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HYDRODYNAMIC EFFICIENCY OF DOUBLE PONTOON SUPPORTED ON PILES

الكفاءة الهيدروديناميكية لحاجز أمواج مزدوج مثبت على خوازيق

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خلاصة : تم معمليا اختبار كفاءة حاجز امواج مزدوج مثبت على صفين من الخوازيق تحت ظروف الأمواج المنتظمة وبمجال واسع من خصائص الأمواج. اعتبرت كفاءة هذا النوع من الحواجز دالة في كل من معامل الانتقال ، معامل الارتداد ومعامل فقد طاقة الأمواج. اختبرت العديد من العوامل المؤثرة للحاجز المزودج بالنظام الخازوقى على كفاءة هذا النوع. أظهرت الدراسة أن معامل الانتقال يقل عندما يزداد غاطس الحاجز المزودج وعندما تقل كل من المسافة بين الحاجزين والمسافة بين الخوازيق. كما أوضحت الدراسة أن النظام الخازوقى يحسن من كفاءة الحاجز المزودج بمقدار يتروح تقريبا ما بين 7% الي 16% عن استخدام الحاجز المزدوج بمفرده. يفضل استخدام هذا النظام الخازوقى مع المسافات الصغيرة بين الحاجزين. باستخدام تحليل الانحدار الغير الخطى تم إيجاد معادلات تقريبية لحساب معامل الانتقال ومعامل الارتداد. إضافة إلى أن الحاجز المقترح يعطى كفاءة مناسبة عند مقارنته بأنواع أخرى من حواجز الأمواج.

ABSTRACT: The efficiency of a double fixed pontoon supported on two rows of piles was examined experimentally under regular waves. The breakwater efficiency is presented as a function of transmission, reflection, and energy loss coefficients. Regular waves with wide ranges of wave heights and periods with constant water depth were used. Different parameters of double fixed pontoon and supporting pile systems were also tested. It was found that the transmission coefficient, K_t, decreases with the increasing value of the relative breakwater draft, d_r/d, and with the decreasing values of both the relative gap between two pontoons, a/b, and the pile gap-diameter ratio, G/D. Pile system improves the efficiency of double Pontoon by about (7-16) % when G/D = 0.5 and a/b = 1.0. The usage of pile system with a double fixed pontoon is more effective in case of small gaps between piles. It is possible to achieve K_t values less than 0.25 when d_r/d = 0.30, a/b = 1.0, and G/D = 0.50. Simple empirical equations were developed for estimating both the wave transmission and reflection coefficients by using non-linear regression analysis. In addition, the proposed breakwater model gives a reasonable efficiency compared with other pontoon types.

1. INTRODUCTION

Floating breakwaters (FBW) offers an alternative solution to conventional fixed breakwaters. A floating breakwater is a floating structure of finite draft and relies on wave-structure interaction in the upper portion of water column. The term floating does not refer to a freely floating structure. The restraint of the structure may vary from freely floating to a rigidly fixed case. Floating breakwater can act as a primary source of wave protection or supplemental protection. Therefore, they are commonly installed at sites such as marinas, yacht clubs, small craft harbours and aquaculture facilities. Floating breakwaters have gained significance in the recent years because of their basic advantages, such as flexibility, easy installation, shorter construction time, and movable from a location to another and they can be realigned into new layout as desired with minimum effort. On the other hand, piles are widely used in practice to support marine structures such as berths, breakwaters, and dolphins.

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Pile breakwaters are normally built in relatively calm seas with soft soil foundation. The main advantages of pile breakwaters are: they allow free passage of sediment, there by reducing the potential erosion on the down-drift side that is normally a result of the construction of a conventional rubble mound breakwater, in addition to, the piling system is a solution to overcome the disadvantages of those floating breakwaters moored with chain or cables. If they are exposed to strong waves, cracks will appear at the connection between the chains and the pontoon and failure may occur at this zone.

2. LITERATURE REVIEW

A tremendous mumber of authors has studied experimentally and theoretically the efficiency of pile breakwaters and different shapes of floating breakwater moored by piles. Wiegal (1961) studied theoretically the wave transmission through a single row of circular piles. Hayashi and Kano (1968) examined experimentally and theoretically the hydraulic properties of a row of closely spaced circular piles. Sawaragi and Iwata(1971) derived a theoretical formula for wave transmission coefficient for a double row of circular piles (Koraim, 2005). Herbich (1989) studied experimentally the wave transmission through a breakwater consisting of closely spaced piles. Mani (1991) studied experimentally the performance of a Y-frame floating breakwater resting on pipes. Mani and Murali (1997) investigated experimentally the performance of a cage floating breakwater fixed on two rows of equally spaced piles with a certain gap to diameter ratio. Tolba (1998) studied the behavior of rectangular floating breakwaters supported on four piles, where the height of the heave motion and the wave pressure on the breakwater surfaces were determined. Mani (1998) studied experimentally the wave transmission through a breakwater that consists of a row of closely spaced pipes mounted on a frame and suspended between supporting piles spaced for a part. Rao et al. (1999) studied experimentally the hydrodynamic coefficient on perforated hollow piles in two rows. Sundar and Subbara(2002) investigated experimentally the hydrodynamic performance characteristics of a quadrant front-face pile-supported breakwater. Neelamani and Rajendran (2002) studied experimentally the behavior of partially submerged "T" and "⊥" types breakwaters supported by piles under regular and random waves. Rao et. al. (2003) studied experimentally the hydraulic performance of a single row of suspended porous pipes under regular waves. Heikal (2004) investigated experimentally the efficiency of a closed frame fixed on two rows of piles. Gunaydin and Kabdusli (2004) studied experimentally the performance of solid and perforated U-type breakwaters resting on piles under regular and irregular waves. Koraim (2005) studied experimentally and theoretically the efficiency of three different breakwater types. The tests models were: a caisson partially immersed in the water and supported on large spaced pile system; a closely spaced vertical square or circular piles; and a caisson partially immersed in water and supported on closely spaced pile system. Chaiheng (2006) studied experimentally the performance of a steeped- slope floating breakwater supported by four piles. Laju et al. (2007) studied experimentally and numerically the hydrodynamic characteristics of barriers that are supported on closely spaced concrete or steel piles with different configurations. Gunaydin and Kabdasli (2007) studied experimentally the performance of solid and perforated π-type breakwaters supported on piles. Suh et al. (2007) investigated experimentally and theoretically the hydrodynamic characteristics of a curtain wall-pile breakwater using circular piles. Rageh et al. (2009) presented experimentally the efficiency of a breakwater that consists of caissons supported on two or three rows of piles. Rageh and Koraim (2009) studied experimentally and theoretically the performance of a floating breakwater that consists of one row of vertical walls supported on large spaced concrete or steel piles.

3. EXPERIMENTAL WORK

3.1. Model Scale

In accordance with the experimental facilities, instruments of the laboratory and the tested wave conditions, a geometrical similarity scale of 1:25 was taken into considerations for the selection of models dimensions and wave properties. Based on this scale ratio, the relations between model and prototype scale factors were obtained by using Froude's model law.

