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EFFECT OF THE OFF-SHORE BERM RUBBLE-MOUND BREAKWATER ON WAVE ENERGY DISSIPATION

By

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ABSTRACT:

The objective of this paper is to experimentally investigate the hydrodynamic performance of the suggested breakwater system when used as a wave energy dissipater. In order to verify the hydrodynamic efficiency of the suggested system; in terms of wave damping and reflection, an experimental study was carried out, through which, different breakwater configurations and variable wave climates were investigated to determine the best structural features to obtain maximum wave damping efficiency and the most suitable surrounding wave conditions. The experimental results show that the submerged stepped rublle-mound breakwater, succeeded in lowering wave height on the lee side of the incident waves. Also it was found that the most dominant structural parameter that affects wave transmissions, reflection and wave dissipation is the slope of breakwaters.

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1- INTRODUCTION: -

Submerged breakwaters (SBW) are coastal structures that are being selected by coastal engineers to overcome beach erosion and coastal hazard. The SBW crown elevation is below the mean water level to be invisible in the coastal region. On the other hand, the submerged structure is usually adopted with a porous material that has the function of ecological restoration in the coastal area.

Physically, the porous structure is able to absorb and dissipate the wave energy when the incident wave transmits through it. Besides, the incident waves are also partially reflected from the submerged structure. The wave transformation over a submerged breakwater has been investigated in a series of studies based on the laboratory and field experiments, such as Mounir, M.A (1992), El Saie (1994), Yong-Sik Cho et al. (2004), Hakeem K. Johnson et al. (2005), Jentsje W. van der Meer et al. (2005), Hakeem K. Johnson (2006), Chan-Hoo Jeon et al. (2006), Ching-Piao Tsaia et al. (2006), Yongxue Wang et al. (2006), Ferrante (2007), K.G. Shirlal et al. (2007) and Seif el-Dein (2010).

The breakwater's performance of dissipating waves has been investigated in details for regular waves. The factors identified with the characteristics of the breakwater, such as the models geometrical parameters (the width and the height), also the wave steepness are discussed. The comparison and analysis of the dissipation coefficients with respect to different factors are presented. The model test results indicate that the submerged berm breakwater has a good characteristic of dissipating waves.

In this paper, our focus is on the experimental modelling of submerged berm breakwater. These structures cause wave energy dissipation through the physical mechanisms of wave breaking and friction.

2. Laboratory Experiments

2.1 Wave Flume:-

A series of laboratory experiments was performed in a wave flume of 1.5 m wide, 0.75 m deep and 40 m long as shown in Fig.(1). A submerged berm breakwater was placed at the center of the wave flume. The flume is equipped with a hydraulic piston wave generator machine installed at one end of the flume, while absorber systems were installed at the two ends so that the reflection from the outer boundaries could be minimized.

