AN EXPERIMENTAL STUDY OF SPHERICAL FLOATING BODIES UNDER WAVES

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ABSTRACT

An experimental research was carried out to investigate the wave attenuate by using spherical floating bodies. The new suggested floating breakwater (F.B.W) consists of one, two, or three rows of spherical floating bodies which having different diameter and draft. The floating bodies were attached by anchor chain to the bed and restrained with others by mesh links. The effect of different F.B.W parameters, different incident waves and the location of breakwater were tested.

The study indicated that the efficiency of the suggested F.B.W increases when used near/at deepwater zone (i.e. the incident waves is short-crested waves). Also, the increasing of the used rows number, the floating bodies draft and diameter has pronounced effect on the wave damping. On the other hand, the study shows that the losses on the incident wave energy increased when the wave steepness increased.

The results were represented in the form of curves. Proposed equations to calculate the transmission wave coefficient for the suggested floating breakwater were obtained by using regression analysis. The results were compared with other previous works and show good agreement.

INTRODUCTION

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.

Different types of floating breakwaters were developed and several conclusions were made. The list of different types of breakwaters that were modeled and/or conducted was quite long, but they could be divided into four basic groups: box, pontoon, mat, and tethered float.

Many investigators studied problems of floating breakwater experimentally.

Carr (1952) and Tolba (1998) studied the same problem when floating rectangular breakwaters were used and many conclusions were then drawn. **Wiegel (1960)** carried out an experimental study to test the efficiency of a rigid thin vertical floating barrier on the wave damping. He gave approximate equation to calculate the wave transmission coefficient behind the barrier. Also **Reddy and Neelamanit (1992)** studied experimentally the differences in the dynamics wave coefficients values which resulted from using partially immersed thin rigid vertical barrier under deepwater waves condition. They concluded that the reflection wave coefficient was increased and the transmission wave coefficient was decreased as the immersed part of the barrier and the wave steepness were increased. **Williams and Mc-Dougal (1996)** conducted two-dimensional analysis of long tethered breakwater with rectangular cross section. They concluded that the increasing the draft as well as the width of the breakwater caused strong effect on the wave attenuation.

Many theoretical solutions for the floating breakwater problems were carried out. **Liu et al (1982)** applied the boundary integral equation method to examine both the vertical and inclined thin floating breakwater, while **Losada et al. (1992), Gesrahab (1995), and Abul-Azm et al. (1997)** used the Eigen function expansion method to solve such problem. **Kriezi et al. (2001)** investigated numerically the effects of the rectangular floating breakwater on wave propagation in shallow water, while **Kutands et al. (2001)** investigated the efficiency of moored floating breakwater using the finite difference technique knowing that the mathematical model is based on the Boussinesq type equations in shallow and intermediate water. **Rageh et al. (2005)** carried out an experimental study to determine the performance of F.B.W. on the wave attenuation. They concluded that the wave energy and heights were decreased with decreasing the gaps of floating bodies. Also, the increasing of the rows of floating bodies in addition to the spacing between them motivated both the wave energy and heights to be decreased.

In the present study, the wave reflection and transmission characteristics were tested applying the new idea of the suggested spherical floating bodies of different diameters and drafts as floating breakwaters.

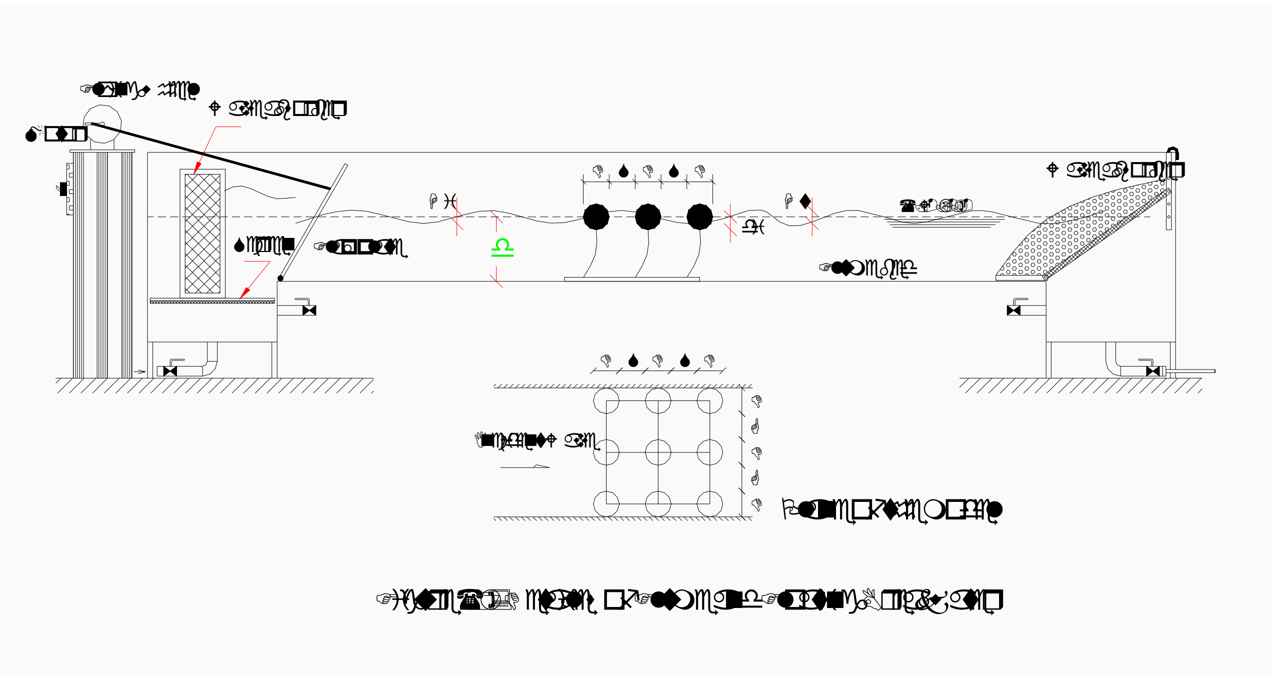
EXPERIMENTAL STUDY

The experiments were conducted in the Irrigation and Hydraulic Laboratory, Faculty of Engineering, El-Mansoura University. The runs were carried out to measure the transmission and the reflection coefficient due to the existence of the suggested F.B.W. using different parameters. The flume dimensions are 15.10m long, 1.00m width, and 1.00m 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 heights were recorded by using Digital Camera and applying the slow

motion technique, the wave heights were measured before and after the model. Figure (1) shows the details of the flume and the floating breakwater.
The following parameters were used for all runs:

- Water depth (d) = 0.50m.;
- Range of incident wave height (H_i) = 6.4 – 14cm.;
- Range of incident wave period (T) = 0.90 – 1.90sec.;
- Range of incident wave length (L) = 125 – 380cm.;
- The ratio between rows spacing and floating diameter (S/D) = 2;
- The gaps of floating bodies to its diameter ratio (G/D) = 0;
- Diameter of the floating bodies (D) = 8.50, 15.00 and 20cm.;
- The draft of the floating bodies to water depth ratio (d_i/d) = 0.10, 0.20, 0.30cm.; and
- Length of anchor line (la) = 0.50, 0.75, and 1.00m.