3.2. Test Facility

Several experiments were carried out in a wave flume 15.1m long, 1.0m wide and 1.0m depth, in the irrigation and hydraulics laboratory at the faculty of engineering, El-Mansoura University. 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 absorbers was used to prevent the reflection of wave at the other end of the flume in order to increase the efficiency of experiments and to reduce the time required between runs while the water is calming down. The first absorber was placed in the front of the wave generator, while the other absorber has a slope of 1:7 installed at the end of the flume. The experiments were carried out with a constant water depth, d, of 0.4 m and with generator motions corresponding to regular wave trains with nine wave periods, T, of 0.62 , 0.66 , 0.74 , 0.80 , 0.90, 1.00, 1.06, 1.12 and 1.2 seconds. These values of T were taken to carry out the experimental tests in transitional and deep water zone.

3.3. Model details

The tested models were placed at the middle of the wave flume. The model consisted of double-box. The box was made of a hardwood of 3 mm thick. It was rigidly fixed between the wall sides of the wave flume. Pile system was fabricated using PVC pipes of 33 mm diameter, the pipes were rigidly bolted to the rectangular floating body which can be removed for varying the draft of the floating body and the distance between piles. Details of the tested breakwater model are shown in Figure (1).

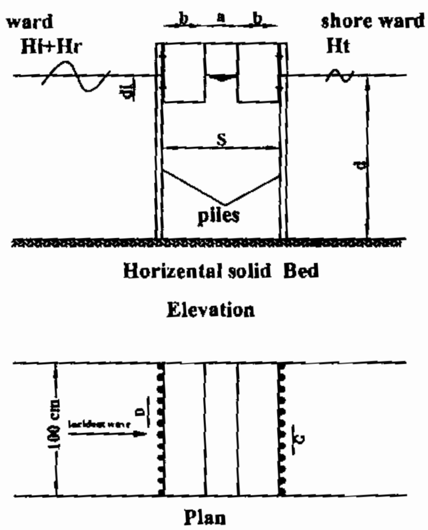

Fig. 1. Model of the under study double pontoon.

3.4. Experimental conditions

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

Table 1. Experimental setup parameters for double fixed floating breakwater supported on a closely spaced pile system:

Parameters	Range	Notes
Water Depth (*d*) (cm)	40 constant	At the breakwater
Wave period (*T*) (sec)	0.62, 0.66, 0.74, 0.80, 0.9, 1.0, 1.06, 1.12and 1.2	
Wave Length (*L*) (cm)	60 to 200	At the breakwater
Width of pontoon (*b*) (cm)	5 constant	
Distance between breakwater(*a*) (cm)	5, 10 and 15	
Depth of immersion (d_i) (cm)	4 , 8 and 12	
Pile Diameter(*D*) (cm)	3.3	
Pile Gap(*G*) (cm)	1.66, 2.47 and 3.3	Perpendicular to wave direction
Pile Spacing(*s*) (cm)	15, 20and25	Parallel to wave direction
Bed slope (S_b)	0%	For solid bed

3.5. Measuring Means

Vertical scales fixed with the Perspex part were used to measure the wave characteristics. The accuracy of these scales was 1.0 mm. The vertical scale was selected to be behind the breakwater model (wave absorber side) to measure the transmitted waves. A digital camera, (auto focus 5 mega pixel), was used for recording the wave characteristics. It was connected to a personal computer, in order to analyze the wave data.

3.6. Wave Height Measurement

The water level variation resulting from wave-structure interaction was recorded by using digital camera. The camera zoom was adjusted exactly perpendicular to the linear scales on the glass flume side at each recording position. The used camera was fixed on vertical stand to avoid the variations of video shots. By using a slow motion technique (e.g. codec) that divides the second into thirty fractions, the recorded waves taken by the camera can by analyzed. Then, a relation between the wave elevation and time can be drawn.

The vertical distance between wave crests and the lowest elevation (trough) represents the incident wave height , H_i, in case of model absence. While, to measure the reflected wave heights, H_r, two recording positions (P_1 and P_2) were positioned in front of the breakwater model (wave generator side) at distances $0.2L$ and $0.45L$ respectively, based on the two point method of Goda and Suzuki (1976). These two vertical scales were positioned to meet the upper and lower limits of the standing wave envelop.

After recording the water surface elevations at two vertical scales by using the camera, the following relationships were used:

H_{max} = max wave height at antinodes = max crest level - min through level (1)

H_{min} = min wave height at nodes = min crest level-max through level (2)

$$H_{max} = H_i + H_r \tag{3}$$
$$H_{min} = H_i - H_r \tag{4}$$

The reflection coefficient, K_r, is the ratio between reflected and incident wave heights, therefore:

$$K_r = H_r / H_i \tag{5}$$

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

$$K_r = \frac{H_{max} - H_{min}}{H_{max} + H_{min}} \tag{6}$$

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

$$H_r = K_r \times H_i \tag{7}$$

Also, to measure the transmitted wave heights, H_t, one recording position (P3) was positioned behind the breakwater model at a distance (1.2m) according to (Chaiheng, 2006). Transmitted wave heights were calculated as shown in equation (8). Then the transmitted wave heights are averaged.

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

The details of wave flume, position of the tested breakwater models, and the location of wave recordings are shown in figure (2).

3.7. Reflection, Transmission, and Energy Dissipation Coefficients

The reflection coefficient, K_r, can be estimated from equation (5). While, the transmission coefficient, K_t, can be estimated from the experimental data as follows:

$$K_t = H_t / H_i \tag{9}$$

In practice, when a wave reaches the structure, some of the wave energy is dissipated by the structure itself . 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):

$$K_L = \sqrt{1 - K_t^2 - K_r^2} \tag{10}$$

in which K_L is the wave energy dissipation coefficient.

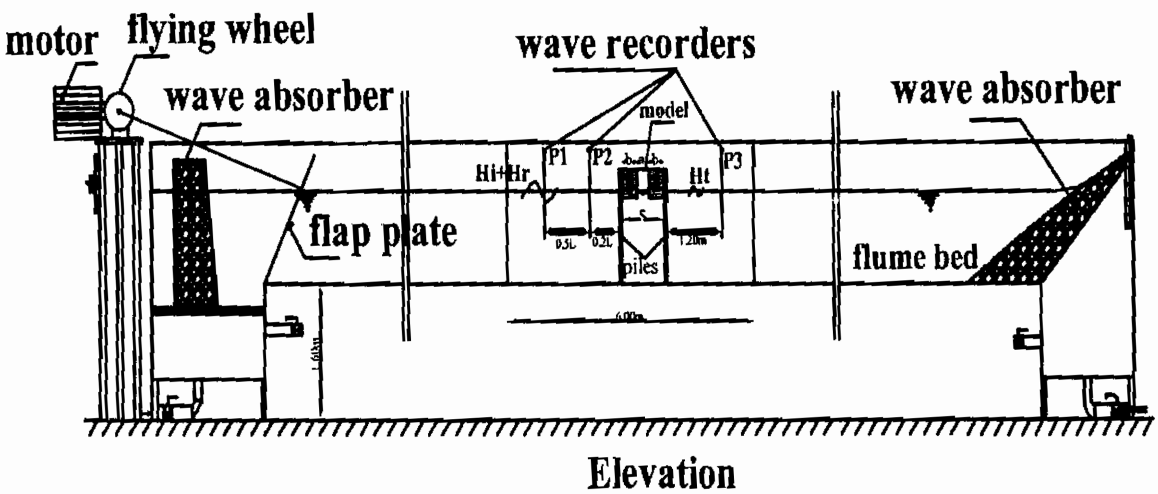

Fig.2. Details of wave flume, position of model and location of wave recorder.

