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Investigating the Energy Dissipation Capability of Solid Piles Breakwater

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Abstract

In terms of the importance of coastal zones, this research started with the motivation of proposing an innovative coastal protection measure (solid piles, evenly distributed and staggered, breakwaters) and investigating their capability of energy dissipation, experimentally. Physical models of solid piles breakwater were designed and constructed. Experimental flume was arranged to test these models and measuring devices were arranged. Contributing parameters (i.e. wave height, period, steepness, piles arrangements and diameters) were varied, Based on the discussions and within the experimented range of parameters, it was clear that solid piles possess an enormous capability of dissipating the wave energy by a percentage that ranged between 20 to 75% which is considered to be significant amount from the coastal engineering point of view.

Keywords: Energy Dissipation; Solid Piles Breakwater.

1. Introduction

The coastal zone (seashore) is a delicate and dynamic area in which the majority of a water body's kinetic energy is dissipated through wave breaking. The most significant result of these processes is transport of beach materials.

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This littoral zone is very important for economic together with social reasons so as to wildlife for habitat and food supply purposes. Therefore; a special care should be directed to protect it. Shoreline protection measures take different forms. Some met certain degrees of success while others encountered obvious failures. This motivated the researcher to initiate the present study.

This paper introduces the problem that motivated the researchers to initiate this study, the study objectives together with the planned methodology to achieve the study goals, the experimental work and the results together with their discussions.

2. Literature review

- Reference [12] studied the wave reflection and transmission for cylindrical pile arrays, (Figure 1). A group of piles in a specific geometric pattern might be represented as a part of a foundation supported by multiple pilings or a porous sea wall or other type of porous coastal structure. "Wave characteristics" of such a structure will include not only the wave transmission but also wave reflection characteristics.