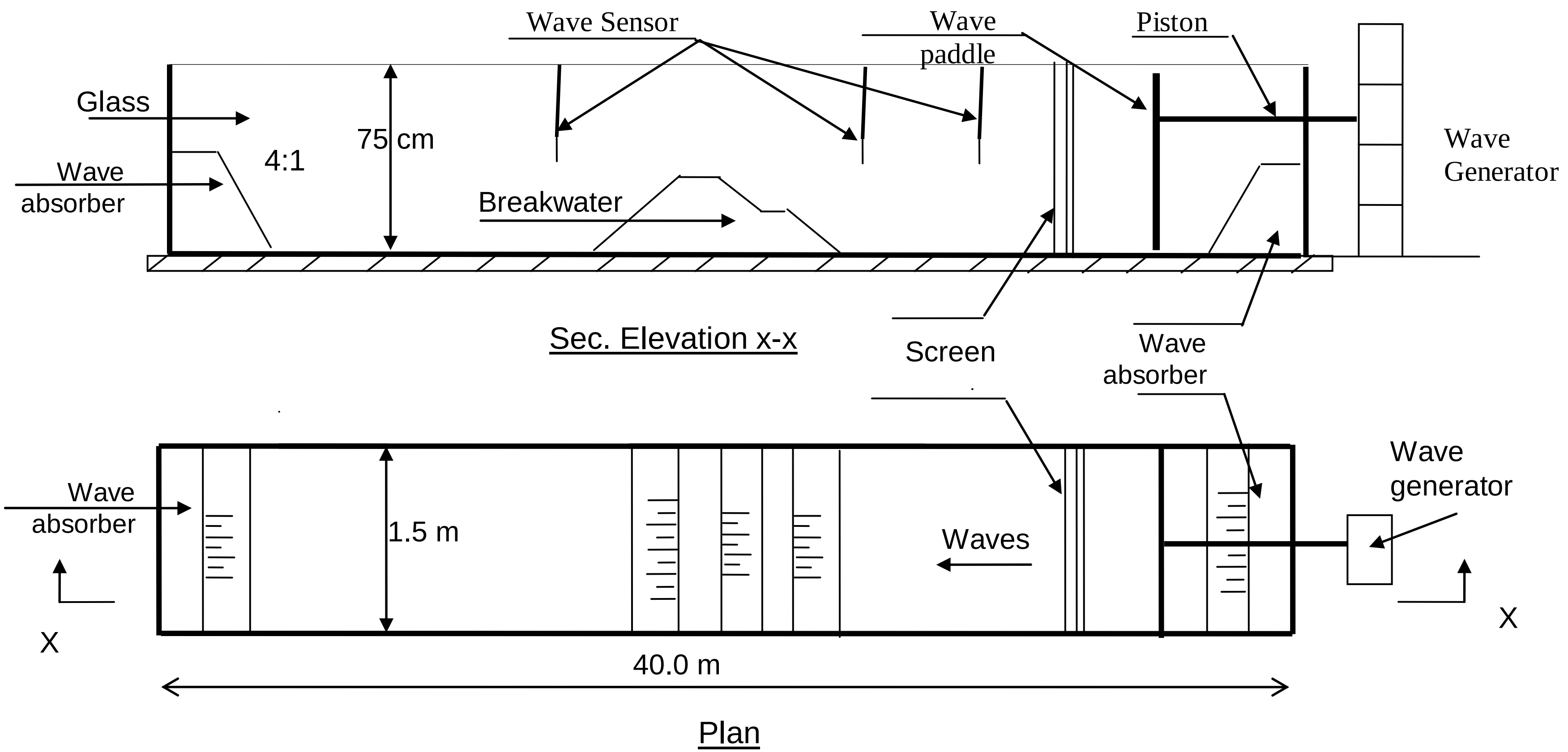

Figure (1) Plan and Sec Elevation of the Experimental Flume

The wave generator has a paddle of 1.495 m wide and 0.75 m deep. The wave generator, driven by an electrical servo-system, can generate a wave of possible maximum wave height from 6 cm to 20 cm with a wave period of 1.20 sec.

The breakwater was chosen trapezoidal in shape and have one berm, it consists of an armor layer of two unit thicknesses of tetrapods, a secondary layer of two unit thicknesses of tetra pods, and a filling material that form the core as shown in Fig.(2).

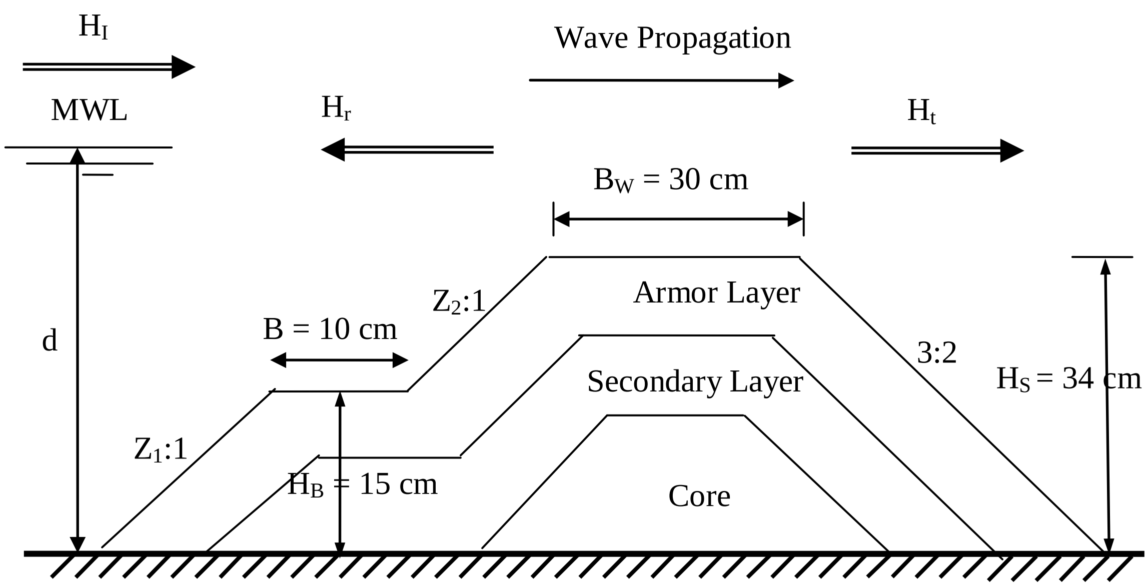

Figure (2) the Breakwater Experimental Model and the different Parameters

2.2 Measuring instruments:

The incident and the reflected wave height were measured at a distance 9.5 m, and 3.40 m from the center of the breakwater respectively. While the transmitted wave height was measured at a distance 0.87 m behind the center of the breakwater

The wave height was measured by the DHI Wave Meter device. The principle of DHI Wave Meter is to measure the conductivity between two parallel electrodes party immersed in water, as shown in Fig (3). With the two electrodes of the gauge connected to the conditioning module, the output voltage is proportional to the length of the immersed part of the electrodes.

2.3. Wave Absorbers:

In order to perform accurate and efficient wave tests in the flume, it is necessary to prevent reflection of waves from both ends or reduce it to an acceptable level. If this is not done, the reflected waves will soon induce standing waves throughout the flume length.