4. EXPERIMENTAL RESULTS AND ANALYSIS

The following parameters were studied such as: wave length, L; wave period, T; wave height, H_i; water depth, d; breakwater width ,b; breakwater draft, d_i; distance between pontoons, a; the gap between piles, G; and distance between pile rows, S. 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 that represent the wave and structure characteristics as in the following equation:

$$(K_t, K_r, K_L) = \phi(\frac{a}{b}, \frac{d_i}{d}, \frac{G}{D}, \frac{S}{D}, \frac{H_i}{L}, \frac{d}{L}) \quad (11)$$

Using the above dimensionless parameters, non-linear regression analysis was carried out using SPSS.13 (SPSS Inc, 2004) software. Empirical equations for estimating the transmission and the reflection coefficients were developed as follows:

$$K_t = 24.052\,(d_i/d)^{-0.007} - 0.226\,(a/b)^{-0.564} - 57.78(G/D)^{-0.001} + 33.667(d/L)^{-0.014} - 0.008(H_i/L)^{-0.575}. \quad (12)$$

$$K_r = -5.26(di/d)^{-0.012} - 17.89\,(a/b)^{-0.005} - 2.27\,(G/D)^{-0.045} + 26.99\,(d/L)^{-0.001} - 0.391(Hi/L)^{-0.31}. \quad (13)$$

Figure (3) shows a sample of data at the three wave recording positions P_1, P_2 and P_3 for the case of an incident wave of frequency f = 0.833Hz (T=1.20sec). The breadth of floating breakwater model, B, is 30cm and its draft, d, equals 12cm. In front of the model (P_1 and P_2 positions) , it is clear that for the period between 0.0 and 5.0 sec, the wave travels from the wave generator side to the measuring positions. For the period between 5.0 and 9.0 sec, the incident wave passes the two measuring points and reflects due to the upward face of the model, and the standing wave begins to build its shape. For the period between 9.0 and 12.0sec, some disturbances take place for the standing wave. After that the standing wave tends to be stable and it becomes suitable for analyzing and giving the exact values of the reflection coefficient, K_r. Downstream the model (P_3) it is clear that during the period between 0.0 to 8.0sec, the wave travels from the wave generator side and passes the structure until it reaches the vertical scale. In the period between 9.0 to 12.0sec, some disturbances take place. After that, the wave is regular during the period between 12.00 sec to 20.0sec. This period is suitable for analyzing and giving the exact values of the transmission coefficients, K_t.

Figures (4a, 4b, and 4c) show the case in which the spacing between pontoons, a, is equal to the width of pontoon, b. It appeared that the transmission coefficient, K_t, decreases and the reflection coefficient, K_r, increases as the wave steepness, H_i/L, increases for all values of G/D. The energy loss coefficient, K_L, seams to have a little variation with the wave steepness, H_i/L. For example, when H_i/L increases from 0.026 to 0.1955 for G/D = 1.0, K_t decreases from 0.711 to 0.164, K_r increases from 0.268 to 0.773, and K_L varies from 0.663 to 0.598, as shown in figure (4a). On the other hand, when the floating body draft ratio, d_i/d, increases, K_t decreases and K_r increases while K_L varies slightly, as shown in figures (4a, 4b, and 4c), when d_i/d increases from 0.1 to 0.3, for G/D = 1.0 and H_i/L = 0.123, K_t decreases from 0.375 to 0.271, and K_r increases from 0.734 to 0.837.

The best values of the transmission coefficient can be achieved by decreasing the values of G/D and increasing the values of d_i/d and H_i/L. Figure (4c), K_t equal exhibits the value of 0.06 when G/D = 0.5, d_i/d = 0.3 and H_i/L = 0.1955.

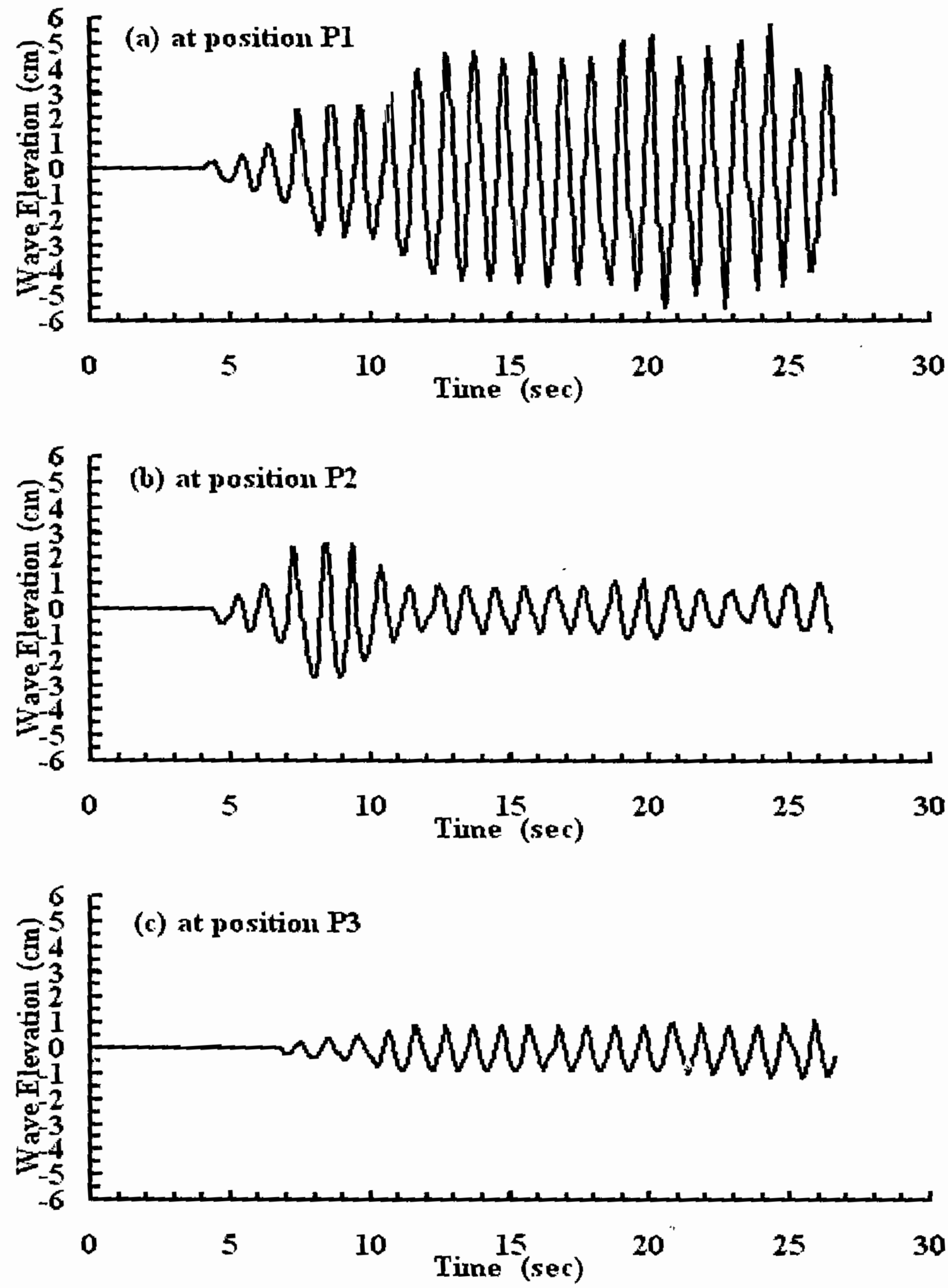

Fig. 3. Variation of wave elevation with time at the wave recording positions, T=1.20 sec.