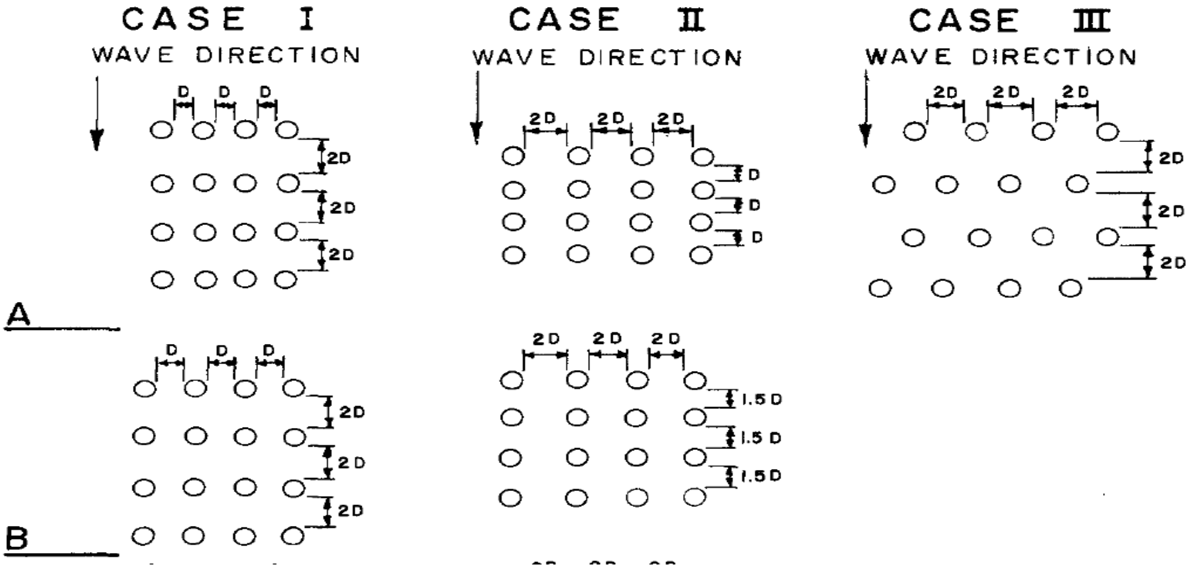

Figure 1: Pile Arrays

- Reference [10] tested the quadratic head loss and scattering of long waves.
- Reference [6] investigated the scattering of water waves by vertical cylinders.
- Reference [9] evaluated the wave transmission by suspended pipe breakwater
- Reference [5] investigated the wave interaction with vertical slotted barrier.
- Reference [4] constructed a model for the scattering of long waves by slotted breakwaters in the presence of currents
- Reference [3] studied the wave interaction with one or two rows of closely-spaced rectangular cylinders.
- Reference [7] Studied multiple-row pile breakwater that consisted of an array of vertical piles and constituted an alternative solution to conventional breakwaters which can be used for coastal protection

under mild wave conditions.

- Reference [1] examined number of row-piles with different heights in experimental study, for shoreline defense, (Figure 2).

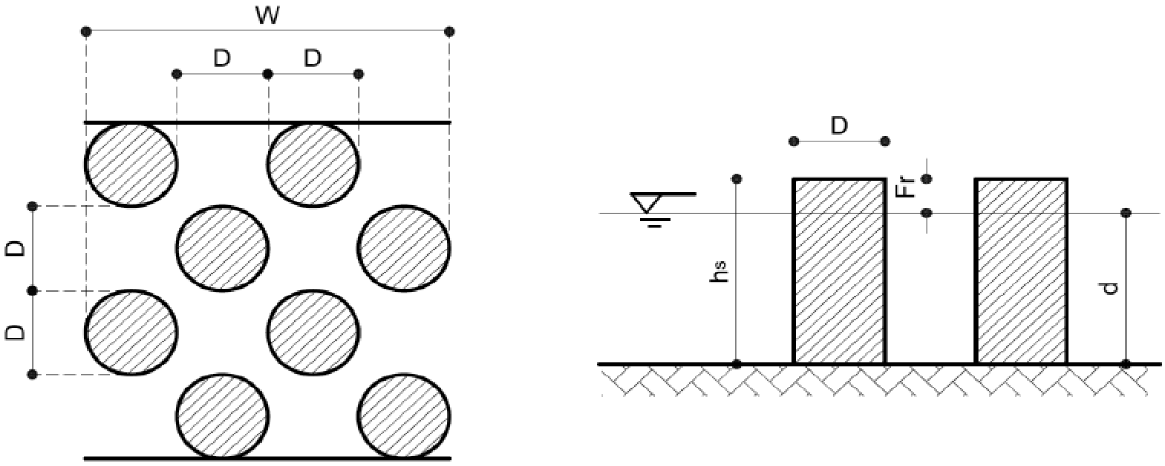

Figure 2: Definition sketch of the multiple-row pile breakwater model

- Reference [8] has developed testing methods and theoretical approaches to study wave run-up and forces on piles in more detail than had been available in previous work.

3. Study objectives and planned methodology

Due to the importance of the protection of the Egyptian zones, this research was initiated with the objective (main objective) of proposing a suitable measure to be implemented to the Egyptian coast. The consequential objectives were to investigate the hydrodynamic performance of the suggested pile breakwater system when used as a wave energy dissipater and calculate coefficients of transmission and reflection. Also, to study different factors affecting the waves such as wave height, wave period, angle and spacing between piles.

4. Experimental work

After assembling, revising and comprehending the literature, apparent was that many researchers investigated, numerically, piles as wave dissipater devices, but there were obvious discrepancies in investigating piles, experimentally. This argument motivated the researchers to complement the ongoing researches by executing experimental work.

The experimental work was carried out in the Research Laboratory in Shorourk Academy Higher Institute of Engineering, Egypt.

4.1. Experimental flume and modeled breakwater

The wave flume is 12.0 m long, 50 cm wide and 60 cm deep. The side walls are glass panels. The flume is provided with a wave generator. The layout and the details of the flume and model are presented on (Figure 4 to 5). The investigated parameters were wave period, wave length and wave height.

