HYDRODYNAMIC EFFICIENCY OF FLOATING BREAKWATERS WITH PLATES

الكفاءة الهيدروديناميكية لحواجز الأمواج العائمة ذات الألواح

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خلاصة: تم اختبار كفاءة حواجز الأمواج الطافية معمليا تحت ظروف الأمواج المتعامدة المنتظمة و بمجال واسع من خصائص الأمواج. اعتبرت كفاءة هذا النوع من الحواجز دالة في معامل الانتقال ومعامل الارتداد و معامل فقد طاقة الأمواج.وقد أختبرت العديد من العوامل المؤثرة على كفاءة هذا النوع من الحواجز كتوصيل ألواح راسية أسفل الجزء العائم في أماكن مختلفة و طول حبل تثبيت الحاجز في القاع و كذلك الطول الموجي. و قد اظهرت الدراسة أن معامل الانتقال يقل عندما يزداد كل من: عرض الحاجز النسبي و عدد الألواح المثبتة أسفل الحاجز و طول حبل التثبيت في القاع بينما يسلك معامل الارتداد عكس ذلك. كما أوضحت النتائج أن هذا النوع من الحواجز يساعد على فقد حوالي من ١٥% إلى ٣٠ % من طاقة الأمواج الساقطة عليه. أضافة الي أن الحاجز المقترح يعطي كفاءة عالية عند مقارنته بحواجز أخري.

ABSTRACT:

The efficiency of the floating breakwaters was experimentally studied under normal and regular waves with wide ranges of wave heights and periods. The efficiency of the breakwater is presented as a function of the transmission, reflection, and dissipation coefficients. Different parameters affecting the breakwater efficiency such as, the connection of the virtical plates under the floating body at different positions, length of mooring wires and the wave length were tested. It was found that, the transmission coefficient decreases with the increase of relative breakwater width (B/L), the number of plates and also with the increase of the relative wire length (l/h) whereas the reflection coefficient takes the opposite trend. In addition, the suggested floating breakwater system dissipates about 15% to 30% from the incident wave energy. Also, the suggested floating breakwater model is efficient compared with other types of pontoon breakwaters.

1. INTRODUCTION:

Recently, Floating Breakwaters become increasingly popular to form small marinas, fishing port and to control shoreline erosion at semi sheltered sites in estuaries and lakes, since their structure can ensure usually acceptable wave attenuation at relatively low costs. Floating breakwater offers an alternative to conventional fixed breakwaters such as rubble mound breakwaters. This type of breakwaters could be considered as a good and cost-effective substitute for the conventional type of breakwaters, especially for

Accepted June 30, 2009.

coastal works where the tranquility requirements are low. This type may be preferred where water depth or foundation considerations preclude the use of a bottom-founded structure. Furthermore, in certain applications, water circulation considerations may require that the breakwater does not pierce the free surface and/or extend down to the seabed.

However, at present stage, the floating breakwater has been mainly constructed for limited purposes as a simple portable breakwater, aqua-cultural facilities and as a floating wharf for yachts and ships. The important advantages of this type are: relatively inexpensive when compared with the other commonly used types; less maintenance cost; ease of construction; may be used in the areas where poor soil conditions prevail. In addition, this type is a conventional solution in deeper waters which can successfully be employed for low and moderate wave energy applications; occupy a relatively small zone and inducing little effects in the seabed creatures.

2. LITERATURE REVIEW:

In the past, several experimental and theoretical studies were carried out for determining the efficiency of floating structures of different shapes. The Bombardon floating breakwater which discussed in Lochner et al. (1948) was the first trial for studying the effect of floating breakwaters on the waves. Carr (1952), and Macagno (1953) investigated the case of a rectangular floating breakwater using linear wave theory. They gave a simple formula for estimating the wave transmission beneath the breakwater. Kato et al. (1966), Brebner and Ofuya (1968), Sutko and Haden (1974), Carver (1979), Yamamoto, et al. (1980), Yamamoto (1981), Carver and Davidson (1983) studied experimentally the two dimensional water wave diffraction by floating rectangular bodies.

McCartney (1985) introduced four types of floating breakwaters, including the box, pontoon, mat, and tethered, and analyzed their advantages and disadvantages. Fugazza and Natale (1988) studied theoretically and experimentally the wave diffraction problem around the fixed and floating caisson breakwater. Mani (1991) measured the transmission coefficients of the pontoon, mat, and tethered breakwaters. Drimer et al. (1992) presented a simplified design for a floating breakwater in which the breakwater width and the incident wave length were much larger than the gap between the breakwater and the sea bed. Gesraha (1995) studied the wave interaction with an infinitely long impermeable, rigid, rectangular pontoon in a finite arbitrary water depth.

Williams and Mc-Dougal (1996) conducted a two-dimensional analysis of a long tethered breakwater with a rectangular cross section. The breakwater can either be analyzed as fully submerged or floating. Murani and Mani (1997) measured the transmission and reflection coefficients of a cage floating breakwater under wave and wave-current conditions. Tolba (1998) summarized the performance of the rectangular floating breakwaters theoretically and experimentally. The tested models were fixed, limited roll motion, heave motion, and floating model connected with a vertical plate.

Bayram (2000) conducted an experimental study of an inclined pontoon breakwater in intermediate water depths for use with small commercial vessels and yacht marinas. Williams et al. (2000) theoretically investigated the hydrodynamic properties of a pair of long floating rectangular pontoon breakwaters. Kriezi et al. (2001) investigated numerically the effects of the rectangular floating breakwaters on wave propagation in shallow waters. Two cases were studied: (a) the floating body was fixed with a certain draft and (b) the floating body was allowed to move vertically. Koutandos et al. (2002) investigated the efficiency of elastically moored floating breakwaters using the finite-difference technique. Their mathematical model was based on the Boussinesq type equations in shallow and intermediate waters.

