) are transmitted with ease whereas steeper waves (greater values of Hi/L) are arrested effectively.

Fig.5 presents the effect of the relative breakwater draft (di/d) and dimensionless wave steepness (Hi/L) on the reflection coefficient (Kr) , By changing the relative breakwater width (B/d) from 0.375 to 0.75.it is seen from figure that the reflection coefficient increases where dimensionless wave steepness increases until a value of 0.16 , after that the reflection coefficient will not increase evidently, and it almost maintains for a constant value for all values of di/d and B/d.Also,the Reflection coefficient in the case of relative width (B/d) equal 0.50 is nearly value for (di/d) ratio equal to 0.20 and 0.30,respectively.this resulted from the difference in the experiments environment . Finally, steeper waves are expected to give higher values of Kr while flat waves give lower values of Kr.

Fig.6 presents the influence of pontoon spacing on the transmission coefficient (Kt) with respect to the dimensionless wave steepness (Hi/L). For changing the relative breakwater draft (di/d) from 0.10 to 0.30. The suggested model was examined under two types of the incident wave height, one is flat waves (lower values of Hi/L) and the other is steeper waves (greater values of Hi/L). It is evident from the results that the Kt decreases as wave steepness (Hi/L) increases for all values of (a/B). For example, the Kt decreases from 0.701 to 0.121 when wave steepness equal to 0.026 and 0.1955, respectively. For a/B =1.00 and di/d=0.20.The best values for the transmission coefficient are obtained when the a/B ratio decreases and the di/d, and Hi/L ratios increases. See figure (6c), Kt equal to 0.132 when a/b=1.00,di/d=0.30, and Hi/L=0.16. Therefore, steeper waves give a lower value of Kt while flat waves give lower values of Kt.

Fig.7 shows the effect of pontoon spacing on the reflection coefficient with respect to the dimensionless wave steepness (Hi/L), by changing the relative breakwater draft (di/d) from 0.10 to 0.30. the variation of reflection coefficient shown in the figure explains that Kr increases with an increase in wave steepness (Hi/L) until a value of 0.14, after that the reflection coefficient will not increase evidently and it almost maintains for a higher constant value for all values of (a/B) and (di/d) ratios. Also, it is seen from figure (7c) that no difference between the values of Reflection coefficient for a/b=1.00and a/b=2.00. This resulted from the difference in the experiments environment. Additionally, a steeper wave gives a higher value of Kr while flat waves give lower values of Kr.

Fig.8 shows Comparison between the Computed and Observed Transmission and Reflection Coefficients for single fixed pontoon by using non-Linear regression. The data points are reasonably evenly distributed on either side of the fitted 45° straight line, which is a line perfect agreement. In general, the agreement between experimental and predicted results is rather good.

Fig.9 presents Comparison between the Computed and Observed Transmission and Reflection Coefficients for double fixed pontoon by using non-Linear regression.The data points are reasonably randomly distributed on either side of a 45° line, which is shown for easier observation of a 1:1 correlation between predicted and observed values. The agreement between observed and predicted Kt and Kr is good.

Fig.10 shows a comparison between the results of the present work for single fixed FB and double fixed FB with results of other authors for different types of pontoon breakwaters moored by chains and cables or restrained body. The transmission coefficient curves of various types of floating breakwaters are extracted and superimposed into the Figure, with B/L ranging from 0 to 1.00.The figure shows that Kt decreases with B/L increasing for all the results, In addition, The figure shows that the suggested floating breakwater models are a suitable efficient compared with other types of pontoon breakwater. However, an exact comparison cannot be made due to the different experimental criteria used in the laboratory by different investigators. The characteristics of the different compared floating breakwaters are shown in Table (3).