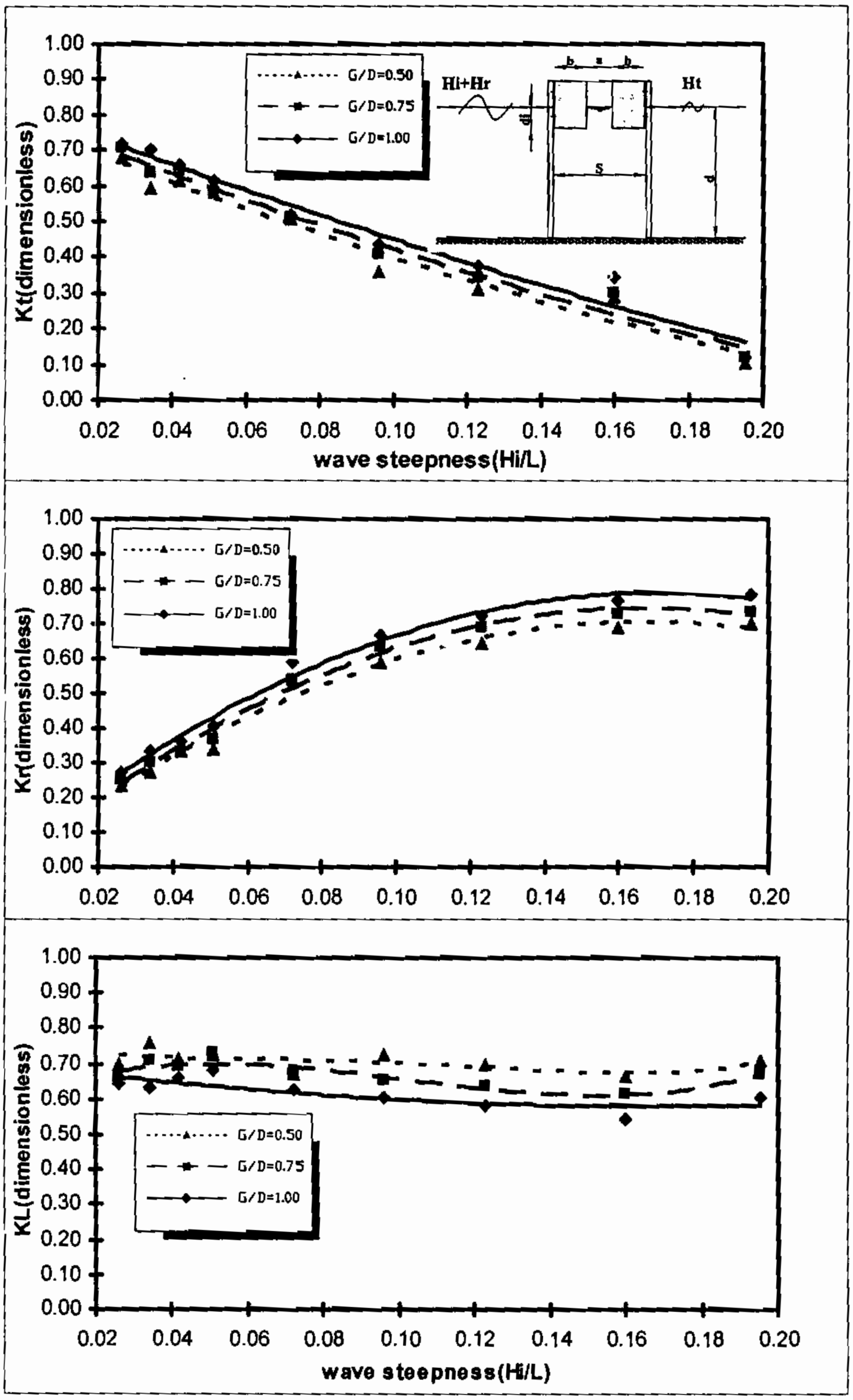

Fig. 4a . Relationship between the hydrodynamic coefficients (K_t,K_r and K_L) and the wave steepness (Hi/L) for different values of gap ratio(G/D) (di/d=0.10 and a=b).

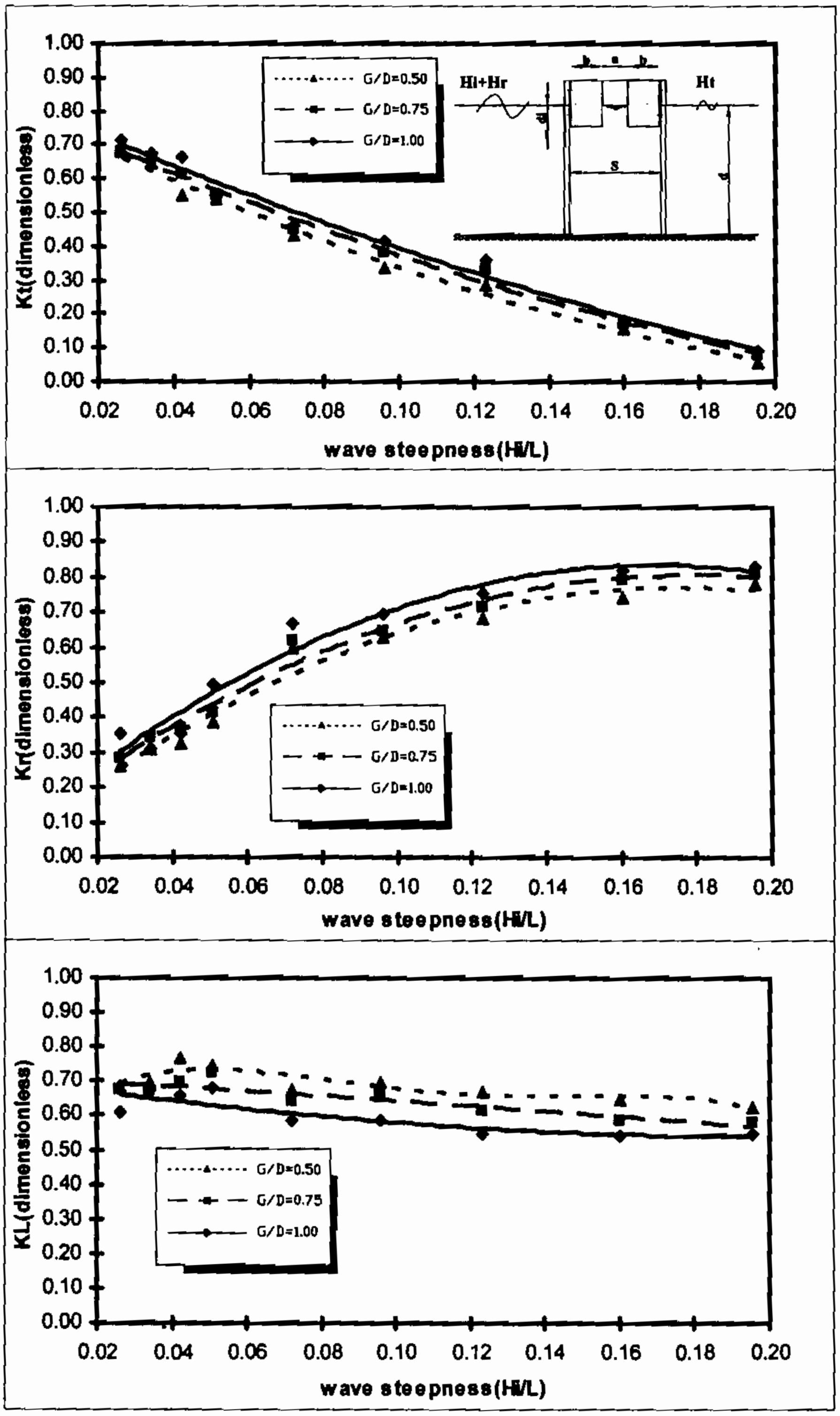

Fig. 4b . Relationship between the hydrodynamic coefficients (K_t,K_r and K_L) and the wave steepness (Hi/L) for different values of gap ratio(G/D) (di/d=0.20 and a=b).