Figure (3) General View for the Wave Meter Devie

To handle this problem, two wave absorbers were built, one at each flume end. Several shapes of wave absorbers with different materials were tested to come out with the most suitable and efficient absorber.

It was found that the sloped graded gravel is very suitable to be used in the current test conditions, and after many trials, the final absorber shape was adopted.

The first absorber is a vertical screen consists of 3 layers, the distances between layers are 25.0 and 40.0 cm.

The second absorber is placed at both end of the flume to prevent the formation of standing waves due to reflection of waves. A 4:1 gravel slope with 2 m length and 0.6 m height was constructed inside a meshed wire casing at the two ends of the flume.

The gravel in both absorbers is graded from 3.0 cm to 8.0 cm diameter and they are both covered with a steel mesh to prevent the slippage of gravel due to wave impact.

3. Experimental Procedure:-

A series of experiments were done. The following steps represent the procedure followed throughout the experiments, and fig (4) shows the used experimental program.

1. The SBW model is installed near the middle of the flume.
2. The water is filled to the required depth used in the experiments.
3. The wave generator is operated with the required wave height..
4. The wave period is recorded.

5. The max wave height (H_{max}) is measured and the minimum wave height (H_{min}) is also measured to determine the incident and reflected wave heights.
6. The transmitted wave height (H_t) is measured.

The water level is changed to the next level and the same procedures are to be repeated again, and the same procedures are repeated. Examples of the measured parameters are shown in table (1).

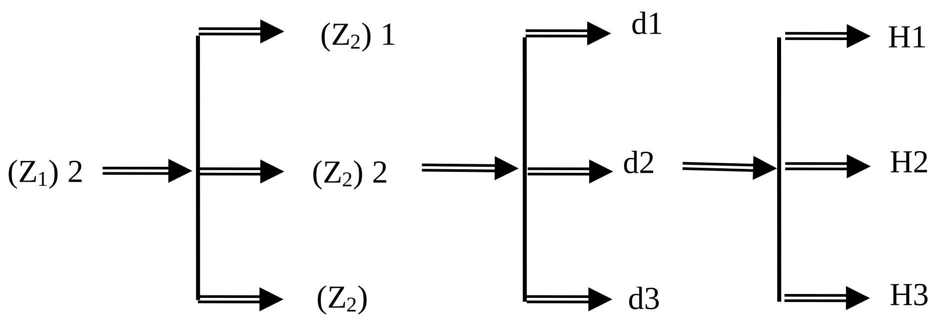

Figure (4) the Experimental Program

Z_1:1	Z_2:1	B (cm)	H_B (cm)	d (cm)	L (m)	H (cm)	H_{max} (cm)	H_{min} (cm)	H_t (cm)	H_I (cm)	H_r (cm)
1:1	2:1	10	15	40	1.936	10	10.19	9.36	9	9.755	0.415
1:1	2:1	10	15	40	1.936	15	15.27	14.06	11.9	14.665	0.605
1:1	2:1	10	15	40	1.936	20	20.31	18.73	14.7	19.52	0.79
1:1	2:1	10	15	36.5	1.845	10	10.1	9.1	8.49	9.60	0.50
1:1	2:1	10	15	36.5	1.845	15	15.18	14.17	10.14	14.675	0.505
1:1	2:1	10	15	36.5	1.845	20	20.63	19.22	13.17	19.925	0.705
1:1	2:1	10	15	34	1.354	10	10.51	9.48	6.26	9.995	0.515
1:1	2:1	10	15	34	1.354	15	15.49	14.22	8.04	14.855	0.635
1:1	2:1	10	15	34	1.354	20	20.74	19.02	11.2	19.88	0.86

Table (1) Measurement parameters

Several parameters were involved in the experiments. These parameters were divided into the following:

3.1 Wave Parameters:

Water depth (d) = (34.0 cm, 36.5 cm, 40 cm)

Wave height (H) = (10.0 cm, 15.0 cm, 20.0 cm)
Wave length (L) = (1.354 m, 1.845 m, 1.936 m)

3.2 Breakwater Parameters:

Height of breakwater (H_S) and is kept constant = 34.0 cm
Crest width of breakwater (B_W) and is kept constant = 30.0 cm
Height of berm from bed level (H_B) and is kept constant = 15.0 cm
Width of berm (B) and is kept constant = 10.0 m
Slope (Z_1:1) = (1.0, 1.5, 2.0).
Slope (Z_2:1) = (1.0, 1.5, 2.0).

3.3 Computed Quantities:

Wave energy may be divided into three parts:

1. The reflected wave energy back to the sea.
2. The transmitted wave energy into the leeward side; due to wave overtopping and penetration.
3. The dissipated wave energy by wave breaking, surface roughness and porous flow.

$$E_I = E_R + E_T + E_D \quad (1)$$

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

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

Where:-
E_I: incident wave energy
E_R: reflected wave energy
E_T: transmitted wave energy
E_D: dissipated wave energy
H_I: incident wave height.
H_r: reflected wave height.