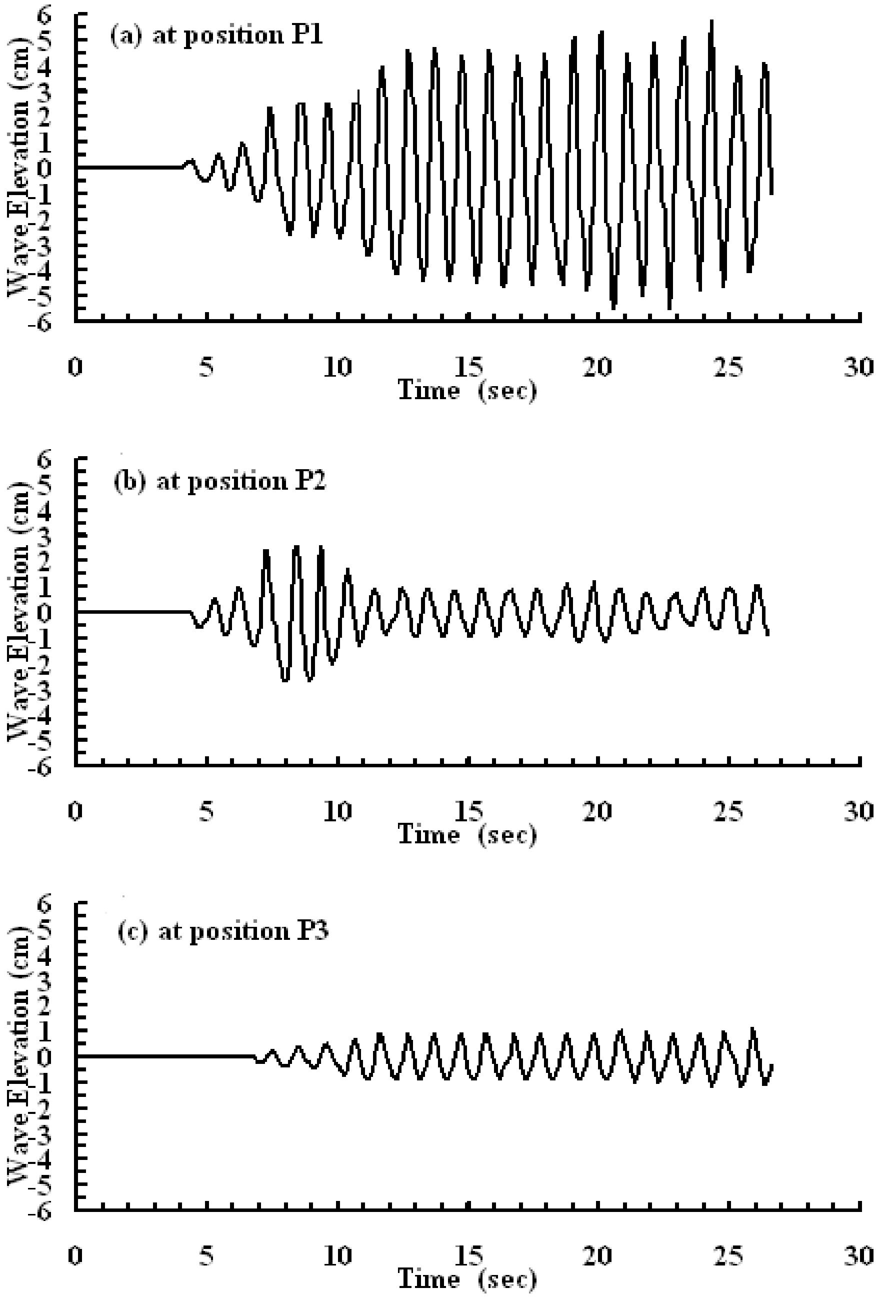
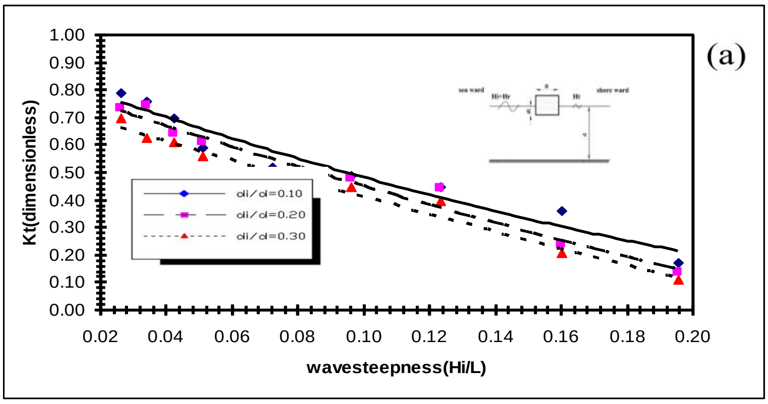


Fig.3. Variation of wave elevation with time at the wave recording positions