4.2. Measuring devices

Wave height measuring devices were used. Two wave probes (Ultra Lab sensors, General Acoustics) were used to measure the surface elevations at location G_1 and G_2, (Figure 3). The incident and the wave height were measured directly before the breakwater position, at G_1. On the other hand, the transmitted wave height was measured after the breakwater position,atG_2.

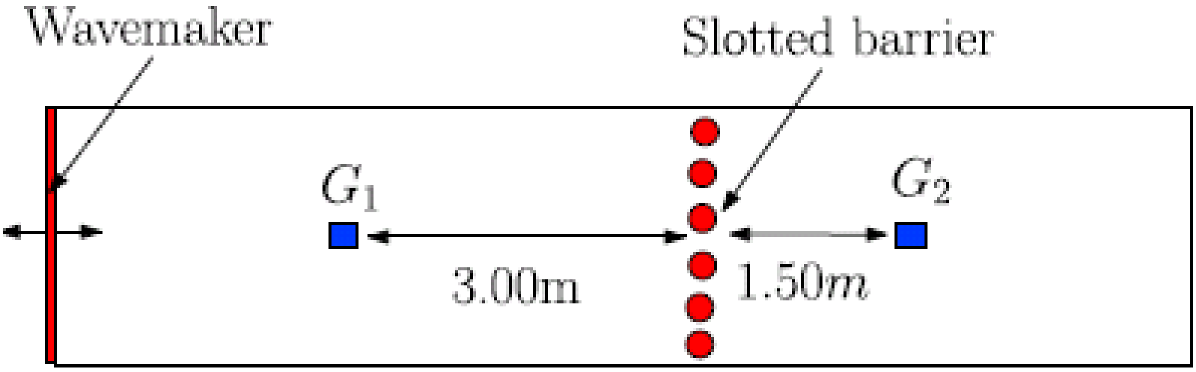

Figure 3: Relative locations of the wave probes, breakwater model and wavemaker

4.3. Wave absorbers

In order to perform accurate and efficient wave tests in the flume, it is necessary to prevent reflection of waves. Therefore; absorbers were installed at the ends of the flume to prevent the reflected waves from inducing standing waves throughout the flume length.

It is to be mentioned that several shapes of wave absorbers, with different materials, were tested to choose the adequate absorber. It was found that the sloped graded gravel was suitable to be used under the current test conditions. The final absorber shape was chosen, after several trials.

4.4. Experimental program

An experimental program was planned, (Table 1). The experiments comprised of 120 runs on solid piles. The following parameters were varied according to the ranges in table 1.

4.5. Experimental procedure

The investigated breakwater models were installed near the middle of the flume and the testing steps proceeded, as follows:

1. The water was filled to the required depth.
2. The wave generator was operated with the required wave height.
3. The wave period was measured.
4. The maximum wave height (H_{max}) was measured and the minimum wave height (H_{min}) was also measured to determine the incident and reflected wave heights.
5. The transmitted wave height (H_t) was measured. The water level was changed to the next level and the same steps were followed. Also, the dimensions of the pile breakwater were changed and the same procedure was replicated.
6. The contributing parameters (i.e. wave height, period, steepness, piles arrangements, diameters…..etc.) were varied and measurements were undertaken, for each case.

Table 1: A sample of the experimental program

Wave height	**Diameter**	**Depth of water**	**Angle**	**Spacing between piles**
(2.5-4.5-6.5-8-12)	(2.5-5-6-7.5)	(16.5 -19.5- 22.5-24.5-27.5)	(0-30-45)	(2.5 -5)
(2.5-4.5-6.5-8-12)	(2.5-5-6-7.5)	(16.5 -19.5- 22.5-24.5-27.5)	(0-30-45)	(2.5 -5)
(2.5-4.5-6.5-8-12)	(2.5-5-6-7.5)	(16.5 -19.5- 22.5-24.5-27.5)	(0-30-45)	(2.5 -5)
(2.5-4.5-6.5-8-12)	(2.5-5-6-7.5)	(16.5 -19.5- 22.5-24.5-27.5)	(0-30-45)	(2.5 -5)
(2.5-4.5-6.5-8-12)	(2.5-5-6-7.5)	(16.5 -19.5- 22.5-24.5-27.5)	(0-30-45)	(2.5 -5)