The suggested F.B.W consisted of a mesh from spherical floating bodies restrained to the bed with anchor lines. The floating bodies gaps(G) and the rows spacing (S) were fixed during runs while the floating bodies diameter (D), draft (di) and the length of anchor lines (la) were changed three times.



During the experimental work, two measuring points at a distance L/4 and L/2 seaward the model face were chosen to determine the incident and the reflected wave heights. The wave period, length and height were recorded by using Sony MVC-CD 500 Digital Still Camera. The slow motion technique was used to measure the wave period, length, and the wave crest and also the trough elevations for each run. The measured wave parameter data are colleted in table (1).

The incident, reflected and transmitted wave heights were recorded, then the transmission wave coefficient ($C_t = H_t/H_i$) and the reflection wave coefficient ($C_r = H_r/H_i$) can be calculated based on measured wave heights.

Table (1): Measured Wave Parameters Data

F (Hz)	T (sec)	L (cm)	Hi (cm)
2.70	1.89	380.00	6.40
3.00	1.72	337.73	7.03
3.30	1.36	246.00	7.90
3.60	1.22	213.00	9.00
4.00	1.07	170.00	10.90
5.00	0.98	147.00	12.10
6.00	0.95	136.67	13.00
7.00	0.90	125.73	14.00

*The eccentricity of the flying wheel was 12.25 cm for all runs.

EXPERIMENTAL RESULTS AND ANALYSIS

The experimental results showed that, the different parameters of floating bodies had a noticeable influence on the wave characteristics of the upstream and downstream suggested F.B.W, which would be discussed in the following analysis of the experimental results.

Effect of Restrained and Anchor Line Length on the F.B.W Efficiency:

The free (unrestrained) and restrained floating breakwater models with chains were tested as shown in figure (2) to (4). The testes showed that, the transmission coefficient of free model case was greater than that of the restrained one. In figure (2), the use of ***one row*** F.B.W, indicted that the difference in the values of C_t increased from about 0.04 when Hi/L was less than 0.06 to about 0.30 when Hi/L = 0.111. Also the use of ***two rows*** of F.B.W as shown in figure (3) cleared that, the difference in the values of C_t was increased from about 0.04 when Hi/L less than 0.06 to about 0.28 when Hi/L = 0.111. It is evident that for using ***three rows*** of F.B.W as shown in figure (4), the restrained model gave values of C_t less than those of free model about 17% to 29% with the increasing of Hi/L. It is worthy to note that the high values of C_t of the free model can be due to the free motion of each floating body, which generated additional waves. Then, the transmitted waves were the result of the generated waves and the portion of incident waves past the breakwater. For the above mentioned advantages the restrained floating breakwaters proved to be better than the free model.

The variation of the transmission wave coefficient with the changing of anchor chain was investigated. The anchor chain length to water depth ratio la/d was changed three times 1.00, 1.25 and 1.50 for the suggested one, two, or three rows of F.B.W. The results showed that the length of anchor chain has a very little effect on the transmission wave coefficients. From which, the anchor chain was used to held the floating breakwater in the place but it had no effect on the wave attenuation. Then, the anchor chain length must be selected taking into consideration the forces in the chain and the tidal range effect in real open sea.

***Effect of floating diameter D on Ct and Cr*:**

To check the influence of the diameter of the float bodies, three values with D/d=0.40,0.33 and 0.17 were used as shown in figures from (5) to (7). The results showed that as the ratio D/d was increased, where the transmission coefficient was decreased and the reflection coefficient was increased as well.

Figure (5) show that the relation between the coefficients of Cr & Ct and wave steepness Hi/L for the different values of D/d. From that figure, it is evident that *for one row* of floating bodies, when the wave steepness Hi/L increases the coefficient Ct decreases and Cr increases. For Hi/L values less than about 0.05, the effect of D/d changes on C_t is insignificant that C_t decreases from 1.00 to 0.969 for D/d increases from 0.17 to 0.40 for Hi/L = 0.017. When Hi/L increases to 0.111, the effect of increasing of D/d from 0.17 to 0.40, while C_t decreases from 0.864 to 0.514.

For two rows of suggested F.B.W, as shown in figure (6), when the wave steepness Hi/L increases the coefficient decreases from 0.891 to 0.393 and C_r increases from 0.266 to 0.729 for D/d = 0.40. For Hi/L values less than about 0.05, the effect of D/d changes on C_t is insignificant that C_t decreases from 0.984 to 0.891 for D/d increases from 0.17 to 0.40 for Hi/L = 0.017. Therefore, when Hi/L increases to 0.111, the effect of increasing of D/d from 0.17 to 0.40, while C_t decreases from 0.786 to 0.393.

For the suggested F.B.W consists of three rows of floating bodies, as shown in figure (7), when the wave steepness Hi/L increases C_t decreases from 0.703 to 0.121 and C_r increases from 0.625 to 0.643 for D/d = 0.40.

The effect of D/d changes on C_t is sensitively for all values of Hi/L but these effect increases also with increases Hi/L. From figure (7), when D/d increases from 0.17 to 0.40 C_t decrease from 0.969 to 0.720 at Hi/L = 0.017 and from 0.743 to 0.183 when Hi/L = 0.111. Generally, when the ratio of D/d increases the efficiency of F.B.W. would be improved.

Effect of floating draft di on Ct and Cr:

Figures from (8) to (10) show the relationship between the coefficients C_t and C_r and wave number kd for the different values of the ratio di/d. From these figures, it is evident that, as the value of draft di was increased for constant water depth, the ratio di/d increased as well as C_t decreased and C_r increased. For example when G/D = 0.00 and di/d increases from 0.10 to 0.30 then C_t decreases from 0.65 to 0.514 for *one rows* of F.B.W [see figure (8], C_t decreases from 0.464 to 0.393 for *two rows* of F.B.W [see figure (9)], and decreases from 0.343 to 0.121 for *three rows* of F.B.W [see figure (10)]. It means that the effect of di/d on C_t which increases due to the increase of the number of rows used.

For the suggested F.B.W consists of one row of floating bodies, see figure (8) as an example, when kd increases from 0.826 to 1.474 C_t changes with small value from 1.00 to 0.989. After this, when kd increases to 2.497 C_t decreases to 0.736 for di/d = 0.30. Also, the difference in C_t values when kd decreases is less than that difference when kd increases during di/d increases from 0.10 to 0.30. It means that the effect of di/d changes is insignificant for kd small (i.e. long incident waves) but when kd increases (i.e. short incident waves) the effect of di/d is sensitively.