for the case of single fixed pontoon when B/d=0.75,di/d=0.30and T=1.20 sec.



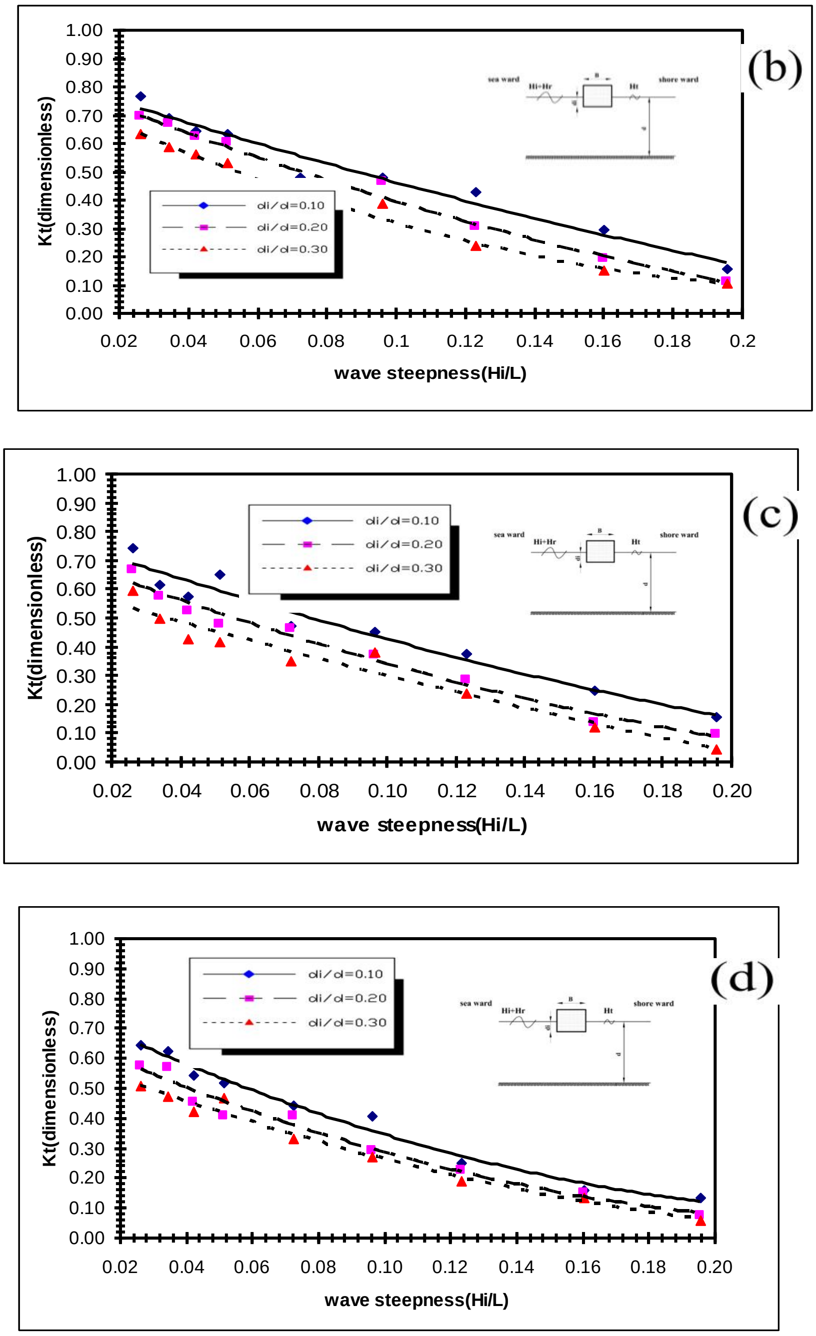
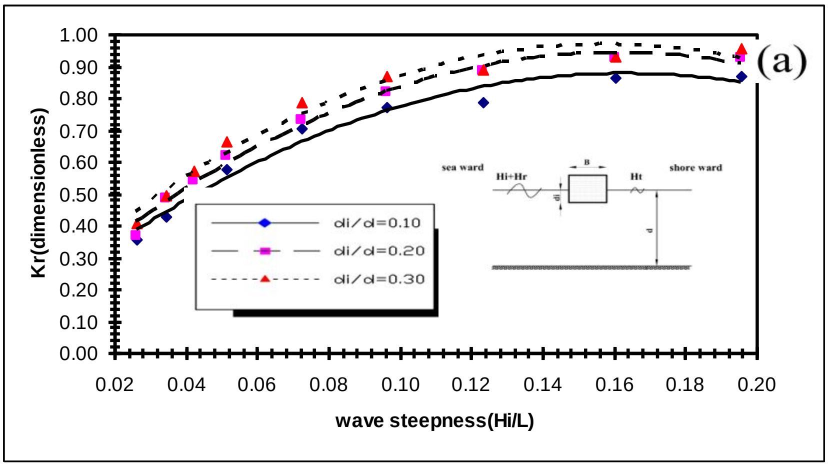