Transmission coefficient ($C_t = H_t / H_I$) = $(E_T / E_I)^{0.5}$

Reflection coefficient ($C_r = H_r / H_I$) = $(E_R/ E_I)^{0.5}$
Coefficient of energy dissipation $C_d = (E_D/ E_I)^{0.5}$
And can be calculated from the following equation

$$C_t^2 + C_r^2 + C_d^2 = 1 \qquad (4)$$

4. Data analysis:

The coefficient of the dissipation (C_d) is an important factor affecting the design of breakwaters and their choice.

The relations of coefficient of the dissipation with respect to the parameters of the wave steepness (H_I/L), the ratio (d/L) relative depth (d/H_S), and the slopes (Z_1 and Z_2) are discussed in the analysis.

4.1 Relation between the coefficient of dissipation(C_d) and wave steepness (H_I/L):

The relation between (C_d) and (H_I/L) for different values of (B/L) was drawn for constant values of (d/L), (d/H_B), (d/H_S), (Z_1), (Z_2), these relations are shown in figure (5).

By examining this figure we can conclude that (C_d) increases as (H_I/L) increases for all values of the other dimensionless parameters.

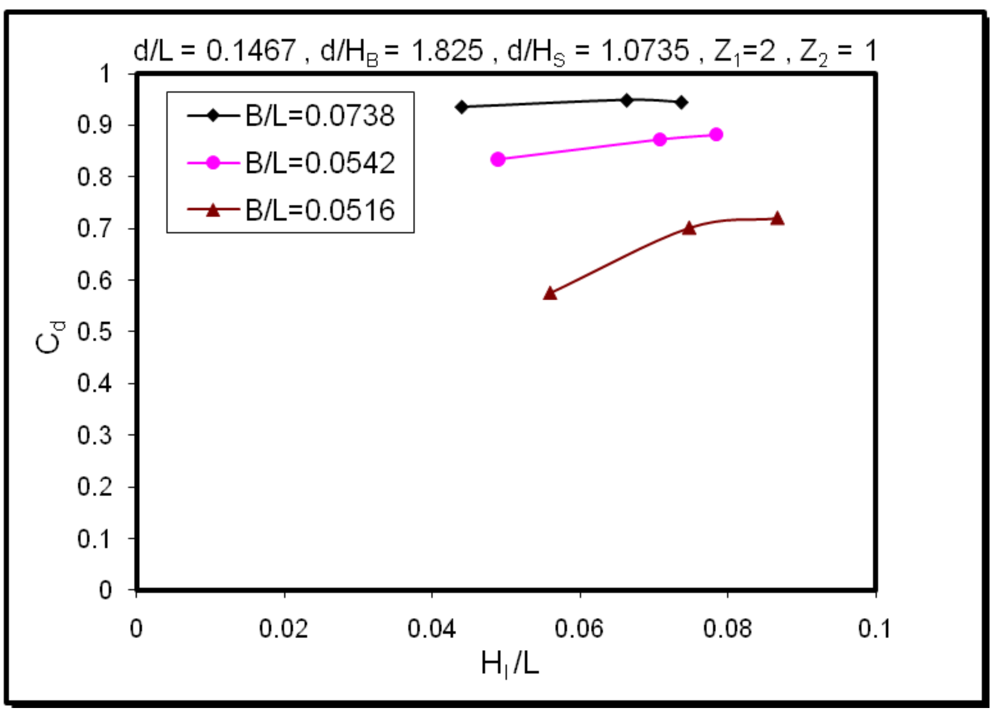

Figure (5) the relation between Wave Steepness (H_I/L)
and the Coefficient of Dissipation (C_d)

It is noticed also, that within the range of the experiments, (C_d) increases rapidly with the increase of (H_I/L), then at a certain value of (H_I/L) this change becomes slow. The value at which this change occurs varies between (H_I/L) = 0.052 and (H_I/L) = 0.072.

The present study shows that the increase in wave steepness causes the increase in the coefficient of dissipation because the effect of roughness of SBW is eliminated and a small amount of energy is dissipated.

4.2 Relation between (C_d) and (d/L):

The relations between (C_d) and (d/L) for different values of (H_I/L) were drawn for constant values of (B/L), (d/H_B), (d/H_S), (B/L), (Z_1), (Z_2), these relations are shown in figures (6).

By examining this figure we can conclude that (C_d) increases as (d/L) increases for all values of the other dimensionless parameters.

It is noticed also, that within the range of the experiments, (C_d) increase rapidly with the increase of (d/L), then at a certain value of (d/L) this change becomes slow. The value at which this change occurs varies between (d/L) = 0.182 and (d/L) = 0.187.