Figure 4: General View of the experimental Wave Flume

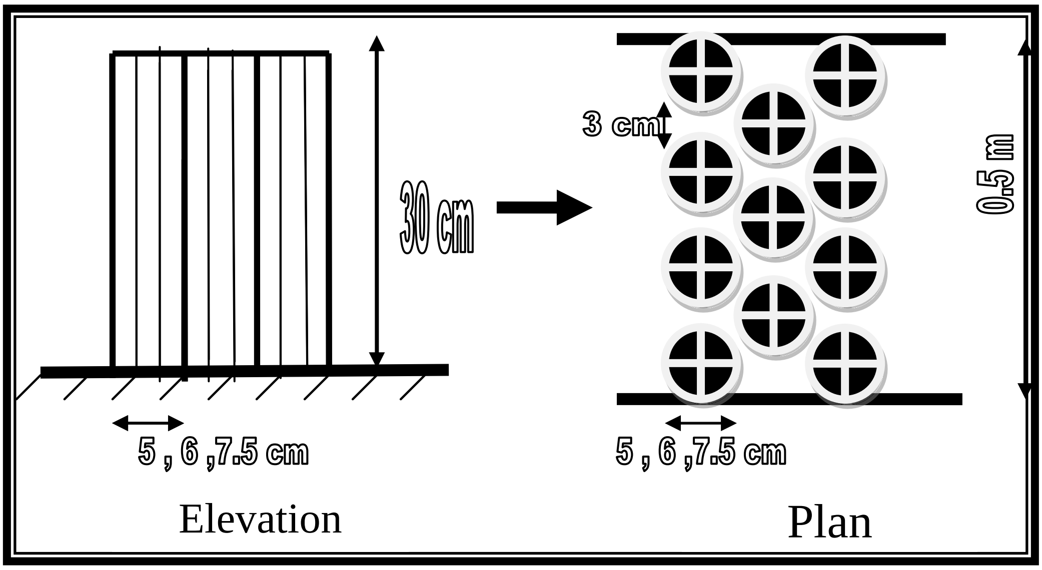

Figure 5.a: Plan and elevation of the model

Figure 5b: Piles breakwater models

Figure 5c: Piles breakwater models

5. Results analysis and discussions

The measurements were analyzed. The incident and reflected waves were calculated, for every tested case, as follows:

$H_i = (H_{max} + H_{min}) / 2$ (1)

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

where:

H_i : incident wave height

H_r : reflected wave height

The dissipated energy was calculated for every tested case based on the following relation

, [11]:

$$E_i = E_r + E_t + E_d \qquad (3)$$

where,

E_i = Incident energy

E_r = Reflected energy

E_t = Transmitted energy

E_d = Dissipated energy, and

$$(\rho g H^2)_i /8 = (\rho g H^2)_r /8 + (\rho g H^2)_t /8 + (\rho g H^2)_d /8 \qquad (4)$$

$$\Delta E = E_i - E_t \qquad (5)$$

$$E_d = \Delta E / E_i \qquad (6)$$

Furthermore, the variables were paired into dimensionless parameters and the different relations were presented on graphs, a sample of which is provided on (Figure 6 to 14).

Additionally, a comparison study was executed to compare the present results with the previous results. (Figure 15 and 16) are provided for comparison purposes.

Based on the undertaken measurements results, figures (6) to (14), it was clear that:

- For all the tested cases, the coefficient of transmission “C_t” decreased as the dimensionless incident wave height “Hi/L” increased.
- For all the tested cases, the coefficient of reflection “C_r” increased as the dimensionless incident wave height “Hi/L” increased.
- For all the tested cases, the coefficient of dissipated energy “C_d” increased as the dimensionless incident wave height “Hi/L” increased.
- For (Figure17) , the coefficient of transmission “C_t” increased as the dimensionless “T√g/d” increased

Figure 15 shows the relationship between Ct and Hi/L calculated using the results from current study and results by Van Weele (1965). Figure 16 shows the relationship between Ct and d/L calculated using the results from cureent study and results by Koftis (2012). It is obvious from (Figure 15and 16), that the present study show the same trend and compares very well with the results from studies conducted by others.