Fig. 4. Effect of the Ratios (di/d) and the wave steepness (Hi/L) on the Transmission coefficient for:

(a) B/d=0.375; (b) B/d=0.50; (c) B/d=0.625; (d) B/d=0.75.



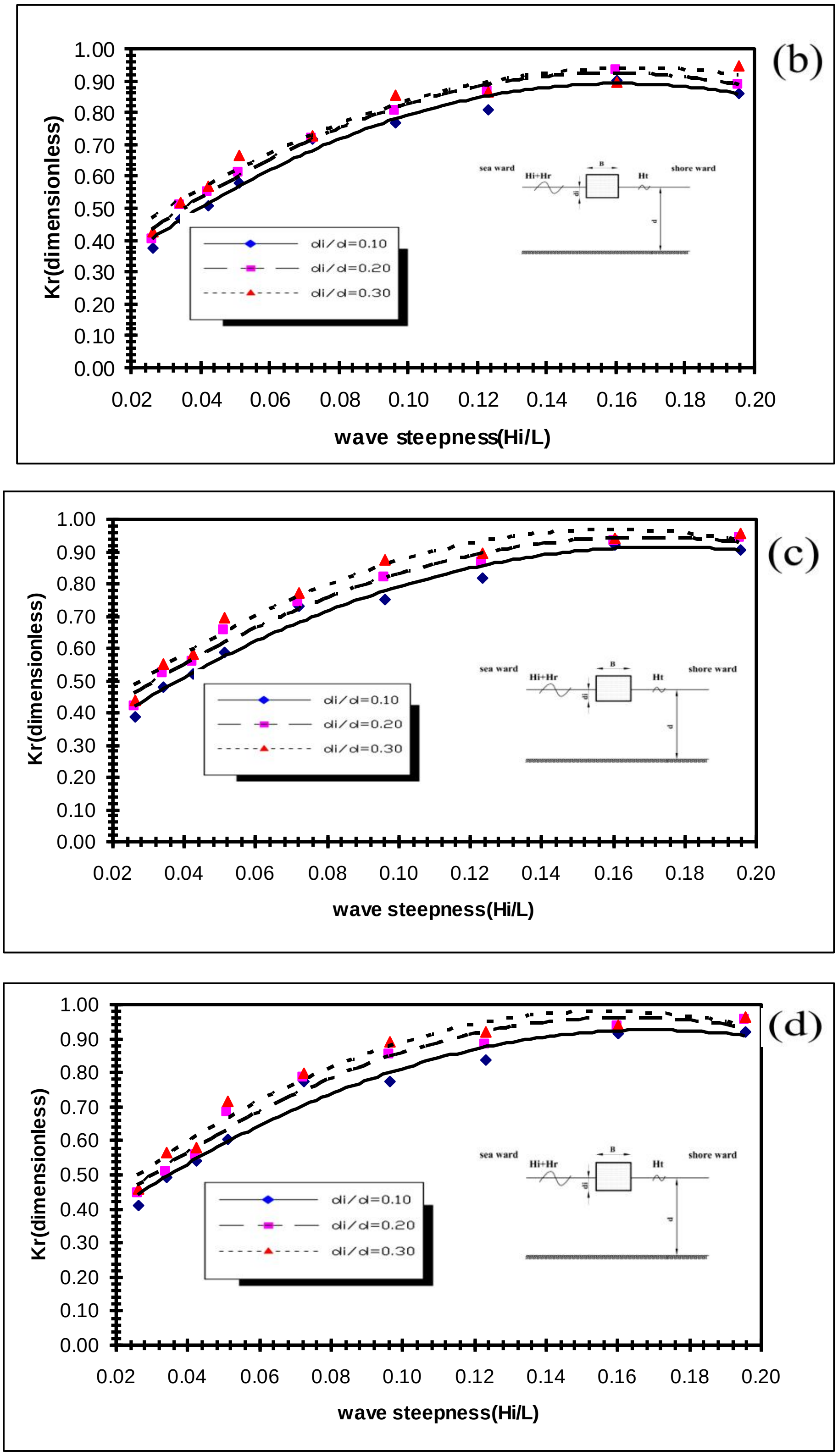


Fig .5. Effect of the Ratios (di/d) and the wave steepness (Hi/L) on the Reflection coefficient for:

(a) B/d=0.375; (b)B/d=0.50; (c)B/d=0.625; (d)B/d=0.75.

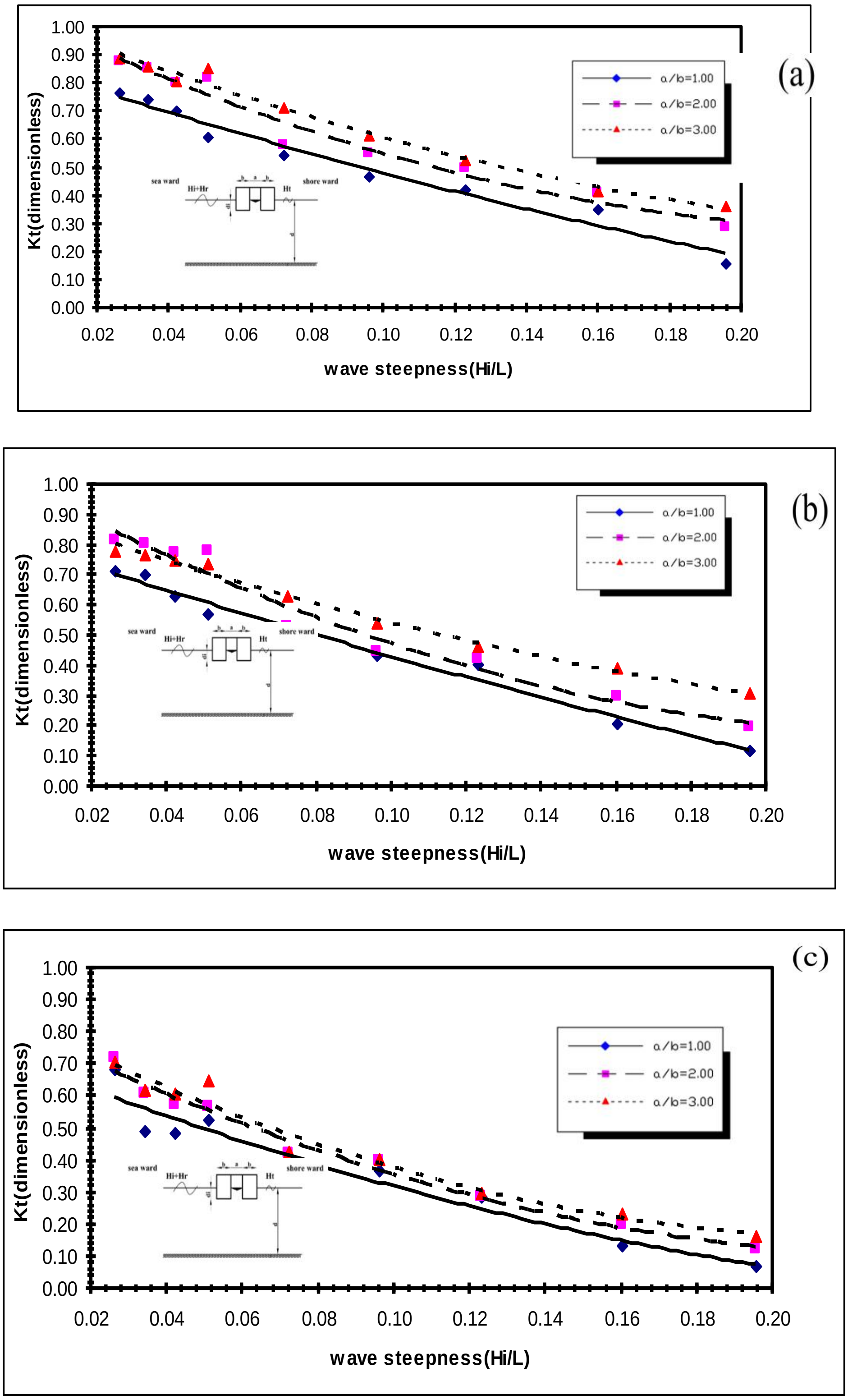


Fig. 6. Effect of pontoon spacing on the Transmission coefficient with Respect to Wave steepness for:

(a) di/d=0.10 (b) di/d=0.20 (c)di/d=0.30.