Liang et al. (2004) proposed the spar buoy floating breakwater and studied the wave reflection and transmission characteristics and the wave induced tension of the mooring lines. Gesrahab (2004) presented a theoretical solution to the problem of oblique wave interaction with rectangular cross section extremely flexible floating pontoons in water of finite depth. Koutandos et al. (2005) studied experimentally the hydrodynamic interaction of regular and irregular waves with floating breakwaters in shallow and intermediate waters in a large-scale facility. Rageh et al (2006) carried out an experimental study to determine the performance of a floating breakwater consisted of a mesh having spherical floating bodies restrained to the bed with anchor lines. Behzad and Akbari (2007) presented the experimental results of an investigation on the response and efficiency of floating pontoon type breakwaters under random waves. Dong et al. (2008) studied three types of structures: the single box, the double box, and the board net. They conducted two dimensional physical model tests in a wave-current flume to measure the wave transmission coefficients under regular waves with or without currents. Rageh and Koraim (2008) studied the efficiency of the breakwater consisted of caissons supporting on the two and three rows of piles using physical models. The efficiency of the breakwater was presented as a function of the transmission, reflection and the wave energy loss coefficients. Regular waves with wide ranges of wave heights and periods and a constant water depth were used.

In this paper, experimental tests were carried out to investigate the efficiency of a suggested floating breakwater systems on the wave attenuation. The influence of the incident wave characteristics (wave length and height) and certain geometric characteristics of the structure (breakwater width and draft), on its efficiency were examined. In addition, the effect of a series of vertical plates with depth (d) connected under the floating body at different positions was studied.

3. EXPERIMENTAL WORK:

This research was conducted in the Irrigation and Hydraulic Laboratory, Faculty of Engineering, Mansoura University, El-Mansoura, Egypt. The experimental runs were carried out to measure the transmission, reflection, and dissipation coefficients due to the existence of the suggested floating breakwater models using different parameters. The flume dimensions were15.0m long, 1.0m width, and 1.0m deep. The wave generator type was a flap type, which was hinged at the bed and connected with a flying wheel and variable speed motor. Two wave absorbers were used at the first and the end of the flume to prevent the wave reflection. The wave periods, and heights were recorded by using Sony MVC-CD 500 Digital Still Camera. Applying the slow motion technique, the wave heights were measured before and after the model instillation.

The suggested breakwater model consisted of a rectangular box made from wood with width "B" and draft "D". Also, a series of plates of depth "d" was connected under the rectangular box. Six cases were studied under regular waves. The model connected with the flume bed by wires of length "l". Details of the tested models are shown in the Figure (1). Figure (2) shows the details of wave flume, position of the tested breakwater model, and location of wave recording.

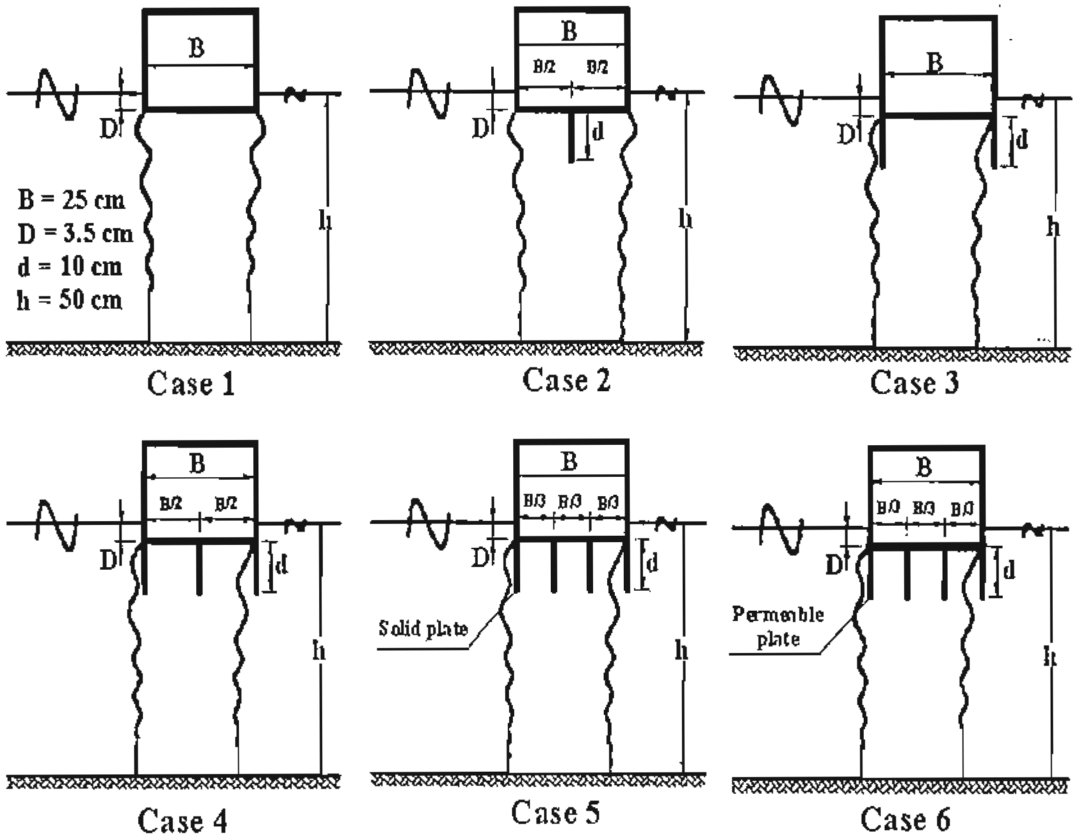

Figure 1. Details of the tested breakwater models.