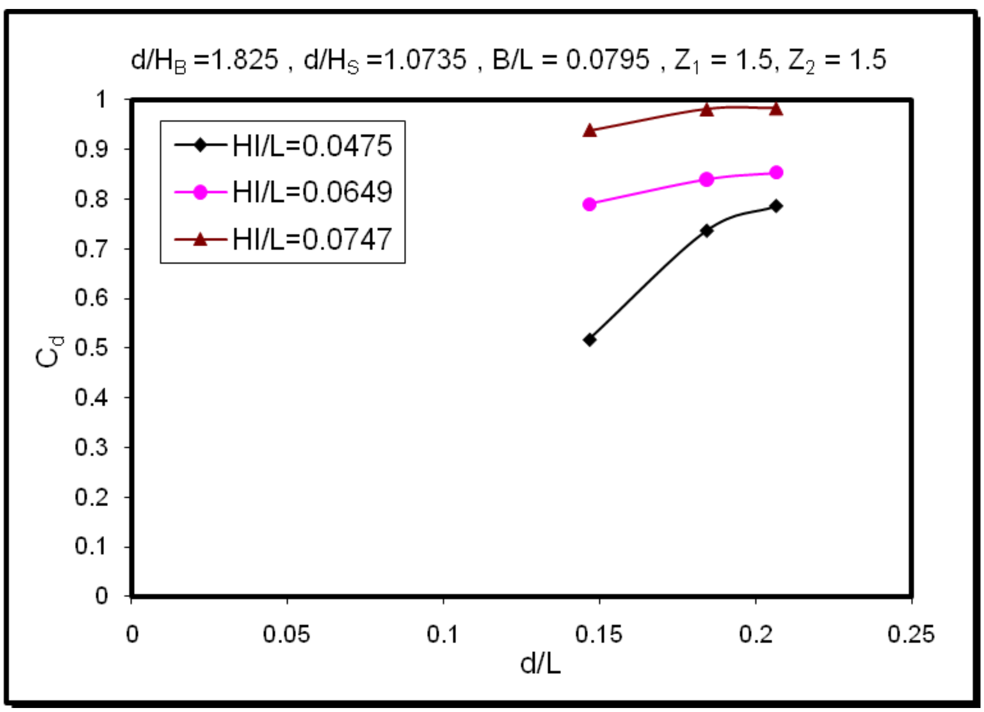

Figure (6) the relation between (d/L) and the Coefficient of Dissipation (C_d)

4.3 Relation between (C_d) and (d/H_S):

The relations between (C_d) and (d/H_S) for different values of (H_I/L) were drawn for constant values of (d/L), (d/H_B), (B/L), (Z_1), (Z_2), these relations are shown in figure (7).

By examining this figure we can conclude that (C_d) increases as (d/H_S) increases for all values of the other dimensionless parameters.

It is noticed also, that within the range of the experiments, (C_d) increases rapidly with the increase of (d/H_S), then at a certain value of (d/H_S) this change becomes slow. The value at which this change occurs is equal to 1.

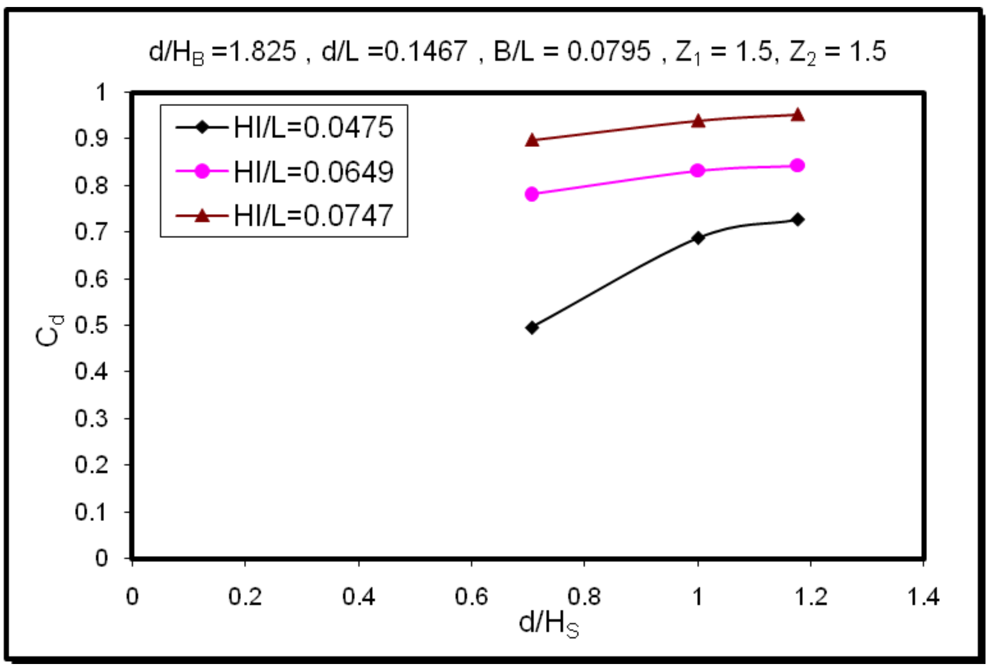

Figure (7) the relation between (d/H_S) and the Coefficient of Dissipation (C_d)

4.4 Relation between (C_d) and (Z_1):

The relations between (C_d) and (Z_1) for different values of (H_I/L) were drawn for constant values of (d/L), (d/H_B), (d/H_S), (B/L), (Z_2), these relations are shown in figure (8).

By examining this figure we can conclude that (C_d) increases as (Z_1) increases for all values of the other dimensionless parameters.

It is noticed also, that (C_d) increase linearly with the increase of (Z_1).