For the suggested F.B.W consists of two rows of floating bodies, see figure (9) as an example, when kd increases from 0.826 to 1.474 C_t changes with a small value from 0.953 to 0.928. After this, when kd increases to 2.497 C_t decreases to 0.579 for di/d = 0.30. Also, the difference in C_t values when kd decreases is less than that difference when kd increases during di/d increases from 0.10 to 0.30. It means that the effect of di/d changes is insignificant for kd which is relatively small (i.e. long incident waves) but when kd increases (i.e. short incident waves) the effect of di/d is getting more sensitive.

For the suggested F.B.W consists of three rows of floating bodies, when kd increases from 0.826 to 1.474, C_t changes with small value from 0.977 to 0.956. After this, when kd increases to 2.497, C_t decreases to 0.671 for di/d = 0.20 as shown in figure (10). Also, the difference in C_t values when kd decreases is less than that difference when kd increases during di/d increases from 0.10 to 0.30.It means that the effect of di/d changes is insignificant for small values of kd but when kd value increases the effect of di/d is getting more clearly sensitive.

It is clear from the results shown in the previous figures from (8) to (10) that, at the same values of D/d and kd, coefficient of C_t decreases and C_r increases with the increase of the value of di/d. The figures also indicate that maximum reflection and the minimum transmission coefficients are found near the deep water zone (i.e. short-crested waves), while the maximum transmission and the minimum reflection occur near shallow water zone (i.e. long-crested waves).

Energy loss and wave-F.B.W. interaction:

Theoretically, energy equilibrium of an incident wave attack the F.B.W can be expressed as follows:

$$E_i = E_t + E_r \tag{1}$$

or

$$\frac{\rho g H_i^2}{8} = \frac{\rho g H_t^2}{8} + \frac{\rho g H_r^2}{8} \tag{2}$$

in which:

E_i = the incident wave energy,
E_t = the transmitted wave energy, and
E_i = the reflected wave energy.

Equation (2) can be rewritten after dividing both sides by H_i^2 as:

$$1 = \left(\frac{H_t}{H_i}\right)^2 + \left(\frac{H_r}{H_i}\right)^2 \tag{3}$$

or

$$1 = C_t^2 + C_r^2 \tag{4}$$

In practice, when the wave reaches the F.B.W, wave reflection and transmission would occur in order to some of the incident wave energy would dissipate. Thus, the equation (4) can be rewritten considering the coefficient of energy loss as follows:

$$1 = C_t^2 + C_r^2 + C_l^2 \tag{5}$$

then, the loss coefficient can be expressed as follows:

$$C_l = \sqrt{\left(1 - C_t^2 - C_r^2\right)} \tag{6}$$

in which:

C_t = the coefficient of transmission,
C_r = the coefficient of reflection, and
C_l = the coefficient of energy loss.

The energy loss increases when the wave steepness increases too (as mentioned before as most of the kinetic energy is concentrated near the water surface) as shown in figures (11), (12), and (13).

General equations for the transmission wave coefficient, c_t:

Using the regression analysis, the general form selected in this work, where the equation relating a dependent Pi-term with a number of independent Pi-terms is in the form of the product of powers of relevant Pi-terms, i.e.,

$$\pi_1 = C\,\pi_2^{a2}\,\pi_3^{a3}\,\pi_4^{a4}\ldots\ldots\ldots\ldots\ldots\pi_m^{am} \tag{7}$$

This equation (7) can be transformed to a linear expression by taking logarithms of both sides of the equation, as follows:

$$\log \pi_1 = \log C + a_2 \log \pi_2 + a_3 \log \pi_3 + a_4 \log \pi_4 + \ldots\ldots\ldots + a_m \log \pi_m \tag{8}$$

Finally, the equation can be rewritten in matrices form as follows:

$$\left|\begin{array}{ccccc} N & \sum \log \pi_2 & \sum \log \pi_3 & \cdots & \sum \log \pi_m \\ \sum \log \pi_2 & \sum \log \pi_2 \log \pi_2 & \sum \log \pi_3 \log \pi_2 & \cdots & \sum \log \pi_m \log \pi_2 \\ \sum \log \pi_3 & \sum \log \pi_2 \log \pi_3 & \sum \log \pi_3 \log \pi_3 & \cdots & \sum \log \pi_m \log \pi_3 \\ \ldots\ldots & \ldots\ldots\ldots\ldots & \ldots\ldots\ldots\ldots & \cdots & \ldots\ldots\ldots\ldots \\ \sum \log \pi_m & \sum \log \pi_2 \log \pi_m & \sum \log \pi_3 \log \pi m & \cdots & \sum \log \pi_m \log \pi_m \end{array}\right| \left|\begin{array}{c} \mathrm{Log}\ C \\ \alpha_2 \\ \alpha_3 \\ \ldots\ldots \\ \alpha_m \end{array}\right| = \left|\begin{array}{c} \sum \log \pi 1 \\ \sum \log \pi_1 \log \pi_2 \\ \sum \log \pi_1 \log \pi_3 \\ \ldots\ldots\ldots \\ \sum \log \pi 1 \log \pi_m \end{array}\right| \tag{9}$$

Where, N is the number of observations.

Then, the values of the parameters $C, a_2, a_3, \ldots\ldots, a_m$ are obtained and can be replaced back into equation (7).

Then the equations can be rewritten as follows:

***For suggested F.B.W consists of one row** *of floating bodies:**

$$C_t = 0.8968\left(\frac{\mathrm{H_i}}{\mathrm{L}}\right)^{0.0004} (\mathrm{kd})^{-0.1427} \left(\frac{\mathrm{D}}{\mathrm{d}}\right)^{-0.0469} \left(\frac{\mathrm{d_i}}{\mathrm{d}}\right)^{-0.0335} \left(\frac{\mathrm{G}}{\mathrm{D}}\right)^{0.0002} \tag{10}$$

***For suggested F.B.W consists of two rows** *of floating bodies:**

$$C_t = 0.00375\left(\frac{\mathrm{H_i}}{\mathrm{L}}\right)^{-1.4191} (\mathrm{kd})^{2.1805} \left(\frac{\mathrm{D}}{\mathrm{d}}\right)^{-0.0618} \left(\frac{\mathrm{d_i}}{\mathrm{d}}\right)^{-0.0928} \left(\frac{\mathrm{G}}{\mathrm{D}}\right)^{0.0081} \left(\frac{\mathrm{S}}{\mathrm{D}}\right)^{-0.0039} \tag{11}$$

***For suggested F.B.W consists of three rows** of floating bodies:*

$$C_t = 0.00314\left(\frac{\mathrm{H_i}}{\mathrm{L}}\right)^{-2.0052} (\mathrm{kd})^{3.072} \left(\frac{\mathrm{D}}{\mathrm{d}}\right)^{-0.0989} \left(\frac{\mathrm{d_i}}{\mathrm{d}}\right)^{-0.1395} \left(\frac{\mathrm{G}}{\mathrm{D}}\right)^{0.0141} \left(\frac{\mathrm{S}}{\mathrm{D}}\right)^{-0.0093} \quad (12)$$

To examine the accuracy of equations (10), (11), and (12), values of the independent variables were applied to the equations to predict values of C_t. The comparison of predicted values with the observed values is shown in figures (14), (15), and (16). The comparison between predicted and observed values shows good agreement.