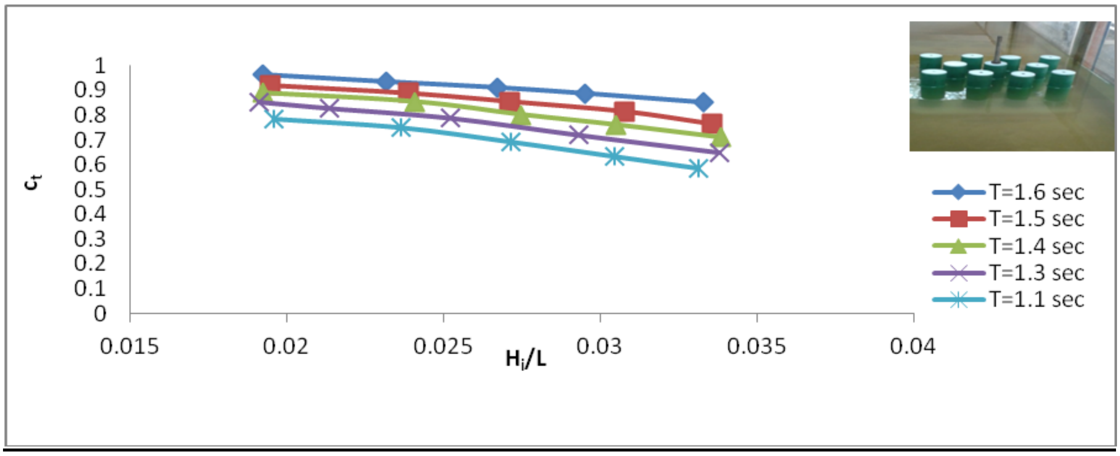

Figure 6: Relation between C_t and H_i/L for solid piles (D=5 cm, angle=0^o)

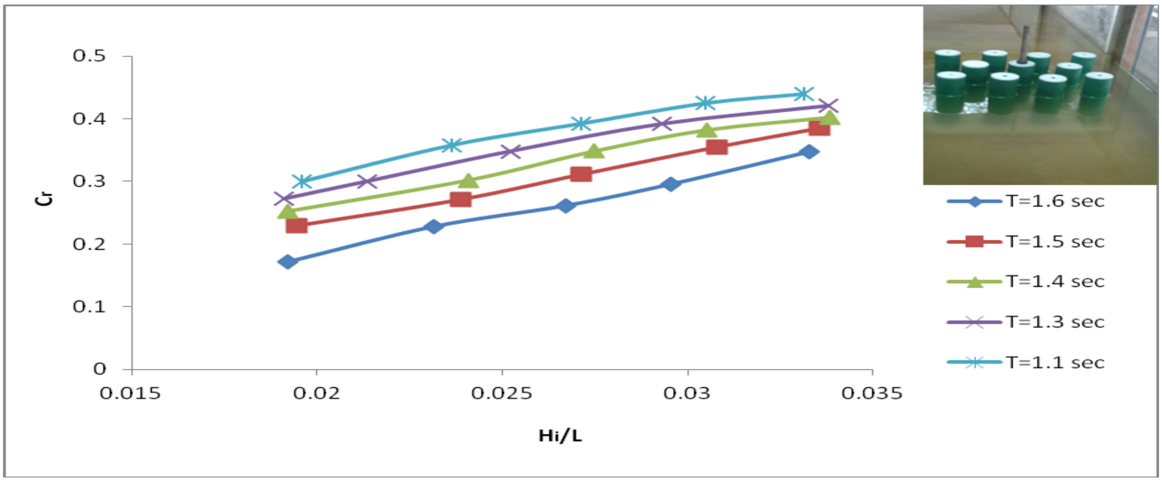

Figure 7: Relation between C_r and H_i/L For solid piles (D=5 cm, angle=0^o)