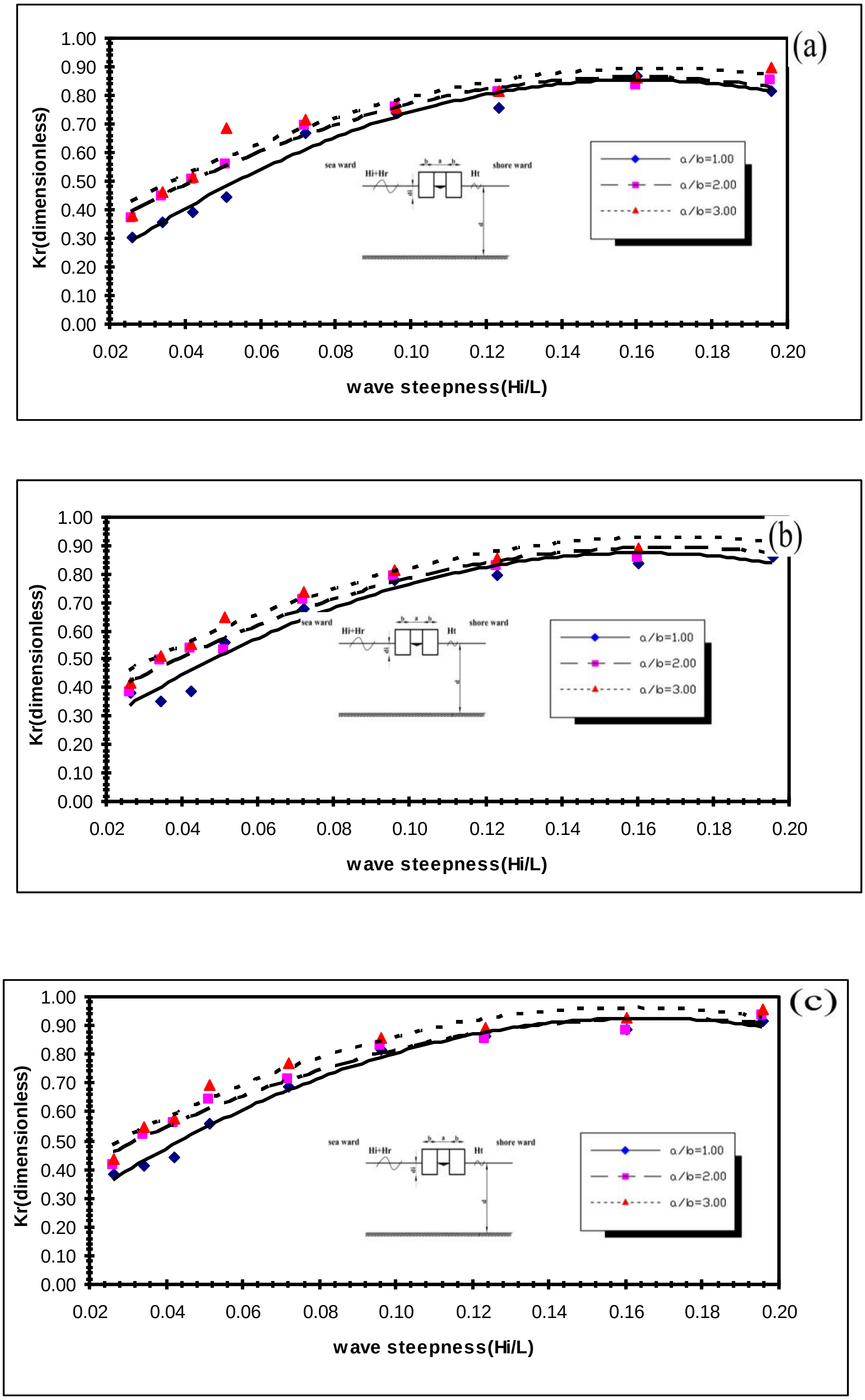


Fig.7. Effect of pontoon spacing on the Reflection coefficient with Respect to Wave steepness for:
(a) di/d=0.10 **(b) di/d=0.20** **(c) di/d=0.30.**

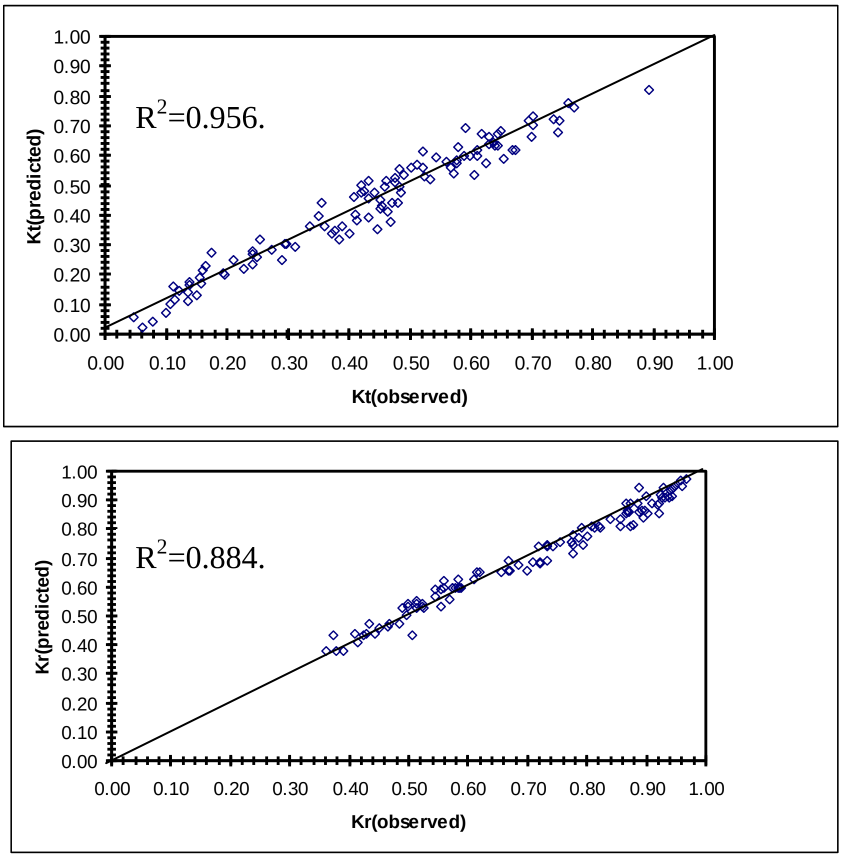


Fig.8. Comparison between the Computed and Observed Transmission and Reflection Coefficient for single fixed pontoon by using non-Linear regression.