Comparison between the new F.B.W. and the results of some previous works:

Comparison between the results of the present work for the suggested F.B.W consist of one, two, or three rows, di/d = 0.30, G/D = 0.00, and S/D = 2.00, with the offers of other authors for different types of floating breakwaters were shown in figure (17). Masashi et al. (1964), Craig, (1982), McCartney (1985), and Williams (1988) breakwater types were discussed in literature review. In the present comparison, the transmission wave coefficient C_t drawn versus the ratio between the width of floating and wavelength B/L.

For the present study B (i.e. the width of F.B.W) can be expressed as, (B = D) for one row of floating breakwater, (B = 2D + S) for two rows of floating breakwater, and (B = 3D + 2S) for three rows of floating breakwater. It means that for the previous works B is the width of the floating breakwater construction, but for the suggested F.B.W, B with its contents of a breakwater structure, also it contents in the mean time water as a barrier. So, using water between rows as wave barrier will decrease the overall construction cost for the suggested F.B.W. The figure shows the efficiency of the suggested F.B.W. compared with other works. The figures show also the strong effect of the ratio of B/L on the transmission wave coefficient.

CONCLUSIONS

In the present research, the idea of the suggested F.B.W to attenuate incident waves was tested under several wave conditions. The suggested F.B.W were compared with other works and showed acceptable agreement.

From the results and analysis the following conclusions can be summarized:

(1) The transmission wave coefficient for the free (unrestrained) floating bodies is 30 % greater than the corresponding value in the restrained floating bodies.
(2) The length of anchor chain has a very little effect on the transmission wave coefficients.
(3) The efficiency of the breakwater increases when the wave conditions changes from long-crested to short-crested waves.

(4) When the number of rows increases from one to three rows, the transmission wave coefficient, C_t decreases from about 0.393 to 0.121. On the other hand, the reflection coefficient, C_r increases under the same conditions.
(5) The transmission wave coefficient C_t decreased and the reflection wave coefficient C_r increased as the floating body draft to water depth ratio di/d increased.
(6) When the wave number kd was increased (i.e. go to deep water zones), the value of C_t decreased and the values of C_r increased too.
(7) The suggested floating breakwater has a highly efficiency in deep water zone than that of shallow water zone.
(8) The losses in incident wave energy [$C_l = \sqrt{1 - C_t^2 - C_r^2}$] increases as the wave steepness increases.
(9) Proposed equations were obtained to calculate the wave transmission coefficient C_t by using regression analysis. These equations are in a good agreement with the experimental results.

NOTATIONS:

The following symbols are used in this research paper:

B	: The width of F.B.W.;
Cr	: The reflection wave coefficient;
Ct	: The transmission wave coefficient;
Cl	: The coefficient of energy loss;
D	: The floating bodies diameter;
d	: Water depth;
di	: The floating bodies draft;
G	: The gaps between floating bodies in the same row;
Hi	: The incident wave height;
Hr	: The reflected wave height;
Ht	: The transmitted wave height;
kd	: The wave number (2πd/L);
L	: The incident wave length;
la	: The anchor line length;
N	: The number of rows used;
S	: The spacing between floating breakwater rows; and
T	: The incident wave period.

REFERENCES

Abul-Azm, A.G. (1997) “Dual Pontoon Floating Breakwater”, J. of Ocean Eng., Vol. 24, No. 5.

Ayman, S.I. (2005) “Suggested Model for the Protection of Shores and Marina”, Ph.D. Thesis, Zagazig University, Egypt.

Carr, J.H. (1952) “Mobile Breakwater”, Proc. 2nd Conf. on Coastal Eng., Houston, Texas, Council Wave Research.

Craig T.B, (1982) "Floating Tire Breakwater Design Comparison", Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 108, No. WW3, August.

Diab R.M, (2005) "Effect of Hinged Floating Breakwaters on Energy Dissipation", M.Sc. Thesis, Faculty of Engineering, Mansoura University, Egypt.

Gesrahab, M.R. (1995) "Hydrodynamic of Floating Pontoon Under Oblique Waves", M.Sc. Thesis, Cairo University, Egypt.

Harms V.W, (1979) "Design Criteria for Floating Tire Breakwater", Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 106, No. WW2, May, pp. 149-170.

Kriezi, E.E., Karambas, T.V., Prinos, P. and Koutitas, C. (2001) "Interaction of Floating Breakwater with Waves in shallow Waters", Int. Conf. IAHR 2001 Beijing, China.

Liu, P.L-F. and Abbaspour, M. (1982) "Propagation of Oblique Incident wave Past Rigid Vertical Thin Barrier", Applied Ocean Research, Southampton U.K., Vol. 14.

Losanda, I.J., Losanda M.A., and Roldan, A.J. (1992) "Wave Scattering by Rigid Thin Barrier", Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE Vol. 108, No. 4.

McCartney, (1985) "Floating Breakwater Design", Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 111, No. 2, pp. No. 19610.

Mani J.S., (1986) "Reflection Characteristics of Wave Absorber- A Case Study", Journal of Institute Engineering India, Part CI, 67(2), 63-67.

Masashi Hom-ma, Kiyoshi Horikawa, and Hiromasa Mochizuka, (1964) "An Experimental Study of Floating Breakwaters", Coastal Engineering in Japan, Vol. 7.

Mario Fugazza and Luigi Natale, (1988) "Energy Losses and Floating Breakwater Response", Journal of Waterway, Port, Coastal and Ocean Eng., Vol. 114, No. 2, March, pp. No. 22282.

Rageh O.S., El-Alfy K.S., Shamaa M.T., and Diab R.M., (2006) "Performance of Hinged Floating Breakwaters Under Waves", 5th Eng. Conf., Mansoura University, Sharm El-Sheikh (Forthcoming).

Reddy M.S. and Neelamanit, S. (1992) "Wave Transmission and Reflection Characteristics of a Partially Immersed Rigid Thin Barrier", Journal of Ocean Eng., Vol. 19, No. 3.

Tolba E.R. (1998) "Behavior of Floating Breakwaters Under Wave Action", Ph.D. Thesis, Suez Canal University, Egypt.

Wiegel (1960) "Transmission of Wave Past a Rigid Vertical Thin Barrier", J. Waterway, Port, Coastal and Ocean Engineering, ASCE, Vol. 86, No. 1.