4.5 Relation between (C_d) and (Z_2):

The relations between (C_d) and (Z_2) for different values of (H_I/L) were drawn for constant values of (d/L), (d/H_B), (d/H_S), (B/L), (Z_1), these relations are shown in figure (9).

By examining this figure we can conclude that (C_d) increases as (Z_2) increases for all values of the other dimensionless parameters.

It is noticed also, that (C_d) increase linearly with the increase of (Z_2).

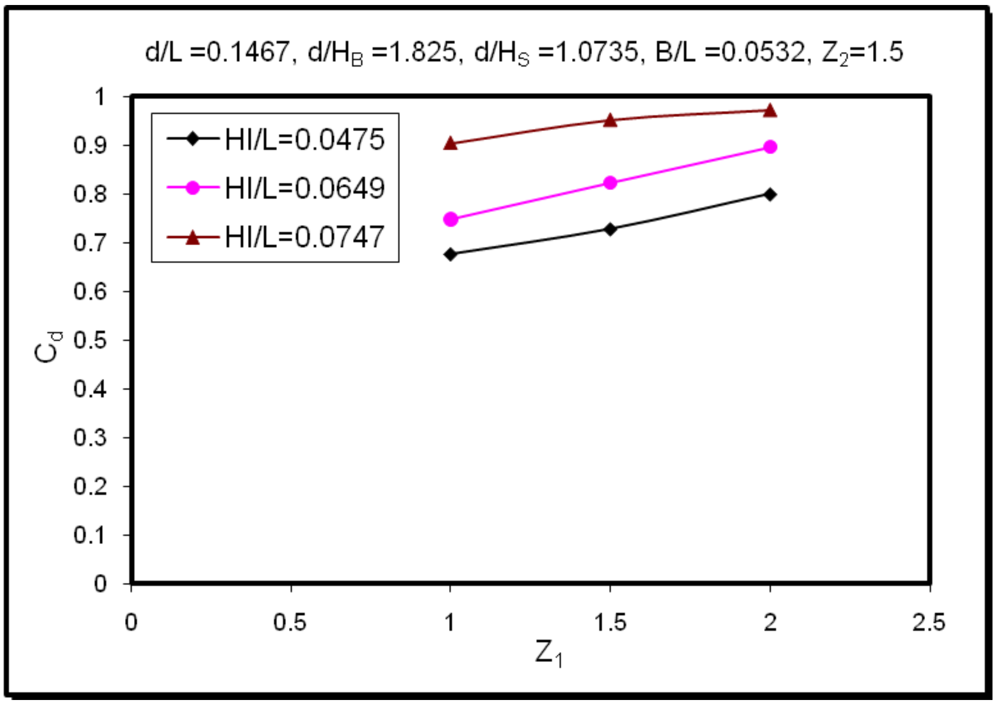

Figure (8) the relation between (Z_1) and the Coefficient of Dissipation (C_d)

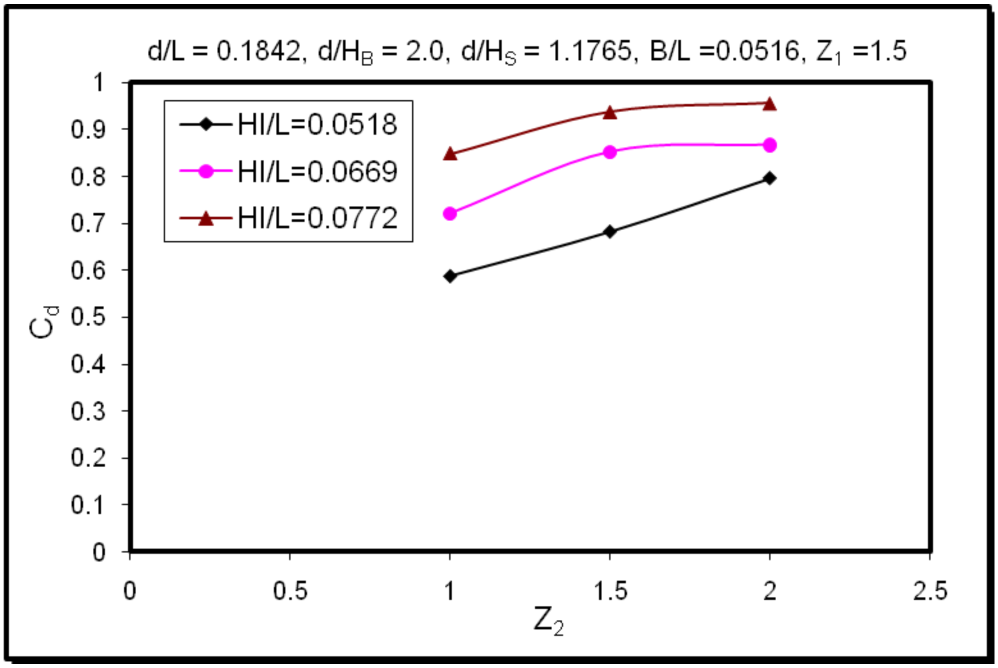

Figure (9) the relation between (Z_2) and the Coefficient of Dissipation (C_d)

5. Comparison with other Investigators:

It is important to compare the obtained results in this study with results obtained by other investigators.