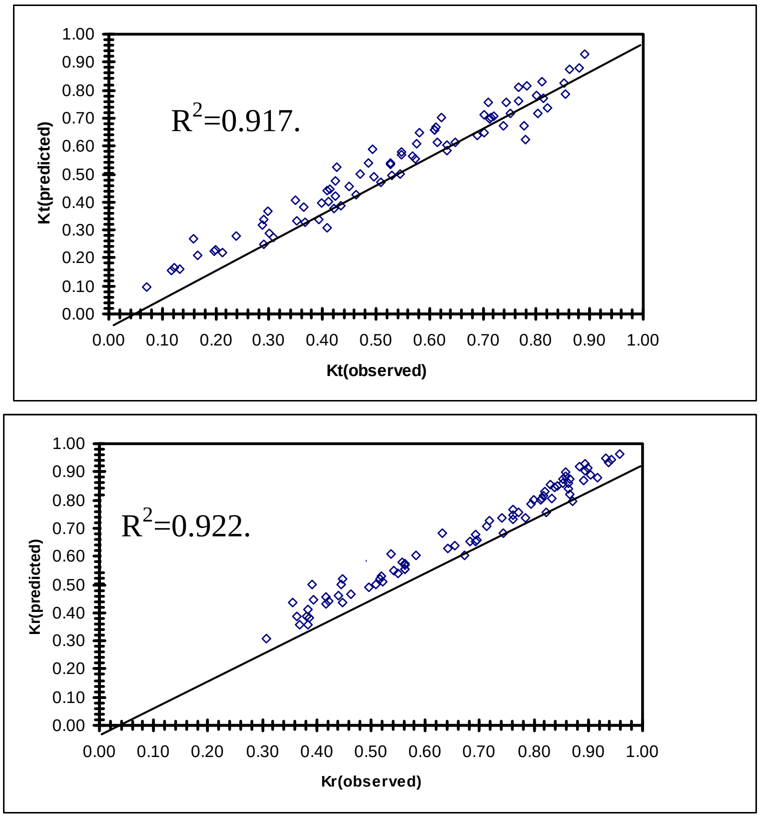


Fig.9. Comparison between the Computed and Observed Transmission and Reflection Coefficient for double fixed pontoon by using non-Linear regression.

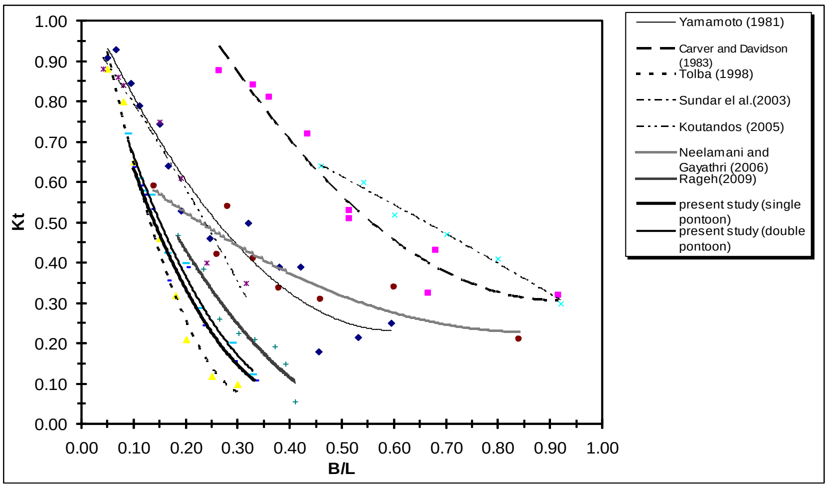


Fig.10. Comparison between the present study with the previous works.

Table (3): Comparison between the present work with other floating breakwaters Moored by chains

Reference	Floating Breakwater Types	H i/L	d i /d	B/L	Notes
(1) Yamamoto (1981).	Rectangular Pontoon	0.01-0.14	0.07	0.05-0.60	Chain mooring
(2)Carver and Davidson (1983).	Trapezoidal Pontoon	0.03-0.10	0.27	0.26-0.60	Moored by taut mooring lines
(3)Tolba (1998)	Restrained rectangular body	0.014-0.048	0.25	0.05-0.40	----------
(4) Sunder et al(2003)	Floating pipe breakwater	0.057	0.15	0.46-0.92	Chain mooring
(5)KoutanDos(2005)	Single fixed floating breakwater	0.031	0.25	0.04-0.315	----------
(6)Neelamani and Gayathri(2006)	Twin- plate breakwater	0.007-0.103	0.16	0.14-0.84	----------
(7) Rageh (2009)	Rectangular pontoon with four plates	0.06-0.08	0.07	0.045-0.45	Chain mooring
(8)present study	Single fixed FB	0.026-0.1955	0.30	0.09-0.33	----------
(9)present study	double fixed FB	0.026-0.1955	0.30	0.09-0.33	----------