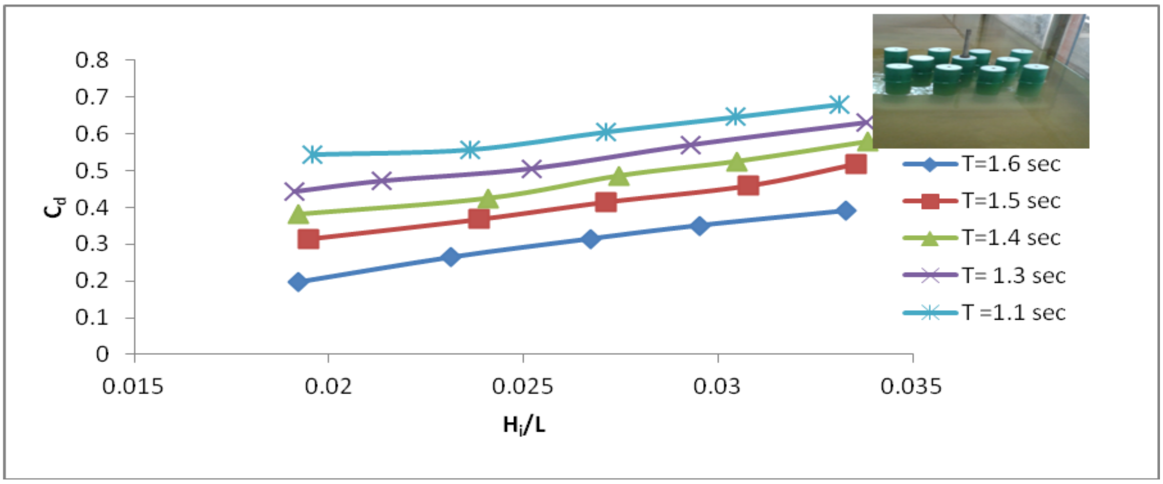

Figure 8: Relation between C_d and H_i/L For solid piles (D=5 cm, angle=0^o)

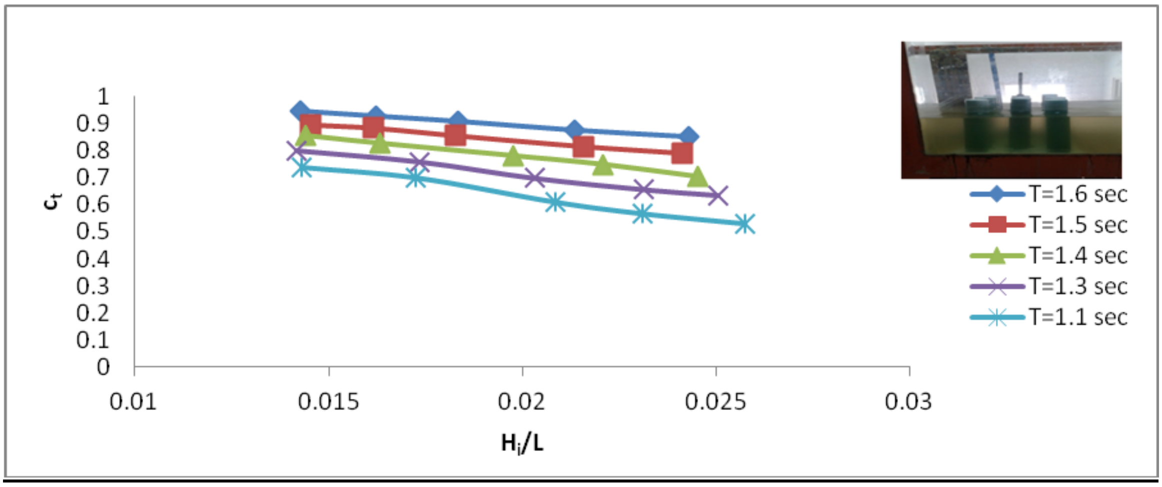

Figure 9: Relation between C_t and H_i/L For solid staggered piles (D=5 cm, angle=0^o)