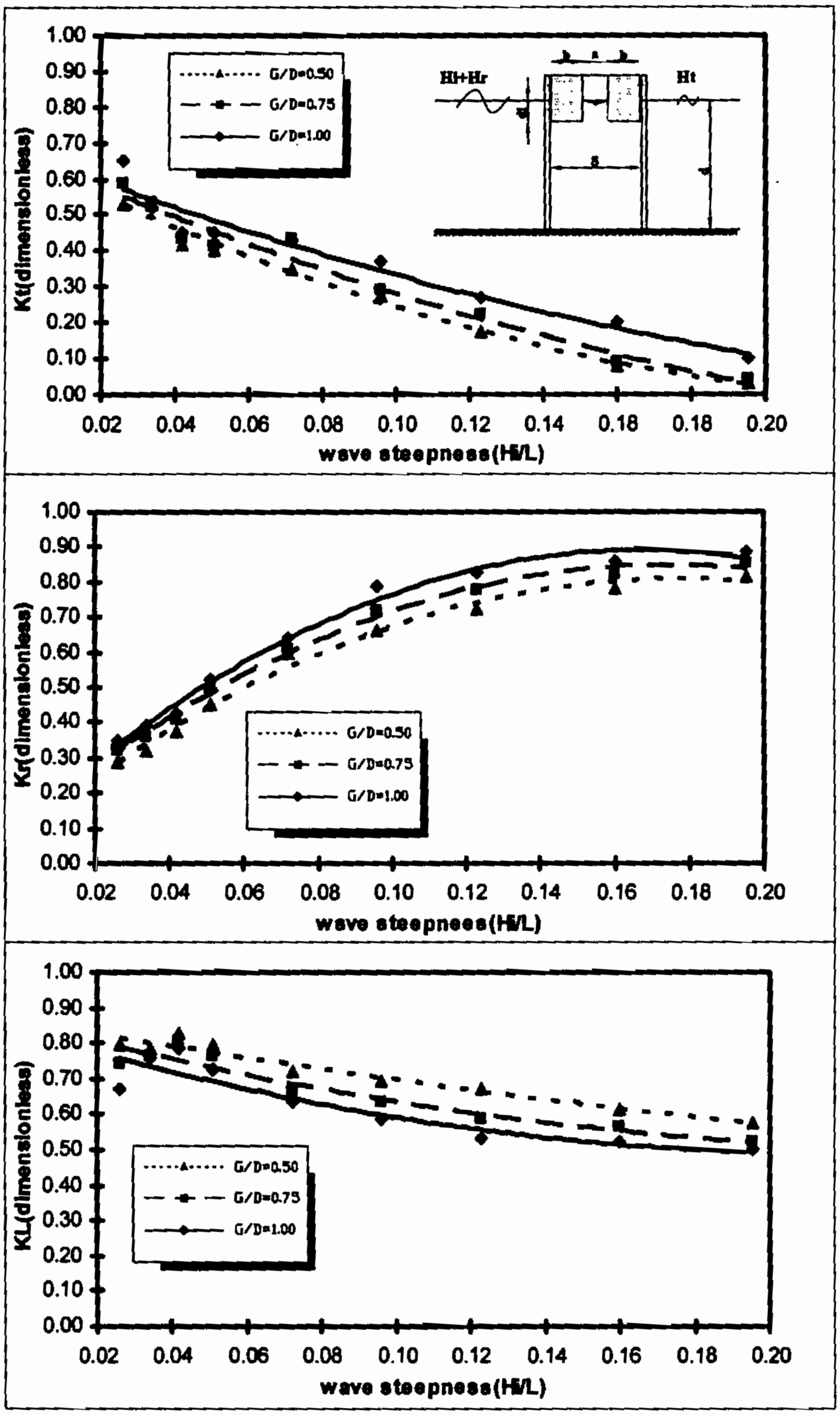

Fig. 4c . Relationship between the hydrodynamic coefficients (K_t,K_r and K_L) and the wave steepness (Hi/L) for different values of gap ratio(G/D) (di/d=0.30 and a=b).

Figures (5a, 5b, and 5c) show the case in which the spacing between pontoons, a, is equal to twice the width of pontoon, b. The three figures show that K_t decreases, K_r increases and K_L decreases slightly with increasing the value of H_i/L. For example, when H_i/L increases from 0.026 to 0.1955 for G/D = 0.5, K_t decreases from 0.81 to 0.216, K_r increases from 0.275 to 0.718 and K_L decreases from 0.591 to 0.584, as shown in figure (5a). On the other hand, when the draft ratio, d_i/d, increases, K_t decreases and K_r increases, as shown in figures (5a, 5b, and 5c), when d_i/d increases from 0.1 to 0.3 for G/D = 1.0 and H_i/L = 0.096, K_t decreases from 0.571 to 0.208 and K_r increases from 0.705 to 0.762.

The best results for this case (a = 2b) are shown in figure (5c) where K_t equals 0.11 when G/D = 0.5, d_i/d = 0.3 and H_i/L = 0.1955. the values of the transmission coefficient are small .This is because of using pile system with decreasing the gap between piles and increasing the floating body draft ratio, d_i/d. both of them increase the wave energy loss. The effect of friction between the breakwater surface and the transmitted waves is considered important.

Figures (6a, 6b, and 6c) show the case in which the spacing between pontoons, a, is equal to three times the width of pontoon, b. With increasing the value of H_i/L, K_t decreases, K_r increases, while K_L obviously decreases. For example , when H_i/L increases from 0.026 to 0.1955 for G/D = 0.50 , K_t decreases from 0.816 to 0.288 , K_r increases from 0.352 to 0.789, and K_L decreases from 0.501 to 0.425 as shown in figure (6a). It may be could that, the efficiency of the suggested floating breakwater decreases by increasing the relative spacing between the two pontoons, a/b. For example, when a/b changes from 1.00 to 3.00 (6a, 6b, and6c) , when the value of d_i/d increases from 0.1 to 0.3 , for G/D = 0.75 and H_i/L = 0.123, K_t decreases from 0.489 to 0.274 and K_r increases from 0.781 to 0.852, while K_L increases from 0.46 to 0.525. In addition, the efficiency of the suggested breakwater is improved by increasing the floating body draft ratio, d_i/d. The best values for this case (a = 3b) are shown in figure (6c) where K_t = 0.126 when G/D = 0.50, d_i/d=0.30 and H_i/L = 0.1955.