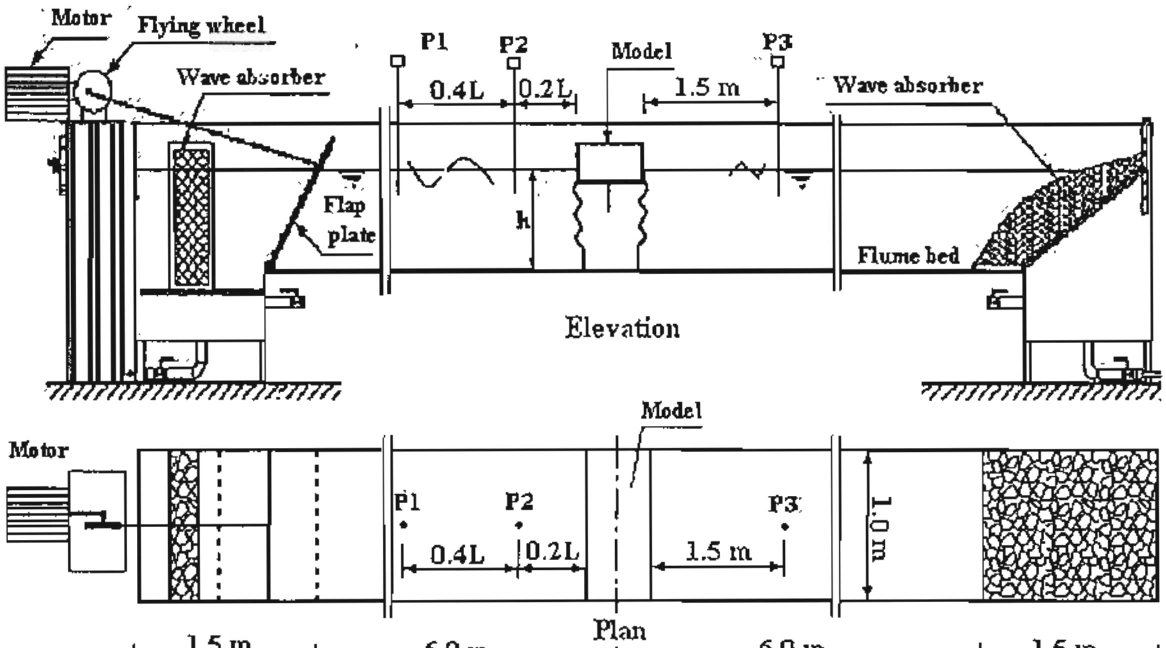

Figure 2. Details of wave flume, model position and wave recording locations.

The following parameters were used for the experimental set up:

- water depth (h) = 50cm.;
- range of incident wave height (H_i) = 5.0 – 10.0cm.;
- range of incident wave period (T) = 0.65 – 1.05sec.;
- range of incident wave length (L) = 66– 170cm.;
- breakwater width (B) = 25cm;
- breakwater draft (D) = 3.5cm;
- number of plates (n) = 1, 2, 3, 4, 4 plates with permeable one;
- plate depth (d) = 10.0cm; and
- wire length (l) = 0.93, 1.25, and 1.5h.

The maximum and the minimum wave heights ($H_{max.}$ and $H_{min.}$) at the wave generator side, upstream the breakwater, and the transmitted wave heights (H_t) at the wave absorber side, downstream the breakwater, were measured to estimate the reflection and the transmission coefficients (k_r and k_t) as follows:

$$H_i = (H_{max.} + H_{min.}) / 2 \quad (2)$$

$$H_r = (H_{max.} - H_{min.}) / 2 \quad (3)$$

Then;

$$k_r = H_r / H_i \quad (4)$$

$$k_t = H_t / H_i \quad (5)$$

In which, H_i and H_r are the incident and the reflected wave heights.

The energy equilibrium of an incident wave attack the structure can be expressed as follows:

$$E_i = E_r + E_t + E_L \quad (6)$$

In which, E_i is the energy of incident wave ($E_i=\rho g\ H_i^2/8$), E_r is the energy of reflected wave ($E_r=\rho g\ H_r^2/8$), E_t is the energy of transmitted wave ($E_t=\rho g\ H_t^2/8$), and E_L is the wave energy losses. Substituting in equation (6) by values of E_i, E_r, and E_t and dividing by E_i, yield:

$$1 = \frac{H_r^2}{H_i} + \frac{H_t^2}{H_i} + \frac{E_L}{E_i} \quad (7)$$

Substituting by equations (4) and (5) in equation (7), the wave energy loss coefficient ($k_L=E_L/E_i$) can be estimated as follows:

$$k_L = 1 - k_r^{\ 2} - k_t^{\ 2} \quad (8)$$

4.EXPERIMENTAL RESULTS AND ANALYSIS:

When a structure is installed in a marine environment, the presence of that structure will alter the flow pattern in its immediate neighborhoods, resulting in one or more of the following phenomena:

1. Formation of lee-wake vortices behind the structure.
2. Generation of turbulence.

3. Occurrence of reflected and diffracted of waves.
4. Occurrence of wave breaking.

These phenomena affect in dissipating of the wave energy in addition to the dissipation caused by the breakwater itself.

Many parameters affecting the breakwater efficiency are studied, such as the wave length, (L), the water depth (h), the breakwater width (B), the breakwater draft (D), the plates number and depth (n and d) and the wire length (l). The analysis presents the efficiency of the breakwater in a form of the relationships between transmission, reflection and energy dissipation coefficients (k_t, k_r, k_d) and the dimensionless parameters represent the wave and structure characteristics as in the following equation:

$$k_t, k_r, \text{ and } k_L = f(B/L, l/h, n) \qquad (9)$$

Figure 3 shows sample of the data at the three wave recording positions P1, P2, and P3 for case 1 of the above mentioned six cases (one plate) when l/h=0.93 and T=0.65 sec. Figures 3a and 3b show that the first 8.0 sec. of the wave elevation, the wave travels from the wave generator to the wave gauge at location P1 and P2, and reflects from the upward face of the breakwater model and the partial standing wave begins to build its shape. At the beginning of the formation of the partial standing wave some disturbance takes place. After that, the wave tends to be stable for some time (t=10 to 15 sec.) which is the period of a suitable zone to estimate the reflection coefficients. After this time, the form of the partial standing wave changes due to the new reflection of the wave from the wave generator, which generates a new incident wave with different characteristics. Figure 3c demonstrates that at the first 10.0 sec., the wave travels from the wave generator and cross the model until it reaches the wave gauge at location P3. Some disturbance appears in the shape of the transmitted wave for few seconds then, the wave seems to be very stable for some time (t=10 to 15 sec.) which is a suitable period to estimate the transmission coefficient.