The comparison is mainly concerned with field data. The field data available were data obtained by Mounir (1992), and El-Saie (1994).

5.1 Comparison with Mounir:

Before we compare the data obtained by Mounir and present study we must discuss the conditions tested by Mounir.

Mounir tested a large number of submerged breakwaters with crest width B_W (20.0 - 40.0 cm), Z:1 (1:1 – 2:1), height of breakwater H_s (25.0 cm) and water depth (22.5 – 35.0 cm). We are interested in the case where its conditions are the most similar conditions to our conditions. This case had an armour layer of two units of thick of stream lined gravel, the width crest of breakwater was 30 cm, the tested range of depths varied from 22.5 cm to 35.0 cm, the face slope (Z) was equal to 1.5.

Figure (10) represent coefficient of dissipation (C_d) versus H_I/L. The difference of results may be due to the different measuring technique. Another variation is due to the different ratio of (B_W/L). in the present study ($B_W/L = 0.155$) is greater than tested by Mounir ($B_W/L = 0.146$).

In figure (10) C_d in the present study is greater compared with Mounir, the value of H_I/L tested by Mounir were also smaller with caused less values of C_d obtained by Mounir than those obtained in the present study also the present study has a berm (B) and this ratio (B/L) get the C_d more grater than Mounir.

From above we conclude that C_d in this study is greater than in Mounir due to using of berm.

5.2 Comparison with El-Saie:

Before we compare the data obtained by EL-Saie and present study we must discuss the conditions tested by EL-Saie.

EL-Saie tested a large number of stepped breakwaters with crest width B_W (15.0 cm), Z:1 (1:1 – 2:1), height of breakwater H_s (40.0 cm), berm width B (10.0 – 30.0 cm), height of berm H_B (15.0 – 25.0 cm) and water depth (20.0 – 30.0 cm). We are interested in the case where its conditions are the most similar conditions to our conditions. This case had an armour layer of two units of thick of gravel, ($B_W/L = 0.148$), ($B/L = 0.103$), ($d/L = 0.212$), ($d/H_S = 0.75$), ($d/H_B = 1.75$) and the face slope (Z_1) and (Z_2) were equal to 1.5.

Figure (11) represent coefficient of dissipation (C_d) versus H_I/L. The difference of results may be due to the different measuring technique. Another variation is due to the different ratio of (B_W/L). In the present study ($B_W/L = 0.155$) is greater than tested by EL-Saie ($B_W/L = 0.148$).

In figure (10) C_d in the present study is less compared with EL-Saie, the value of d/H_S tested by EL-Saie were also smaller with caused higher values of C_d obtained by EL-Saie than those obtained the present study also the present study has a ratio (B/L) less than of EL-Saie, those get the C_d more less than Saie.

From above we conclude that C_d in this study is less than in EL-Saie due to using of small (B/L) ratio than EL-Saie.