For all configurations, when the gap ratio, G/D, decreases, K_t and K_r decrease, while K_L increases. For example, when the value of G/D decreases from 1.0 to 0.5 for H_i/L = 0.072, K_t decreases from 0.503 to 0.449, K_r decreases from 0.591 to 0.524 and K_L increases from 0.606 to 0.685, as shown in figure (4b).

Figure (7) shows a comparison between the results of the present work and results of other researchers, for different types of pontoon breakwaters moored by piles. The transmission coefficient curves of various types of floating breakwaters and the values of b/L are plotted in the figure. The figure shows that K_t decreases as b/L increases for all results. In addition, the figure shows that the suggested floating breakwater model has a suitable efficiency compared with other types of pontoon breakwaters. Table (2) shows the characteristics of different types of floating breakwaters supported by piles.

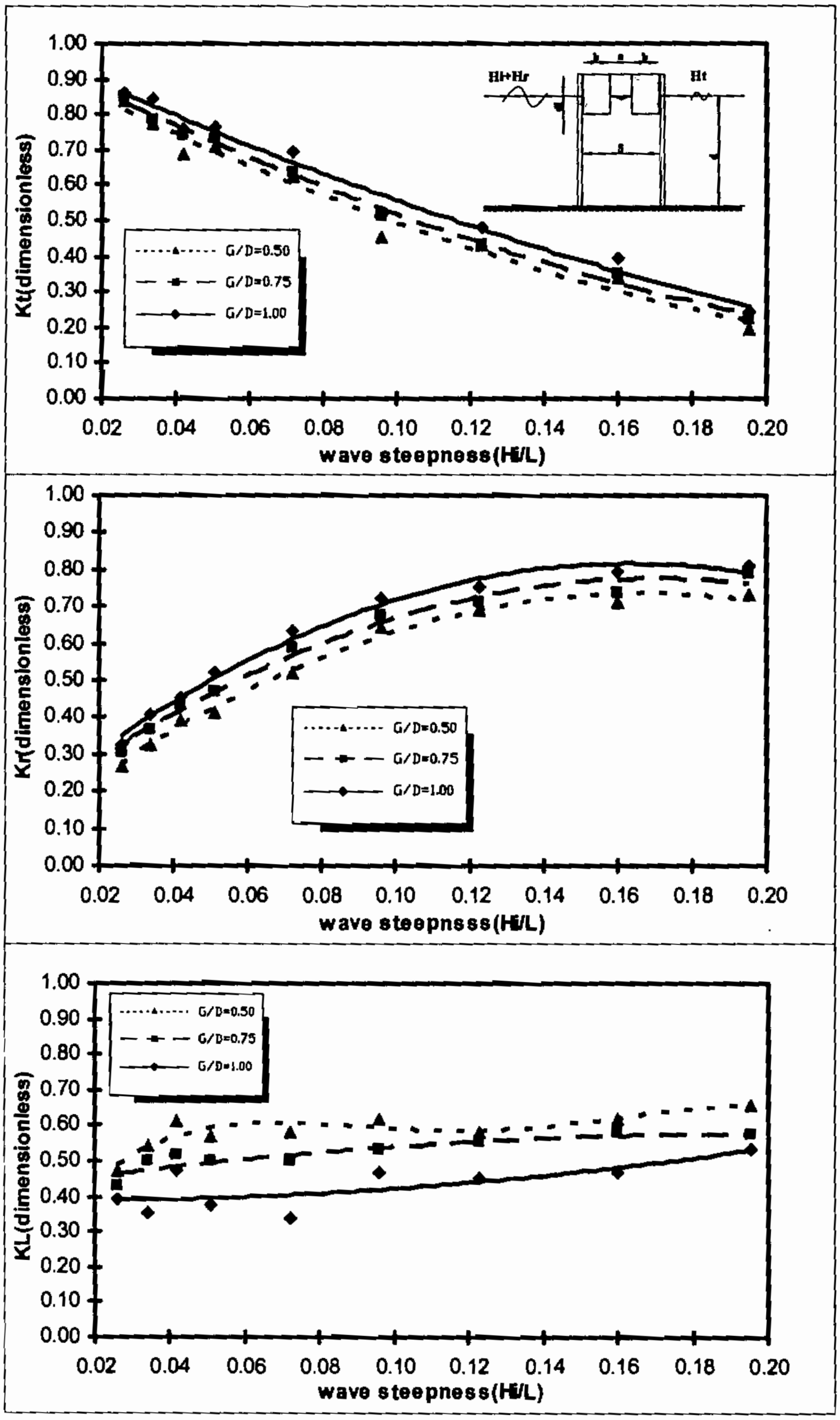

Fig. 5a . Relationship between the hydrodynamic coefficients (K_t,K_r and K_L) and the wave steepness (Hi/L) for different values of gap ratio(G/D) (di/d=0.10 and a=2b).