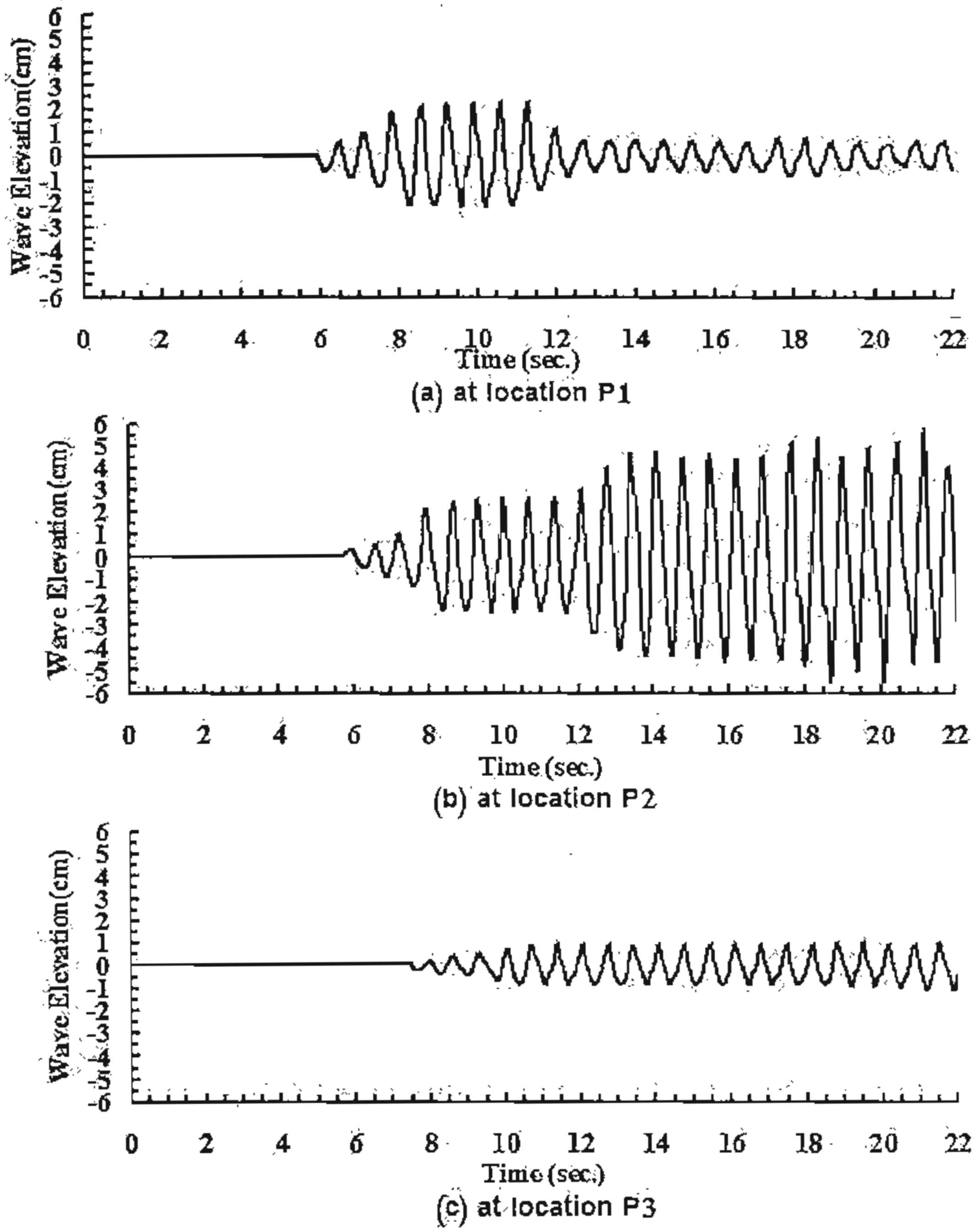

Figure 3. Variation of wave elevation with time at the wave recording positions for the case of one plate for l/h=0.93 and T=0.65 sec

Figure (4) presents the relationship between the transmission coefficient (k_t) and the relative breakwater width (B/L) for the different six cases when the relative weir length l/h=0.93, 1.25, and 1.5. The figure shows that, k_t decreases as B/L increases. This means that, the breakwater reduces the transmitted wave as wave becomes short. The above-mentioned behavior may be attributed to as the wave becomes short, the water particle velocity and acceleration suddenly change and the turbulence caused due to this sudden change causes a dissipation in the wave energy. Also, k_t decreases as the number of plates increases. This is due to the increase of the friction between the plates and the transmitted waves. Also, k_t decreases as l/h increases. This is attributed to the additional generated waves. When l/h=0.93, the model is tethered and its motion generates additional waves. For l/h=1.25 and 1.5, the breakwater takes its maximum sway motion at the beginning and it becomes stable, then the generated waves decrease. Also, the use of permeable plate (case 6) causes an increase in the values of k_t but these values are smaller than in case 5 .