Williams A.N. and McDougal W.G., (1996) "A Dynamic Submerged Breakwater", Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 122, pp. 288-296.

Williams K.J., (1988) "An Experimental Study of Wave Obstacle Interaction in a Two-Dimensional Domain", Journal of Hydraulic Research, Vol. 26, pp. 429-450.

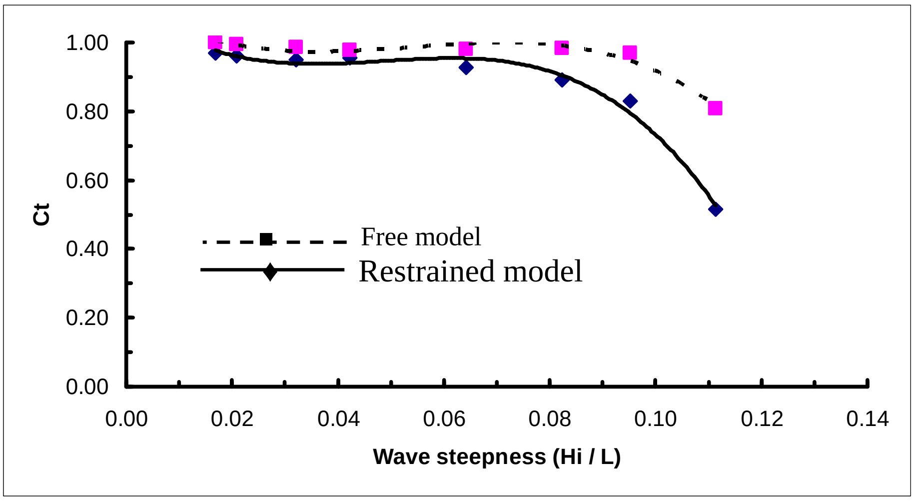


Figure (2): Relationship between Hi/L and C_t for restrained and free models (One Row of F.B.W, G / D = 0.00, D / d = 0.40, di / D = 0.75, la / d = 1.00)

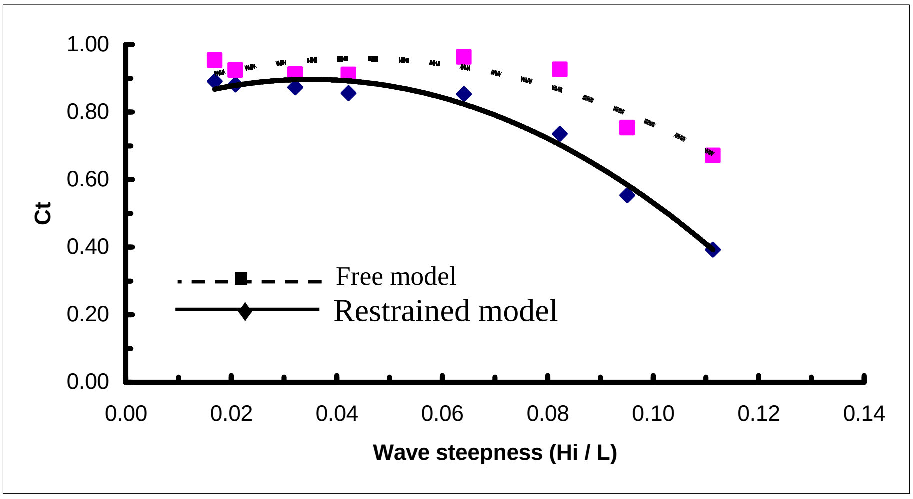


Figure (3): Relationship between Hi/L and Ct for restrained and free models (Two Rows of F.B.W, G / D = 0.00, D / d = 0.40, di / D = 0.75, la / d = 1.00)

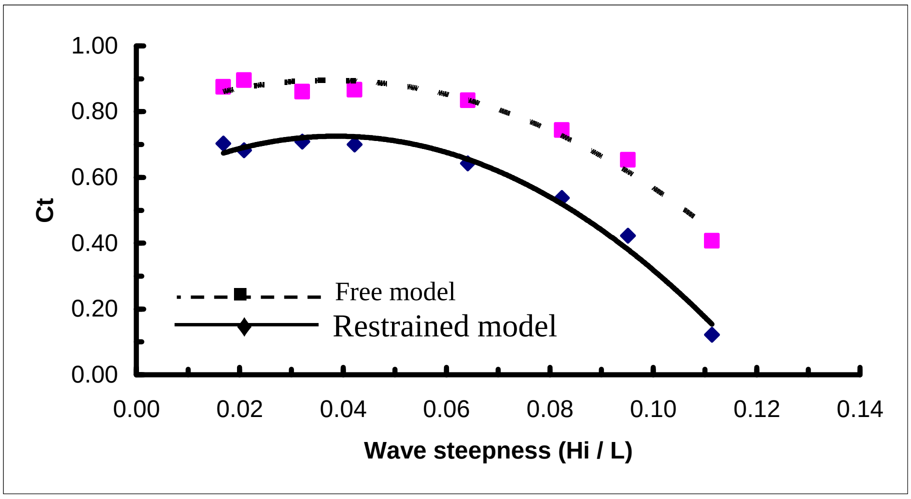


Figure (4): Relationship between Hi/L and C_t for restrained and free models (Three Rows of F.B.W, G / D = 0.00, D / d = 0.40, di / D = 0.75, la / d = 1.00)

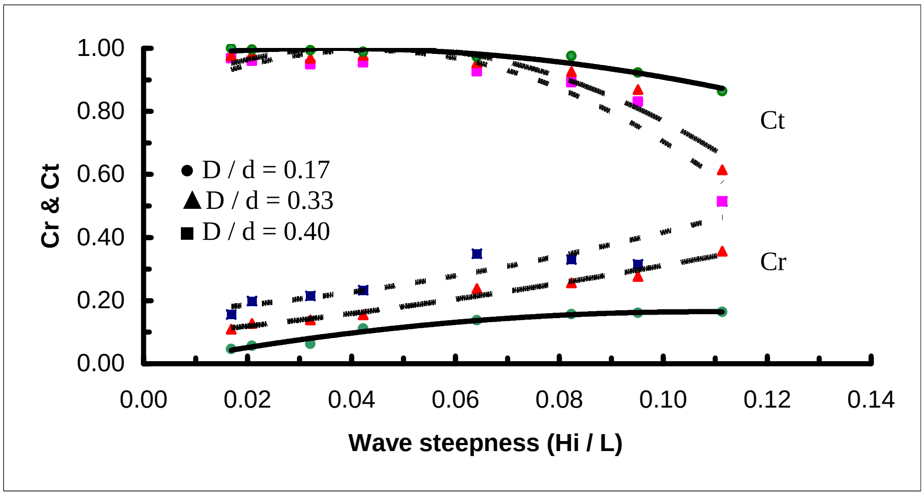


Figure (5): Relationship between Hi/L and C_r, C_t for different values of D/d ratio (Restrained Body, N = 1, G / D = 0.00, di / D = 0.75, la / d = 1.00)