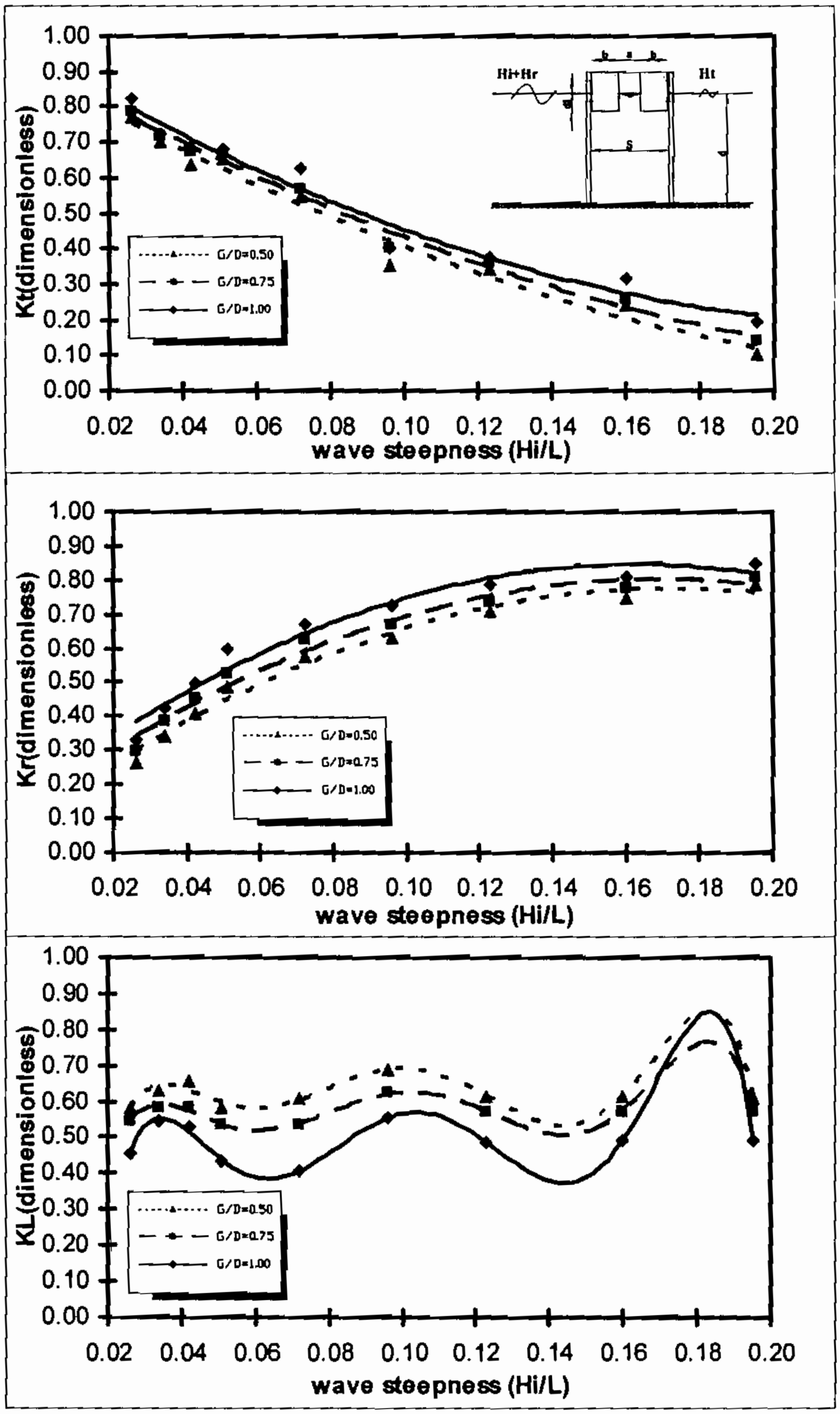

Fig. 5b . Relationship between the hydrodynamic coefficients (K_t,K_r and K_L) and the wave steepness (Hi/L) for different values of gap ratio(G/D) (di/d=0.20 and a=2b).

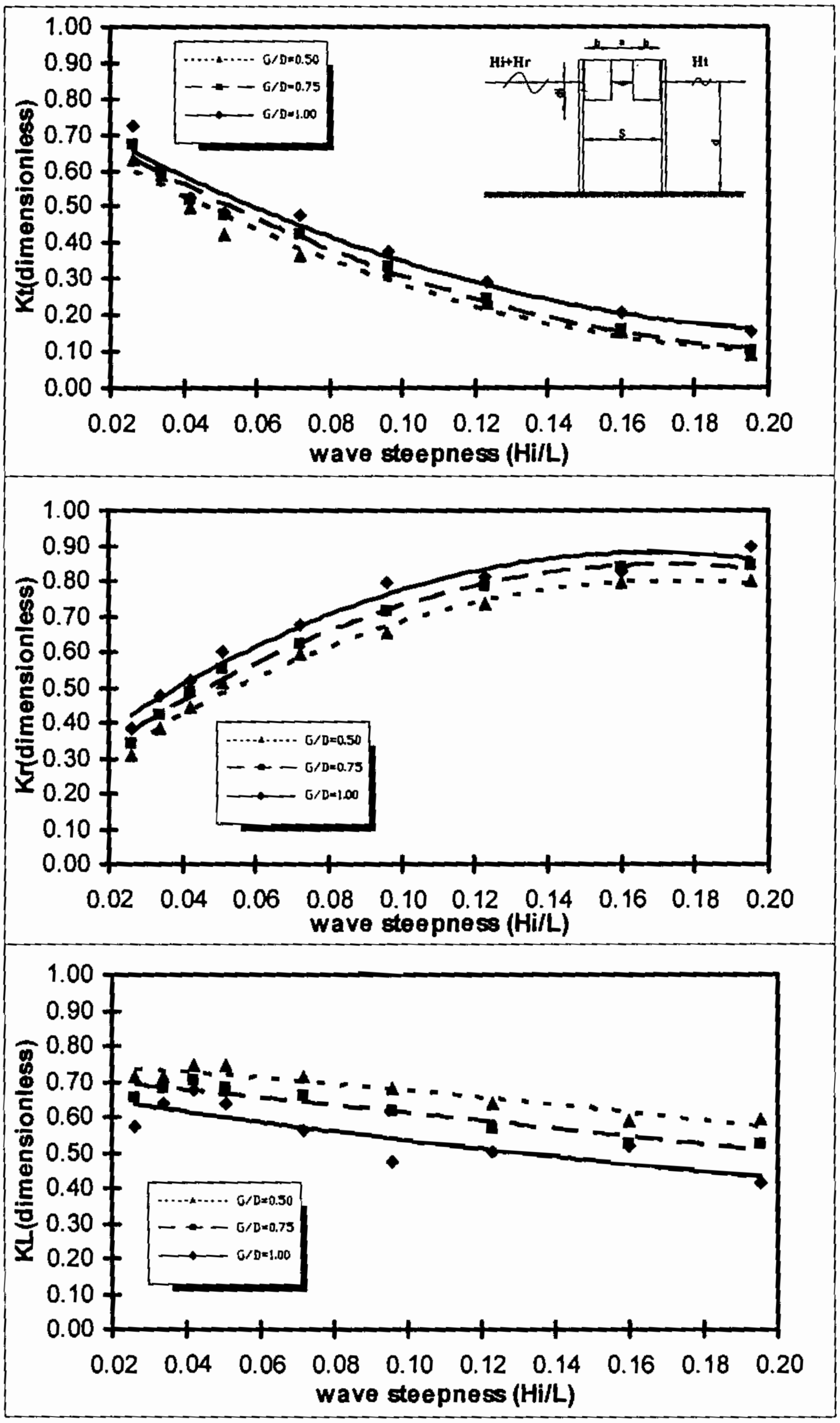

Fig. 5c . Relationship between the hydrodynamic coefficients (K_t,K_r and K_L) and the wave steepness (Hi/L) for different values of gap ratio(G/D) (di/d=0.30 and a=2b).