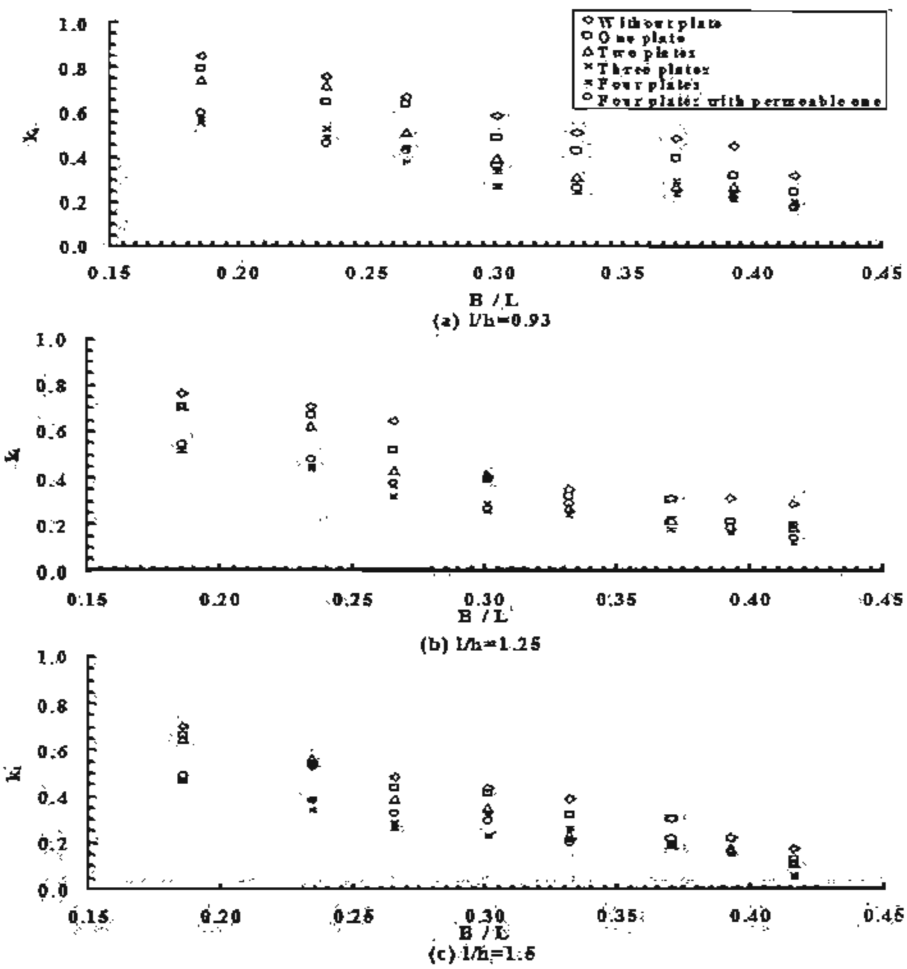

Figure 4. Relationship between the relative breakwater width (B/L) and the transmission coefficient (k_t) for the six different cases.

Figure (5) presents the relationship between the reflection coefficient (k_r) and the relative breakwater width (B/L) for the six different cases when the relative wire length l/h=0.93, 1.25, and 1.5. The figure shows that, k_r takes the opposite trend of k_t in which k_r increases as B/L, number of plates and l/h increase. Also, the use of permeable plate (case 6) causes a decrease of k_r values but these values are smaller than case 5.