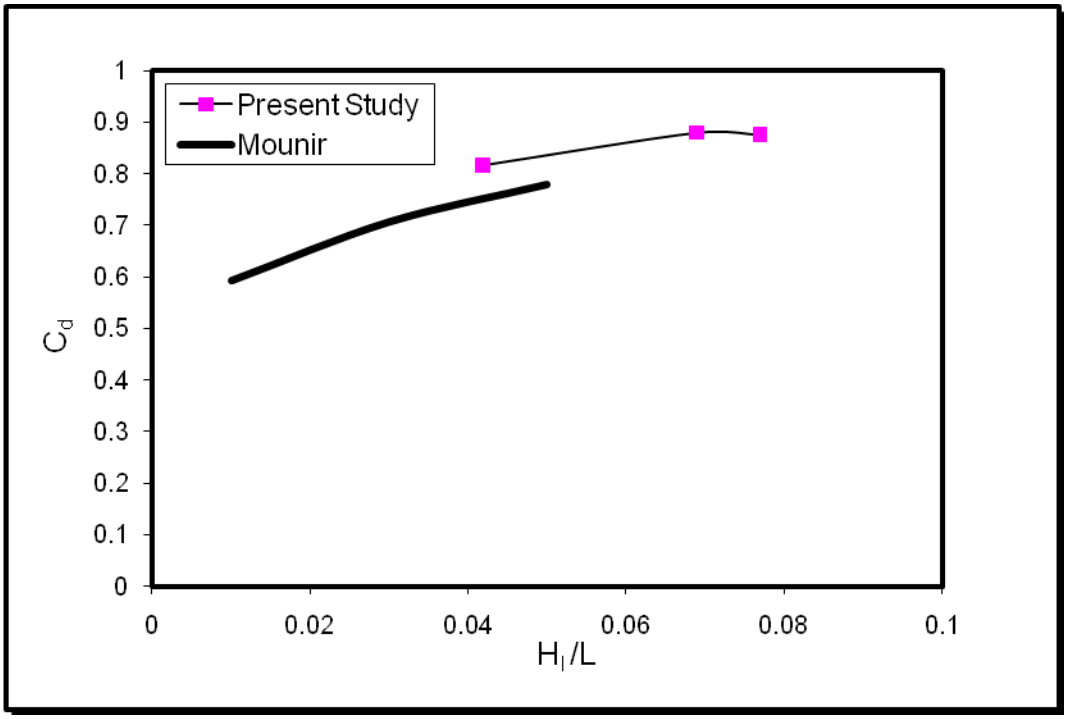

Figure (10) Comparison with Monuir 1992

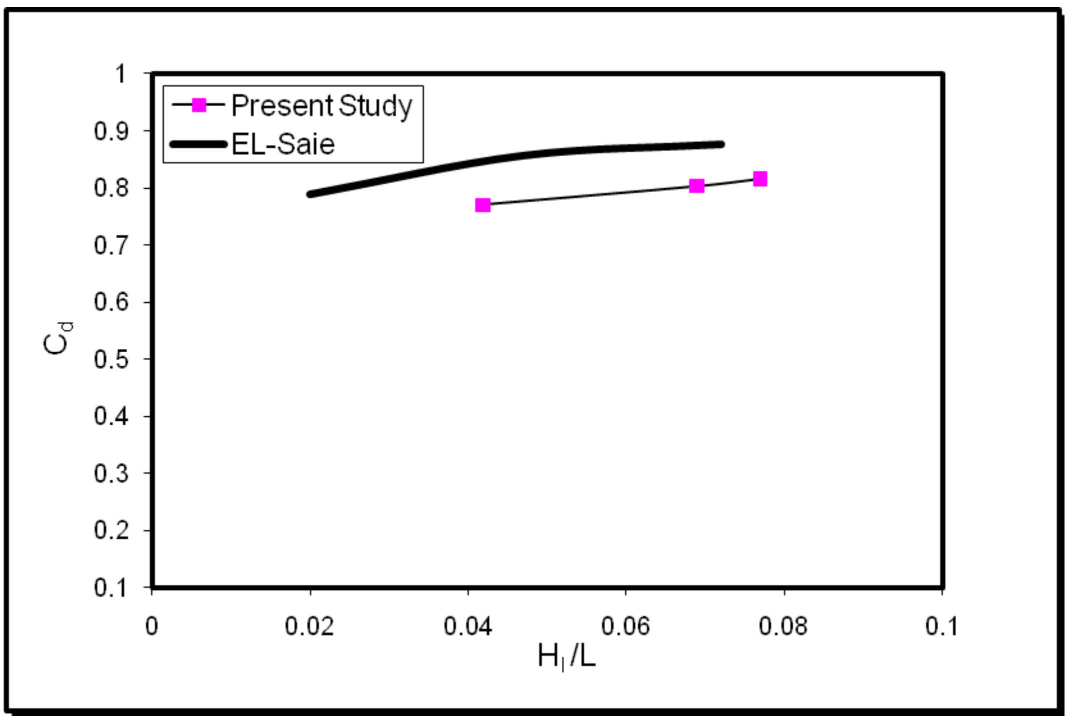

Figure (11) Comparison with EL-Saie 1994

6. Conclusions:-

The analysis of the results leaded to the following conclusions:

1. Coefficient of dissipation (C_d) increases with the increase of H_I/L, d/L, d/H_S, B/L, Z_1, and with the increase of Z_2, where other parameters are constant.
2. The amount of wave energy dissipation is affected by wave steepness (H_I/L), for high value of steeper wave steepness, the waves break and therefore more energy is dissipated.
3. The best ratio of d/H_S was found to be complicated depending on the values of H_I/L, d/L, d/H_B, B/L, B_W/L, Z1 and Z_2. In moderate conditions similar to that on the Egyptian coasts a value of $d/H_S = 1.2$ is preferred (agrees with the results of Mounir [9]).
4. The increase of the slope (Z_2) of the breakwater causes the increases of the dissipated energy.

Symbols:

B	:	Width of berm of breakwater	[L]
B_W	:	Width of the top of breakwater	[L]
C_d	:	Coefficient of Dissipation.	[-]
C_r	:	Coefficient of Reflection.	[-]
C_t	:	Coefficient of Transmission.	[-]
d	:	Water Depth	[L]
E_D	:	Dissipated wave energy	$[ML^2T^{-2}]$
E_I	:	Incident wave energy	$[ML^2T^{-2}]$
E_R	:	Reflected wave energy	$[ML^2T^{-2}]$
E_T	:	Transmitted wave energy	$[ML^2T^{-2}]$
H	:	Wave Height obtained from wave generator	[L]
H_B	:	Height of Berm from bed Level	[L]
H_I	:	Incident Wave Height	[L]
H_r	:	Reflected Wave Height	[L]
H_S	:	Crest breakwater Height	[L]
H_t	:	Transmitted Wave Height	[L]
L	:	Wave Length	[L]

T	:	Wave Period	[T]
Z_1	:	First slope of Breakwater (from bed to berm)	[-]
Z_2	:	Second slope of Breakwater (from berm to top of breakwater)	[-]

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