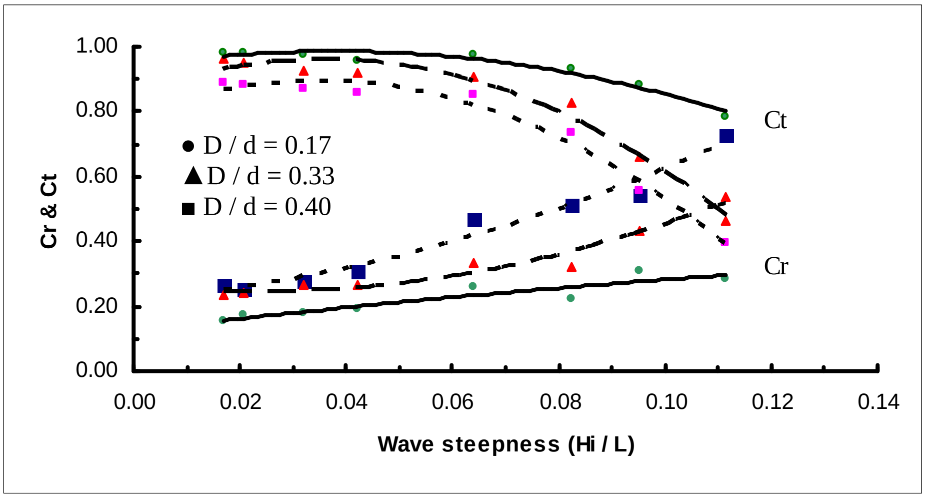


Figure (6): Relationship between Hi/L and Cr, Ct for different values of D/d ratio (Restrained Body, Two Rows, S /D = 2.00, G / D = 0.00, di / D = 0.75, la / d = 1.00)

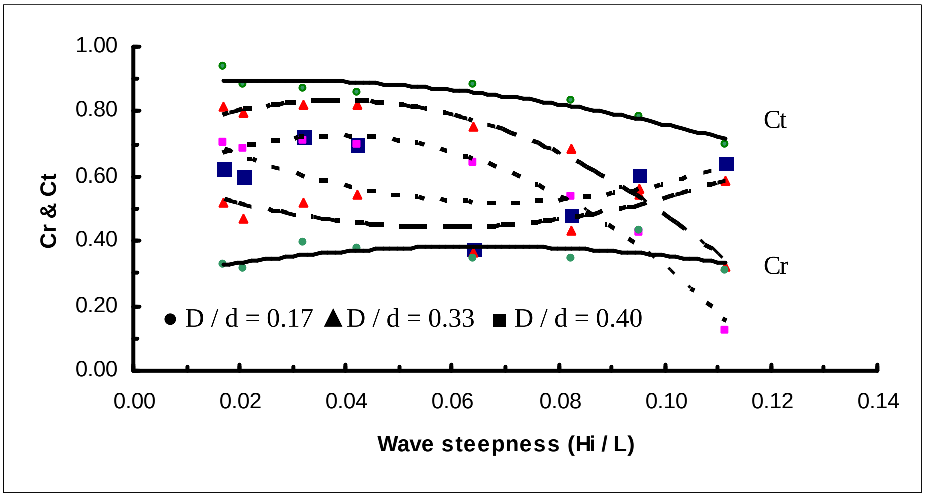


Figure (7): Relationship between Hi/L and C_r, C_t for different values of D/d ratio (Restrained Body, Three Rows, S /D = 2.00, G / D = 0.00, di / D = 0.75, la / d = 1.00)

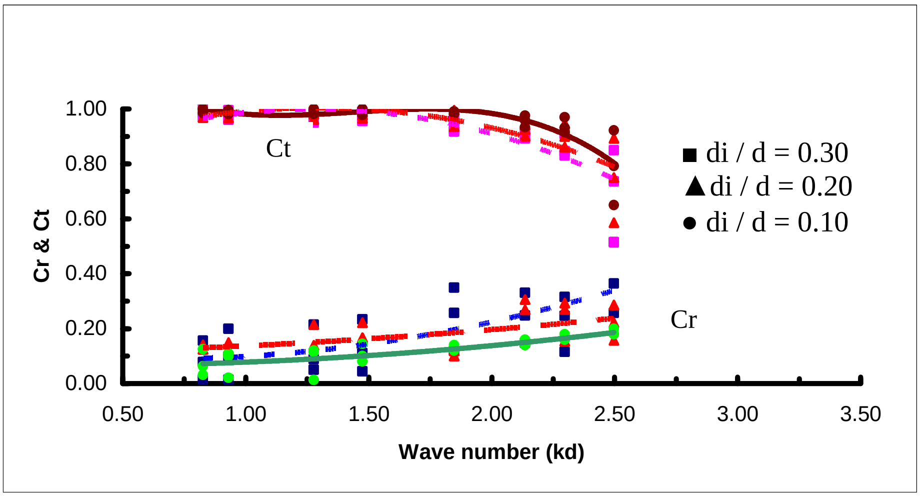


Figure (8): Effect of kd on C_r, C_t for different values of di/d ratio (Restrained Body, N = 1, D / d = 0.40, la / d = 1.00)

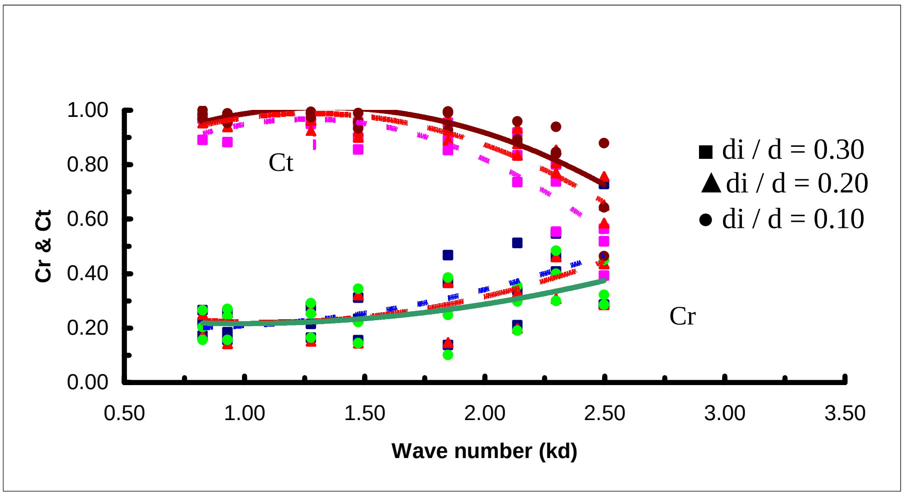


Figure (9): Effect of kd on C_r, C_t for different values of di/d ratio (Restrained Body, N = 2, D / d = 0.40, la / d = 1.00)