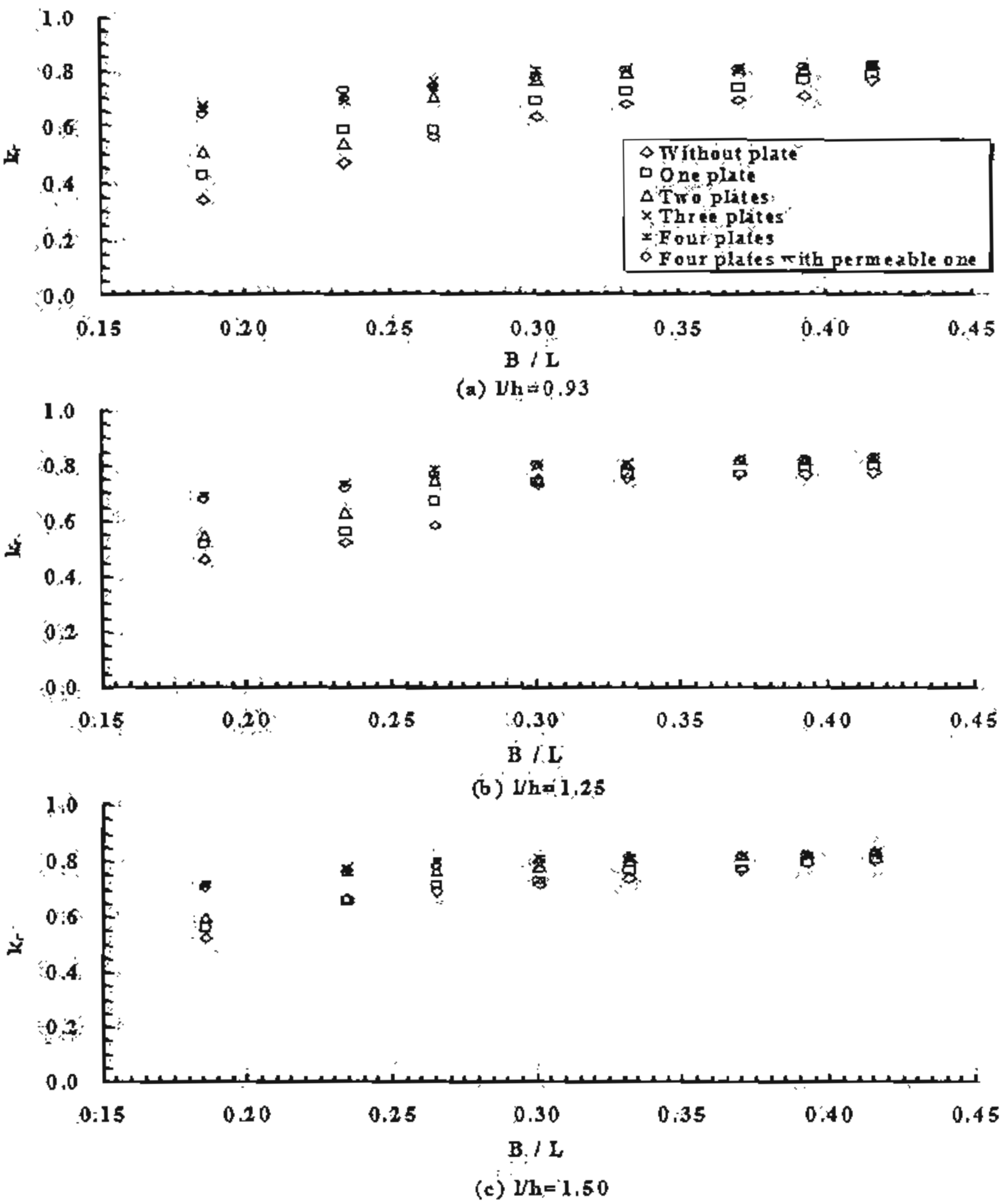

Figure 5. Relationship between the relative breakwater width (B/L) and the reflection coefficient (k_r) for the six different cases.

Figure (6) presents the relationship between the wave energy dissipation coefficient (k_d) and the relative breakwater width (B/L) for the six different cases when l/h=0.93, 1.25, and 1.5. The figure shows that, k_d slightly increases with B/L increases in which k_d increases from 0.15 to 0.30 when B/L increases from 0.19 to 0.42. Also, the effect of the number of plats and l/h on the value of k_d is relatively small and can be neglected.

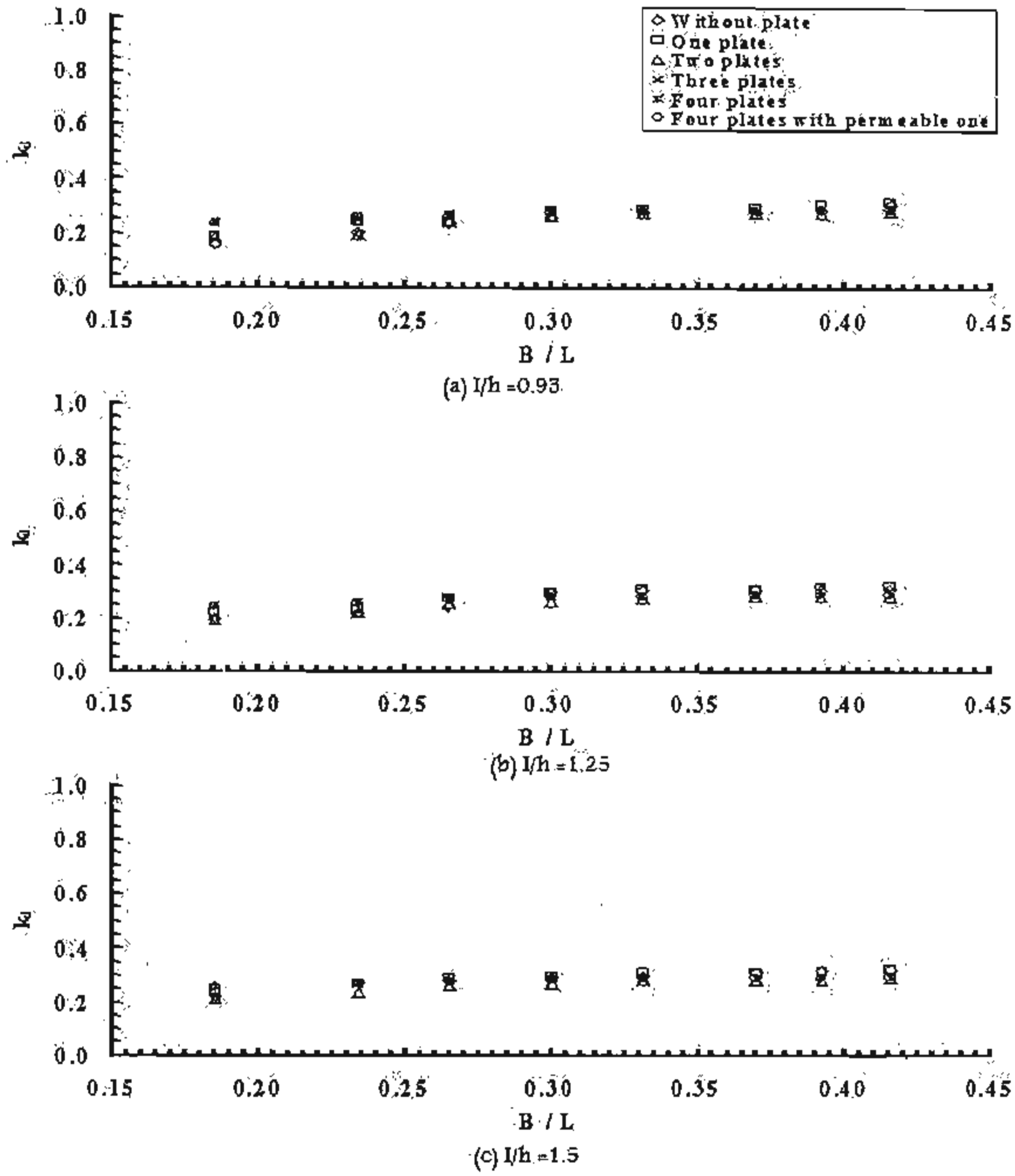

Figure 6. Relationship between the relative breakwater width (B/L) and the energy dissipation coefficient (k_d) for the six different cases.