5. MODEL APPLICATION FOR FULL SCALE CASE

The sea state dominating our area (Egypt) area as follow; recommended water depth d=10 m, incident wave height Hi=1.5m, the wave period T=5.6 sec, and the wave length L=40.56 m (d/L=0.247). The dimensions of the proposed breakwaters are assumed as follows:

Breakwater width (in case of single pontoon) (B) =6.0 m
Depth of submergence (di) =1.00 m
Breakwater width (in case of double Pontoon) (b) =2.0 m
Distance between two breakwaters (a) =2.0 m
We can summarized the dimensionless ratios as follows
Relative breakwater width (B/d) =0.60
Relative breakwater draft (di/d) =0.10
Wave steepness (Hi/L) =0.038
Relative water depth (d/L) =0.248
Relative distance between two breakwaters (a/b)=1.0
According to experimental results, we can get the degree of protection for each proposed breakwater which summarized in the form of (Kt and Kr) as shown:
Single Pontoon (Kt=0.622, Kr=0.509)
Double Pontoon (Kt=0.511, Kr=0.430)

6. CONCLUSIONS

The efficiency of suggested floating breakwater systems was studied by using physical models .The wave transmission, reflection, and energy dissipation characteristics were studied for regular waves of different wave heights and periods at a constant water depth. The salient conclusions drawn from the present study are given below.

6.1. Single fixed pontoon.

1) An increase in relative width of pontoon, B/d, from 0.375 to 0.75 leads to a reduction in Kt by about 20% and the increasing in Kr by about 6%.
2) An increase in relative draft of pontoon, di/d, from 0.10 to 0.30 leads to a reduction in Kt by about 9% and the increasing in Kr by about 4%.
3) By using nonlinear regression analysis, the equations were obtained to calculate the wave transmission coefficient, Kt, and reflection coefficient, Kr, as follows:

$$Kt=0.001(di/d)^{-2.106}+0.779(d/L)^{0.412}-2.904(Hi/L)^{0.531}+0.526(B/d)^{-0.308}. \quad (16)$$

$$Kr=-0.000028(di/d)^{-3.325}+1.382(d/L)^{-0.006}-0.23(Hi/L)^{-0.39}+6.237(B/d)^{18.87}. \quad (17)$$

6.2. Double fixed pontoon.

1) The a=b system given better and more effective wave attenuation than a=2b and a=3b system.
2) An increase in the relative draft of pontoon, di/d, from 0.1 to 0.3 leads to a reduction in Kt by about 8%.
3) No significant differences are observed on wave attenuation between single and double pontoon when a/b=1.00 and di/d greater than 0.20.

4) Two simple empirical equations for estimating the transmission and the reflection coefficients are developed by using non linear regression analysis as follows:

$Kt = 0.686(di/d)^{-0.169}+14.042(d/L)^{17.57}-1.938(Hi/L)^{0.354}+0.334(a/b)^{0.271}$. (18)

$Kr = -0.024(di/d)^{-0.741}-1.02(d/L)^{6.16}-23.372(Hi/L)^{-0.012}+24.859(a/b)^{0.003}$. (19)

REFERENCES

[1] Abul-Azm, A., (1993). "Wave Diffraction through Submerged Breakwater". Applied Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 119, No. (6), pp 587-605.

[2] Bayram, A., (2000). "Experimental Study of a Sloping Float Breakwater". Applied Ocean Engineering, Vol. 27, pp 445-453.

[3] Bhat, Sh., (1998). "Performance of Twin-Pontoon Floating Breakwaters ".M.Sc Thesis, Faculty of Graduate Studies, Department of Civil Engineering, University of British Columbia, P 197.

[4]Brebner, A., and Ofuya, A., (1968). "Floating Breakwaters". Applied The Eleven Conference of Coastal Engineering, pp 1-21.

[5] Briggs, M., Ye, W., Demirbilek, Z., and Zhang, J., (2002). "Field and Numerical Comparisons of the RIBS Floating Breakwater". Applied Journal of Hydraulic Research, Vol. 40, No. 3, pp 289-301.

[6] Chaiheng, L., (2006). "System Performance of a Composite Stepped-Slope Floating Breakwater".M.Sc Thesis, Faculty of Civil Engineering, University Teknologi Malaysia, Malaysis, P 281.

[7] Dong, G., Zheng, Y., Li, Y., Teng, B., Guan, C., and Lin, D., (2008). "Experiments on Wave Transmission Coefficients of Floating Breakwaters". Applied Ocean Engineering, Vol. 35, pp 931-938.

[8] Fugazza, M., and Natale, L., (1988). " Energy Loss and Floating Breakwater Response". Applied Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 114, No. 2, pp 191-205.

[9] Gesraha, M., (2004). "An Eigenfunction Expansion Solution for Extremely Flexible Floating Pontoons in Oblique Waves". Applied Ocean Research, Vol. 26, pp 171-182.

[10] Goda,Y. , and Suzuki, Y., (1976) "Estimation of incident and reflected waves in random wave experiments" Proc.15th Costal Eng. Conf., pp 828-845.

[11] Gunaydin, K., and Kabdash, M., (2007)."Investigation of π- Type Breakwaters Performance under Regular and Irregular Waves". Applied Ocean Engineering, Vol. 34, pp 1028-1043.

[12] Gunaydm, K., and Kabdash, M., (2004).“Performance of Solid and Perforated U-Type Breakwaters under Regular and Irregular Waves”. Applied Ocean Engineering, Vol. 31, pp 1377-1405.

[13] Hegde, A., Kamath, K., and Deepak, J., (2008).“Mooring Forces in Horizontal Interlaced Moored Floating Pipe Breakwater with Three Layers “. Applied Ocean Engineering, Vol. 35, pp 165-173.