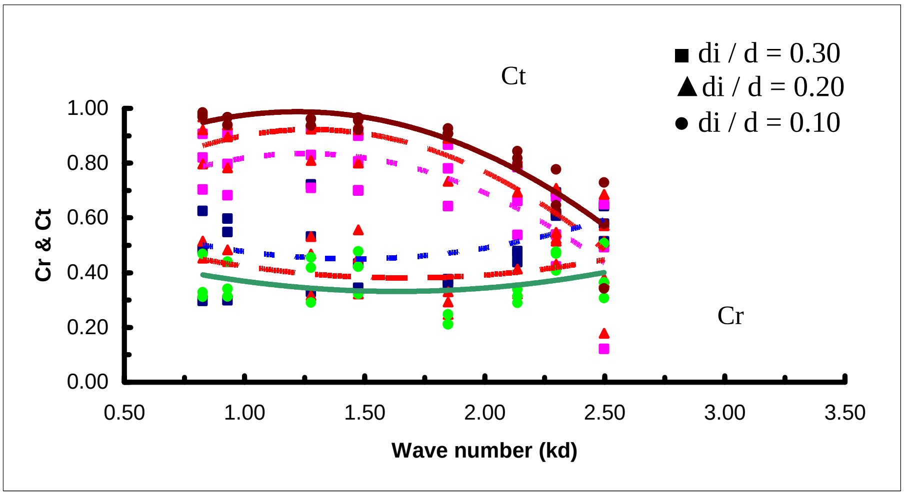


Figure (10): Effect of kd on C_r, C_t for different values of di/d ratio (Restrained Body, N = 3, D / d = 0.40, la / d = 1.00)

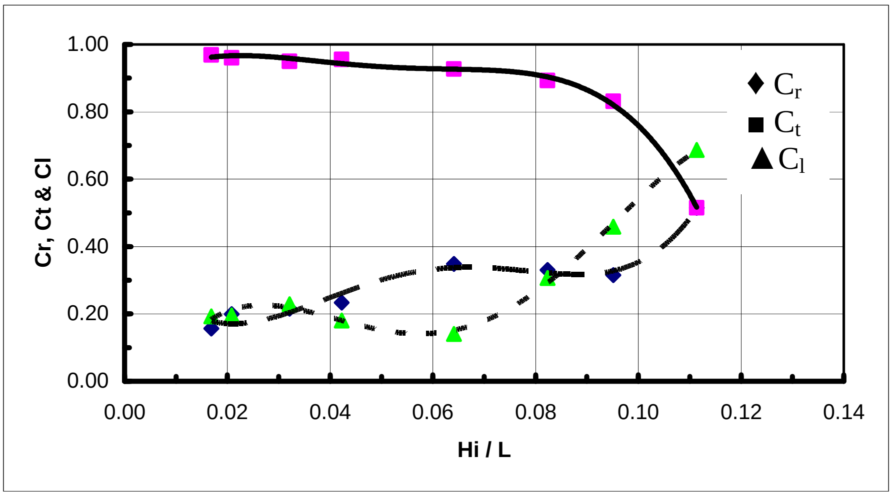


Figure (11): Variation of C_r, C_t and C_l with Hi/L (Restrained Body, One Row, G / D = 0.00, di / D = 0.75, la / d = 1.00)

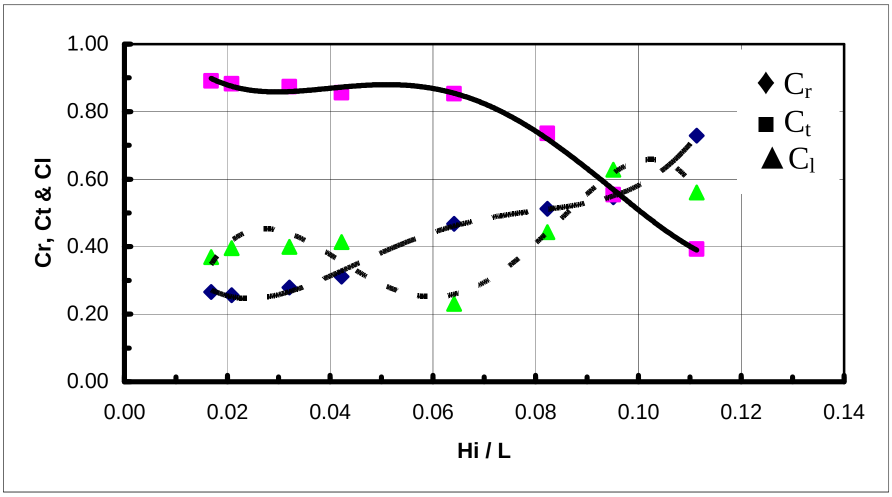


Figure (12): Variation of C_r, C_t and C_l with Hi/L (Restrained Body, n = 2, S /D = 2.00, G / D = 0.00, di / D = 0.75, la / d =1.00)

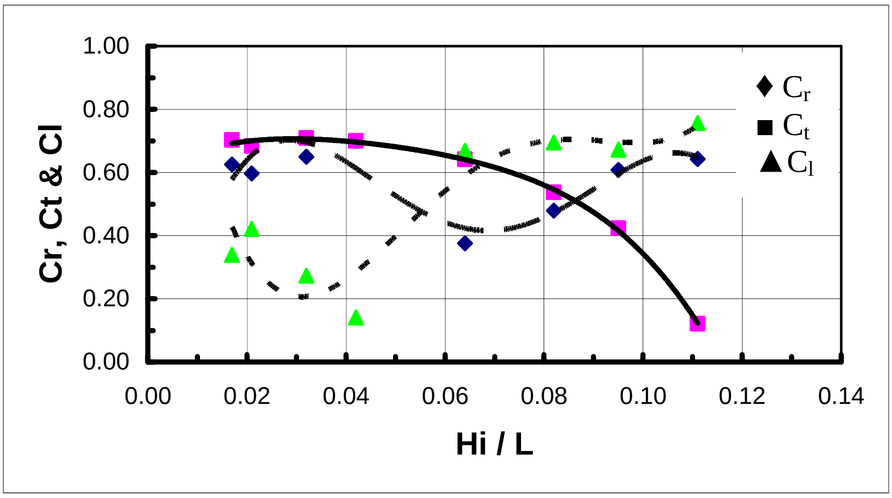


Figure (13): Variation of C_r, C_t and C_l with Hi/L
(Restrained Body, Three Rows, S /D = 2.00, G / D = 0.00, di / D = 0.75, la / d = 1.00)