Figure 7 presents a comparison between the results of the present work for the use of for impermeable plates (case 5),when l/h=1.5 with results of other authors for different types of pontoon breakwaters.. The figure shows that, k_t decreases with the increas of B/L for all of the present research. In addition, the figure shows that, the suggested breakwater model is efficient compared with other types of pontoon breakwaters.Table (1) presents a comparison between the present study and other studies

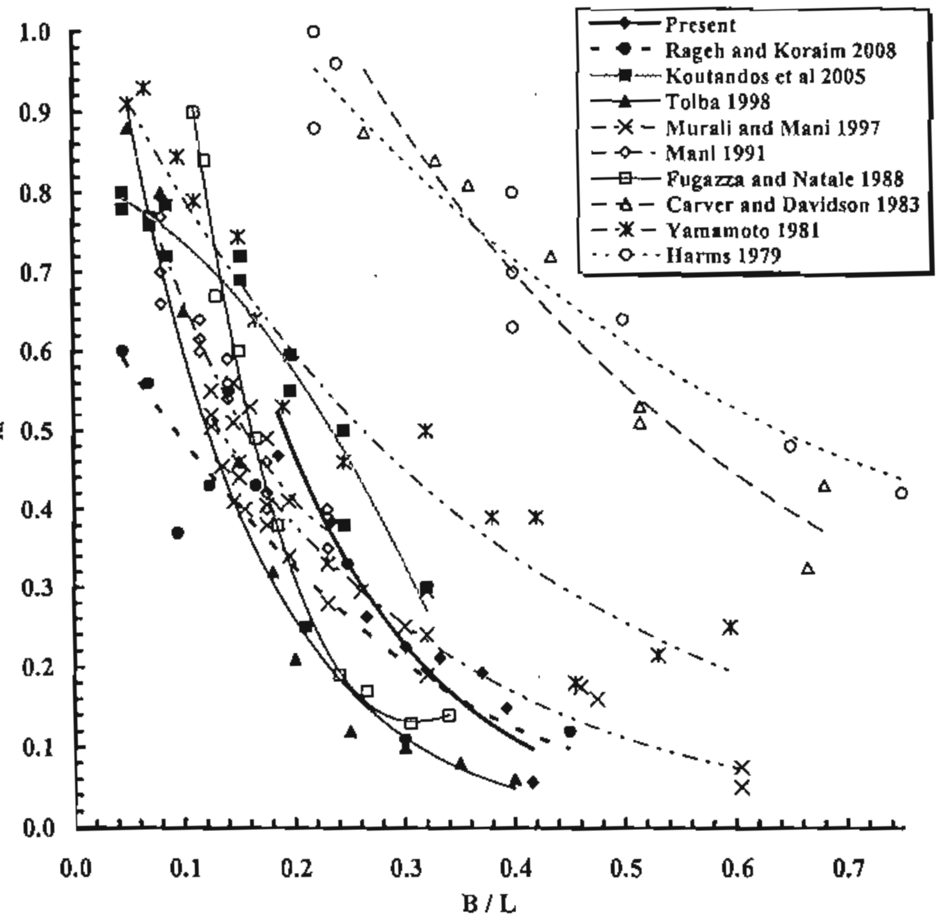

Figure 7. Comparison between the present breakwater model and the studies of different pontoon type breakwaters for some researchers.

Table (1) Characteristics of different laboratory-type floating breakwaters.

Reference	Floating breakwater type	H_i/L	D / h	B / L	Notes
Present	Rectangular pontoon	0.06-0.08	0.07	0.05-0.45	Four plates of d/h=0.2
Rageh and Koraim 2008	Rectangular caisson	0.01-0.10	0.4	0.05-0.45	Fixed on two rows of piles
Koudandos 2005	Rectangular pontoon	0.01-0.05	0.25	0.05-0.32	Two plates of d/h=0.1
Tolba 1998	Rectangular pontoon	0.04-0.06	0.25	0.05-0.40	
Murali and Mani 1997	Cage (double trapezoidal)	0.01-0.11	0.46	0.12-0.60	Two rows of permeable pipes
Mani 1991	Y- Frame (Trapezoidal pontoon)	0.01-0.10	0.46	0.08-0.23	One row of permeable pipes
Fugazza and Natale 1988	Rectangular caisson	0.03-0.10	0.27	0.10-0.35	
Carver and Davidson 1983	Trapezoidal pontoon	0.03-0.10	0.27	0.26-0.60	
Yamamoto 1981	Rectangular pontoon	0.01-0.14	0.07	0.05-0.60	
Harms 1979	Floating tire (rectangular)	0.03-0.06	0.23	0.22-0.75	Wave guard type

5. CONCLUSIONS:

The efficiency of suggested floating breakwater systems was stuided by using physical models. The influence of the incident wave and structure characteristics on the breakwater efficiency were examined. In addition, the effect of a series of vertical plates which connected under the floating body at different positions was studied. The following points could be drawn from this study:

1- The transmission coefficient (k_t) decreases with the increasing of values of B/L, number of plates and the relative length l/h. k_t value is less than 25% when B/L value is larger than 30% for the case of l/h equal to 1.5 using four impermeable plates (case 5).

2- The reflection coefficient (k_r) increases with the increase of B/L, number of plates and l/h. k_r value is more than 80% when B/L value is larger than30% for the case of l/h equal to 1.5 for the use of four impermeable plates.

3- The wave dissipation coefficient (kd) slightly increases with the increase of B/L

4-. The effect of the number plats and the value of l/h on k_d is relatively small and can be neglected.

The suggested floating breakwater model is efficient compared with other types of pontoon breakwaters. In general this model dissipates about 15% to 30% from the incident wave energy.