[14] Hom-ma, M., Harikaw, K., and Mochizuki, H., (1964). “An experimental Study on Floating Breakwater”. Applied Coatel Engineering in Japan, Vol. 7, pp 85-94.

[15] Koutandos, E., Karambas, Th., Koutitas, C., and Prinos, P., (2002). “Floating Breakwater Efficiency in Intermediate and Shallow Waters”. Applied Int. Conf. Hydrodynamic and Engineering, Portland, pp 1-10.

[16] Koutandos, E., Prinos, P., and Gironelia, X., (2005). “Floating Breakwater Under Regular and Irregular Wave Forcing: Reflection and Transmission Characteristics “. Applied Journal of hydraulic Research, Vol. 43, No. (2), pp 174-188.

[17] Kriezi, E., Karambas, V., Prinos, P., and Koutitas, C., (2001). “Interaction of Floating Breakwater with Waves in Shallow Waters”. Applied Int. Conf. IAHR 2001, Theme E, Beijing, china, pp 1-14.

[18] Loukogeorgaki, E., and Angelides, D., (2005). “Stiffness of Mooring Lines and Performance of Floating Breakwater in Three Dimensions”. Applied Ocean Engineering. Vol. 27, pp 187-208.

[19] Mani, J., (1991). “Design of Y-Frame Floating Breakwater”. Applied Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 117, No. (2), pp 105-119.

[20] Martinelli, L., Ruol, P., and Zanuttigh, B., (2008). “Wave Basin Experiments on Floating Breakwater with Different Layouts”. Applied Ocean Engineering, Vol. 30, pp 199-207.

[21] Mc-Cartney, M. (1985) “Floating Breakwater Design.” J. of Waterway, Port, Coastal, and Ocean Eng., Vol. 111, No. 2.

[22] Murali, K., and Mani, J., (1997). “Performance of Cage Floating Breakwater”. Applied Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 123, No. (4), pp 172-178.

[23] Neelamani, S., and Rajendran, R., (2002). “Wave Interaction With ‘⊥ ‘ Type Breakwaters”. Applied Ocean Engineering, Vol. 29, pp 561-589.

[24] Neelamani, S., and Vedagiri, M., (2002). “Wave Interaction with Partially Immersed Twin Vertical Barriers”. Applied Ocean Engineering, Vol. 29, pp 215-238.

[25] Ozeren. Y., (2009). “Experimental and Numerical Investigation of Floating Breakwater Performance “. Ph.D. Thesis, the University of Mississippi, P 391.

[26] Rageh O., El – Alfy, K., Shamaa, M., and Diab, R., (2006). "An Experimental Study of Spherical Floating Bodies under Waves" Tenth International water Technology Conference, pp 357-375.

[27] Rageh, O., (2009). "Hydrodynamic Efficiency of Floating Breakwater with Plates ". Applied Journal of Mansoura Engineering,Faculty of Engineering Mansoura University,Vol.34,No.2,June 2009,pp126-141.

[28] Sannasiraji, S., Sundar, V., and sundaravadivelu, R.,(1998). "Mooring Forces and Motion Response of Pontoon-Type Floating Breakwater". Applied Pregamon, pp 27-48.

[29] Stiassne, M., Agnon, Y., and Naheer, E., (1981). "Scattering of Water Waves by a System of Vertically Floating Plates". Applied International Symposium on Hydrodynamics in Ocean Engineering.

[30] Sundar, V., and Subba rao, B., (2002). "Hydrodynamic Pressure and Forces on Quadrant Front Face Pile Supported Breakwater ". Applied Ocean Engineering, Vol. 29, pp 193-214.

[31] Sundar, V., and Subbarao, V., (2003)."Hydrodynamic Performance Characteristics of Quadrant Front-Face Pile-Supported Breakwater". Applied Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol. 129, No. (1), pp 22-33.

[32] Tolba, E., (1998)." Behavior of Floating Breakwater under Wave Action" Ph. D. Thesis, Suez Canal University, Egypt, P148.

[33] Tsoukala, V., and Moutzouris, C., (2009). "Wave Transmission in Harbors through Flushing Culverts". Applied Ocean Engineering, Vol. 36, pp 434-445.

[34] Usha, R., and Gayathri, I., (2005). "Wave Motion over a Twin-Plate Breakwater". Applied Ocean Engineering, Vol. 32, pp 1054-1072.

[35] Vethamony, P., (1995). "Wave Attenuation characteristics of a Tethered Float System". Applied Pregamon, pp 111-128.

[36] Wang, Y., Wang, G., and Li, G., (2006)."Experimental Study on the Performance of the Multiple-Layer Breakwater ". Applied Ocean Engineering, Vol. 33, pp 1829-1839.

[37] Williams, A., and Abul-Azm, A., (2000). "Dual Pontoon Floating Breakwater ". Applied Ocean Engineering, Vol. 24, No. (5), pp 465-478.

[38] Yamamoto, T., Yoshida, A., and Ijima, T., (1980). " Dynamics of Elastically Moored Floating Objects ". Applied Ocean Engineering, Vol. 2, No. (2), pp 85-92.

NOTATION

The following symbols are used in this paper
Symbol Definition
a : Distance between double breakwaters
b : Breakwater width (in case double breakwaters)
B : Breakwater width (in case single breakwater)
d : Depth of water
di : Breakwater draft
Hi : Incident wave length
Hr : Reflected wave height
Ht : Transmitted wave height
KL : Energy loss coefficient
Kr : Reflection coefficient
Kt : Transmission coefficient
L : Incident wave length
R2 : Correlation coefficient
T : Wave period
FBs : Floating breakwaters