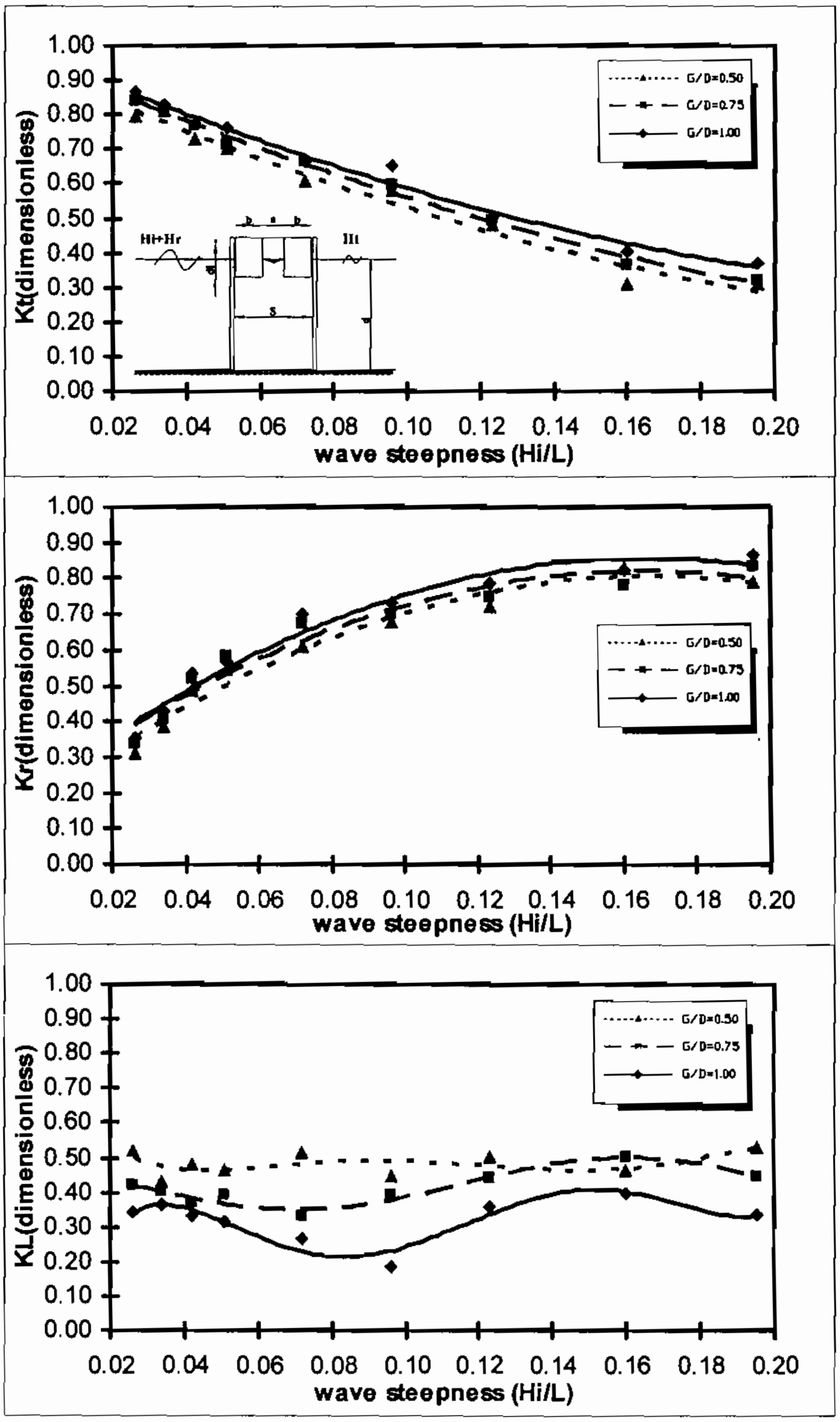

Fig. 6a . Relationship between the hydrodynamic coefficients (K_t,K_r and K_L) and the wave steepness (Hi/L) for different values of gap ratio(G/D) (di/d=0.10 and a=3b).

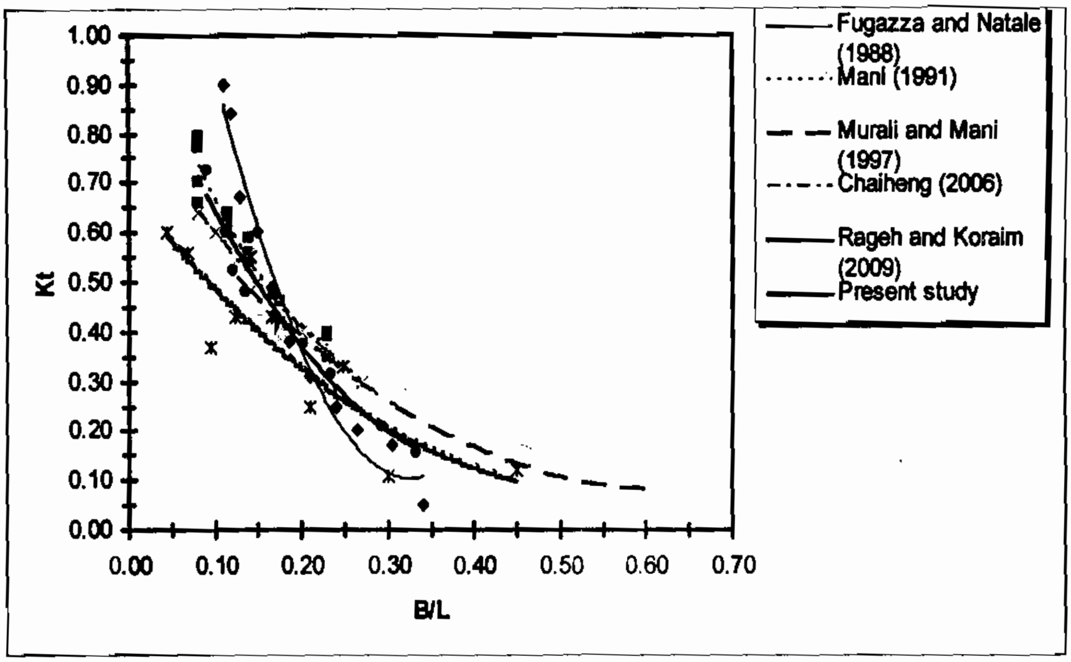

Fig. 7. Comparison between the present study and previous research works.

Table 2. Comparison between the present proposed model and other floating Breakwaters supported by piles.

Reference	FB Types	H_i/L	d_i/d	B/L	Notes
(1) Fuggazza and Natale (1988)	Rectangular caisson on piles	0.03-0.10	0.27	0.11-0.34	--------
(2) Mani (1991)	Y-Frame with pipes (trapezoial pontoon)	0.01-0.10	0.46	0.08-0.23	Rested on the pipes
(3) Murali and Mani (1997)	Cage Floating Breakwater (double trapezoidal)	0.01-0.10	0.46	0.125-0.625	Rested on the pipes
(4) Chalheng(2006)	2-row S.S.F.B.W.	0.01-0.08	0.133	0.08-0.27	Moored by piles
(5) Rageh and Koraim (2008)	Rectangular caisson fixed on rows of piles	0.01-0.1	0.4	0.045-0.45	--------
(6) present study	Fixed double pontoon with closely spaced piles	0.026-0.1955	0.2	0.09-0.33	a=2b G/D=0.50

5. CONCLUSIONS

The efficiency of the suggested floating breakwater was studied by using a physical model. 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 following conclusions could be drawn from the present study:

(1) The transmission coefficient, K_t, decreases as wave steepness, H_i/L, increases while the reflection coefficient, K_r, increases as wave steepness, H_i/L, increases, for all cases under study.

(2) Pile system improves the efficiency of the double Pontoon by about (7-16)% when G/D = 0.5 and a/b = 1.0.

(3) The efficiency of the suggested model increases slightly by decreasing the value of relative gap, G/D, from 1.0 to 0.5.

(4) The usage of pile system with small gaps between the double pontoon is more effective than using it with large ones.

(5) The transmission coefficient, K_t, decreases with the increasing value of relative breakwater draft, d_r/d, and with the decreasing value of both relative gap between two pontoons, a/b, and the pile gap-diameter ratio, G/D.

(6) Simple empirical equations for estimating the wave transmission and reflection coefficients were developed using non-linear regression analysis.

(7) The proposed breakwater model gives a reasonable efficiency compared with other pontoon types.

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NOMENCLATURE

The following symbols are used in this paper:

a	Distance between double pontoons;
B	Width of floating breakwater;
b	Width of pontoon;
D	Pile diameter;
d	Water depth;
d_i	Draft of pontoon;
f	Frequency
G	Gap between piles;
H_i	Incident wave height;
H_t	Transmitted wave height;
H_r	Reflected wave height;
K_t	Transmission coefficient
K_r	Reflection coefficient;
K_L	Energy loss coefficient;
L	Incident wave length;
P_1, P_2, P_3	Measuring positions;
S	Pile spacing parallel to wave direction; and (S=B)
T	Wave period.