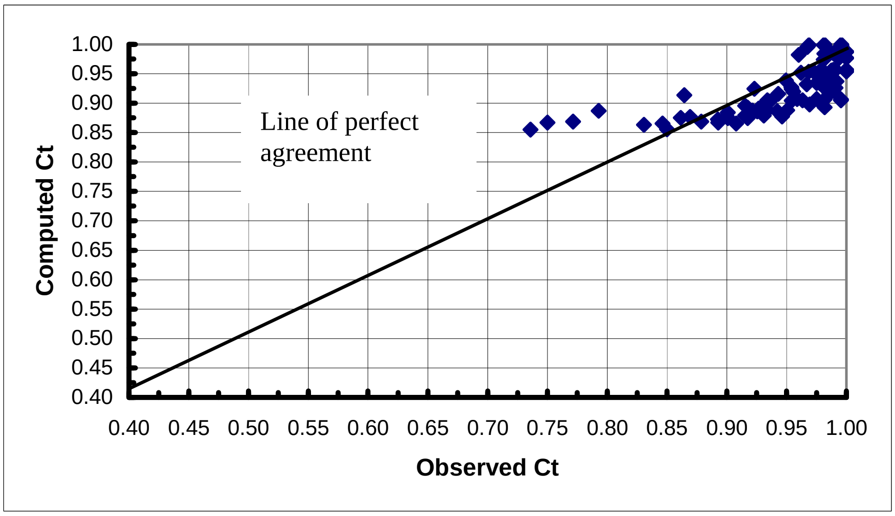


Figure (14): The Comparison between the Computed and Observed Transmission Coefficient for One Restrained Rows of F.B.W.

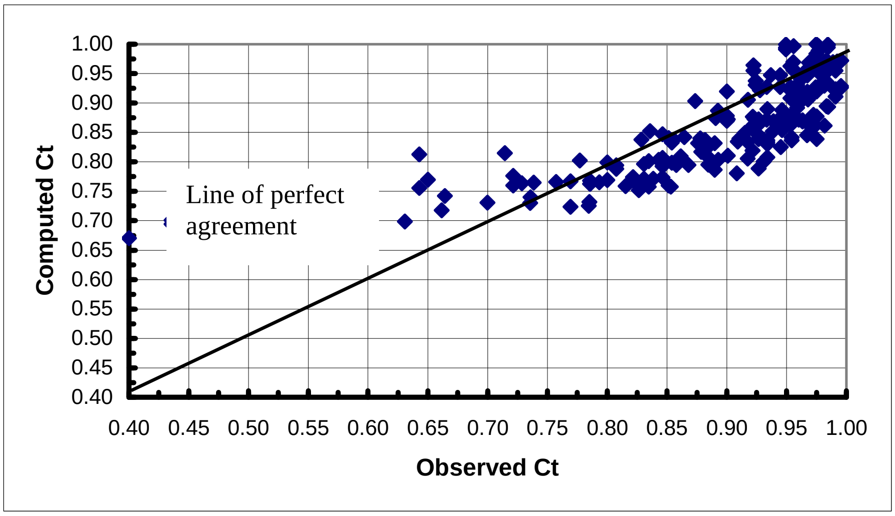


Figure (15): The Comparison between the Computed and Observed Transmission Coefficient for Two Restrained Rows of F.B.W.

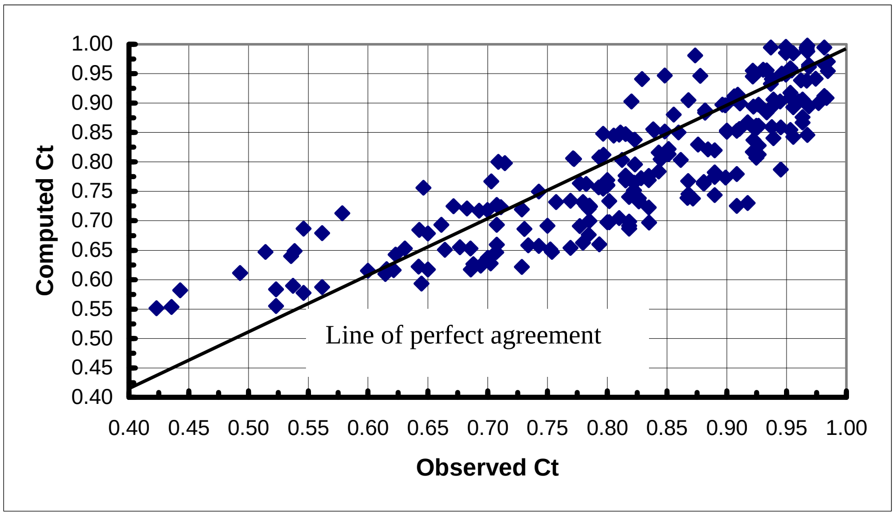


Figure (16): The Comparison between the Computed and Observed Transmission Coefficient for Three Restrained Rows of F.B.W.

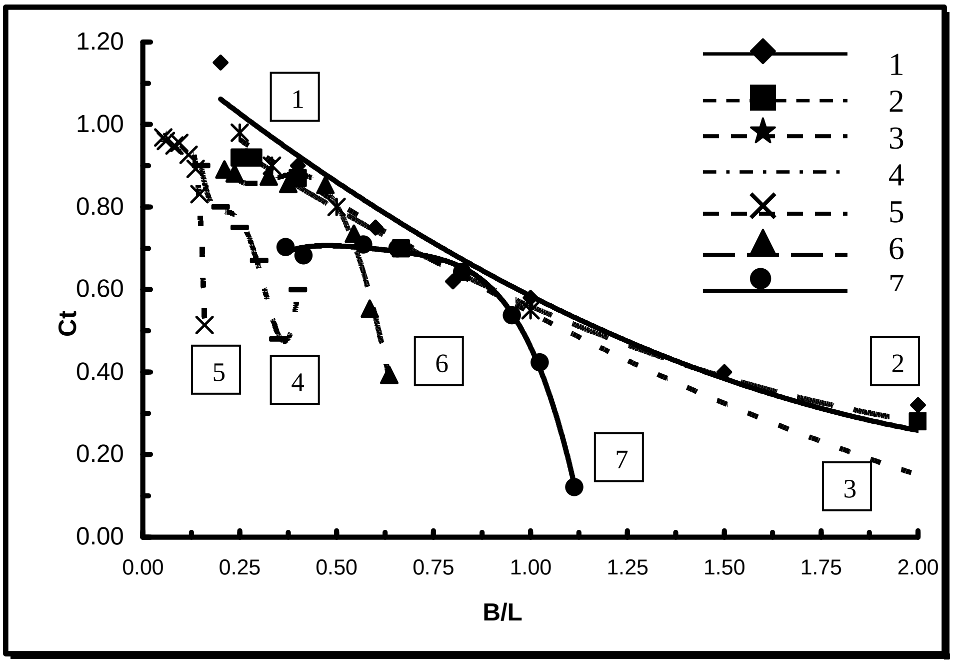


Figure (17): Comparison between the suggested F.B.W and other works