REFERENCES:

1. Bayram, A. (2000), "Experimental study of a sloping float breakwater", Ocean Engineering Vol. 27, pp: 445–453.
2. Behzad, M. and Akbari, M. (2007), "Experimental investigation on response and efficiency of moored pontoon type floating breakwaters", Iranian Journal of Science & Technology, Engineering, Vol. 31, No. B1, pp: 95-99
3. Brebner, A. and Ofuya, A.O. (1968), "Floating breakwaters", In: Proceeding of 15th Coastal Engineering Conference, pp: 1055-1085.
4. Carr, J.H. (1952), "Mobile breakwater", In: Proceeding of the Second Conference on Coastal Engineering, Berkeley, California, pp: 281-295.
5. Carver, R.D. (1979), "Floating breakwater wave-attenuation tests for East Bay Marina, Olympia Harbor, Washington; Hydraulic model investigation", Technical Report HL79-13, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.
6. Carver, R.D. and Davidson, D.D. (1983), "Sloping floating breakwater model study", In: Proceeding of the Specialty Conference on Design Construction, Maintenance and Performance of Coastal Structures, 83A, pp: 417-432.
7. Drimer, N., Agnon, Y., and Stiassnie, M. (1992), "Simplified analytical model for a floating breakwater in water of finite depth", Applied Ocean Research Vol. 14, pp: 33–41.

8. Dong, G.H., Zheng, Y.N., Lia, Y.C., Teng, B., Guan, C.T. and Lin, D.F. (2008), "Experiments on wave transmission coefficients of floating breakwaters", Ocean Engineering, Vol. 35, pp: 931–938.
9. Gesrahab, M.R. (1995), "Hydrodynamic of floating pontoons under oblique waves", MSc. Thesis, Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University, Giza, Egypt.
10. Gesrahab, M.R. (2004), "An Eigen function expansion solution for extremely floating pontoons in oblique waves", Applied Ocean Research, Vol. 26, pp: 171-182.
11. Fugazza, M. and Natale, L. (1988), "Energy losses and floating breakwater responses", J. of Waterway, Port, Coastal and Ocean Engineering, ASCE Vol. 114, No.2, pp: 191–205.
12. Kato, J., Hagino, S., and Uekita, Y. (1966), "Damping effect of floating breakwaters", J. of Waterways and Harbor Division-ASCE, Vol. 95 No. 3, pp: 1068-1078.
13. Kriezi, E.E., Karambas, T.V., Prinos, P. and Koutitas, C. (2001), "Interaction of floating breakwaters with waves in shallow waters", International Conference IAHR 2001, Beijing, China, pp: 69-76.
14. Koutandos, E.V., Karambas, T.V., Prinos, P. and Koutitas, C. (2002), "Floating breakwaters efficiency in intermediate and shallow waters", 5th International Conference of Hydro-Science and Engineering, Warsaw, Poland, pp:
15. Koutandos, E., Prinos, P., and Gironella, X. (2005), "Floating breakwaters under regular and irregular wave forcing: reflection and transmission characteristics", J. of Hydraulic Research Vol. 43, No. 2, pp: 174-188.
16. Liang, N.K., Huang, J.S., and Li, C.F. (2004), "A study of buoy floating breakwater", Ocean Engineering Vol. 31, pp: 43-60.
17. Lochner, R., Faber, O., and Penny, W.G. (1948), "The Bombardon floating breakwater", The Civil Engineer in War, Vol. 2, Docks and Harbors, The Institution of Civil Engineers, London, England.
18. Macagno E.O. (1953), "Fluid mechanics: experimental study of the effects of the passage of a wave beneath an obstacle", In: Proceedings of the Academic des Sciences, Paris, France.
19. Mani, J.S. (1991), "Design of Y-frame floating breakwater", J. of Waterway, Port, Coastal, and Ocean Engineering-ASCE Vol. 117, No. 2, pp: 105–119.
20. McCartney, B.L. (1985), "Floating breakwater design", J. of Waterway, Port, Coastal, and Ocean Engineering-ASCE Vol. 111, No. 2, pp: 304–318.
21. Murani, K. and Mani, J.S. (1997), "Performance of cage floating breakwater", J. of Waterway, Port, Coastal, and Ocean Engineering-ASCE Vol. 123, No. 4, pp: 172-179.
22. Rageh, O.S., El-Alfy, K.S., Shamaa, M.T. and Diab, R.M. (2006), "An experimental study of spherical floating bodies under waves", In: Proceedings of 10th International Water Technology Conference, IWTC10, Alexandria, Egypt, pp: 357-375.

23. Rageh, O. S., and Koraim A. S. (2008), "Hydrodynamic efficiency of partially immersed casinos supported on piles", 12[th] International Water Technology Conf.- Alexandria, Egypt, 1365-1380.
24. Sutko, A.A. and Haden E.L. (1974), "The effect of surge, heave and pitch on the performance of a floating breakwater", In: Proceedings of the Floating Breakwater Conference, Newport, Rhode Island, pp: 41-53.
25. Tolba, E.R. (1998), "Behavior of floating breakwater under wave action", Ph.D. Thesis, Suez Canal University, Egypt.
26. Williams, A.N. and Mc-Dougal, W.G. (1996), "Dynamic Submerged Breakwater", J. Waterway, Port, Coastal and Ocean Engineering-ASCE, Vol. 122, No. 6, pp: 288-296.
27. Williams, A.N., Lee, H.S., and Huang, Z. (2000), "Floating pontoon breakwaters", Ocean Engineering Vol. 27, pp: 221–240.
28. Yamamoto, T. (1981), "Moored floating breakwater response to regular and irregular waves", Applied Ocean Research Vol. 3, pp: 114-123.

NOTATION:

The following symbols are used in this paper

Symbol	Definition
B	breakwater width;
d	plate depth;
D	breakwater draft;
E_i	energy of incident waves;
E_L	energy wave losses;
E_r	energy of reflected waves;
E_t	energy of transmitted waves;
g	acceleration of gravity;
h	water depth at the breakwater site;
H_i	incident wave height;
$H_{max.}$	maximum wave height seaward the model
H_{min}	minimum wave height seaward the model
H_r	reflected wave height;
H_t	transmitted wave height;
k_r	reflection coefficient;
k_t	transmission coefficient;
l	wire length;
L	wave length at breakwater site;
n	number of plates
T	wave period; and
ρ	water density.