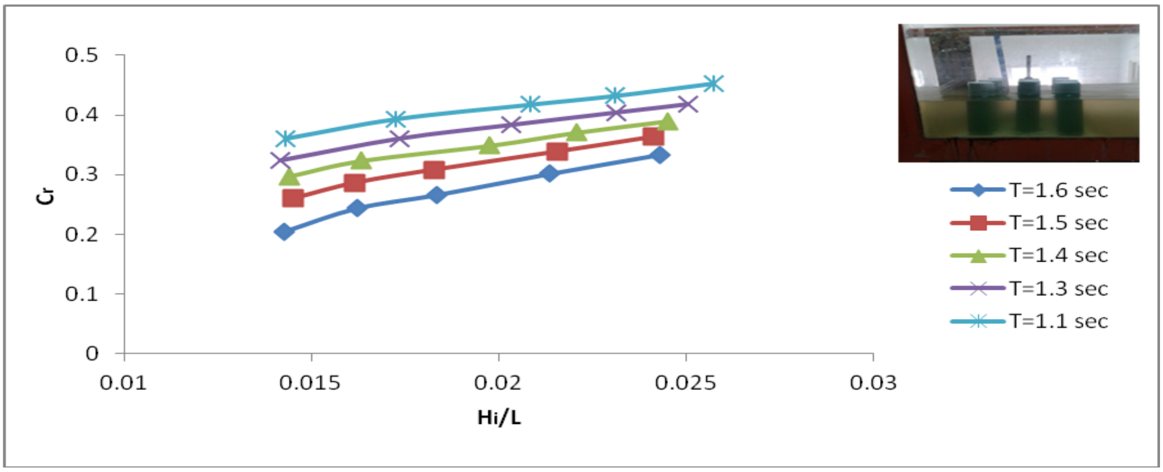

Figure 10: Relation between C_r and H_i/L For solid staggered piles (D=5 cm, angle=0^o)

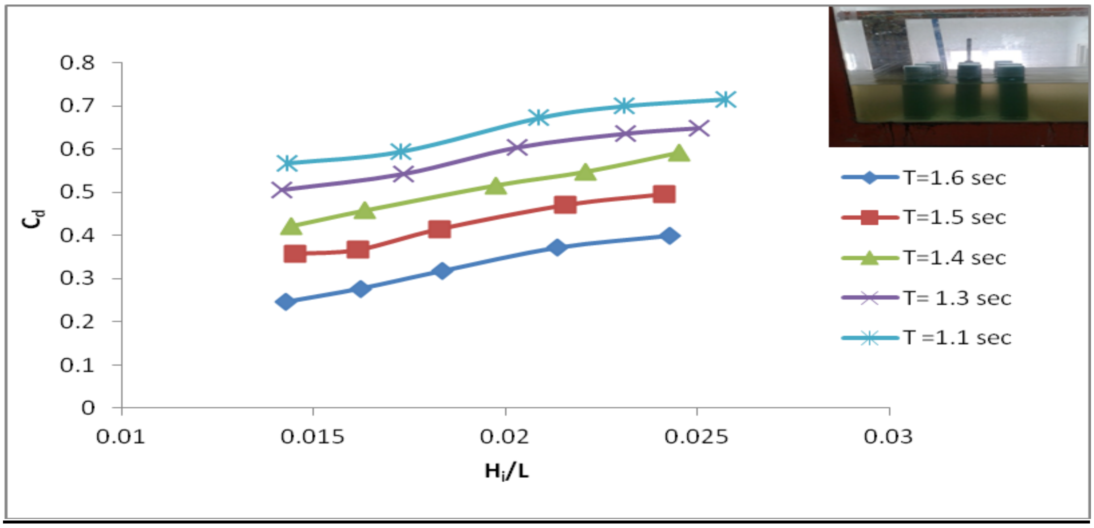

Figure 11: Relation between C_d and H_i/L For solid staggered piles (D=5 cm, angle=0^o)

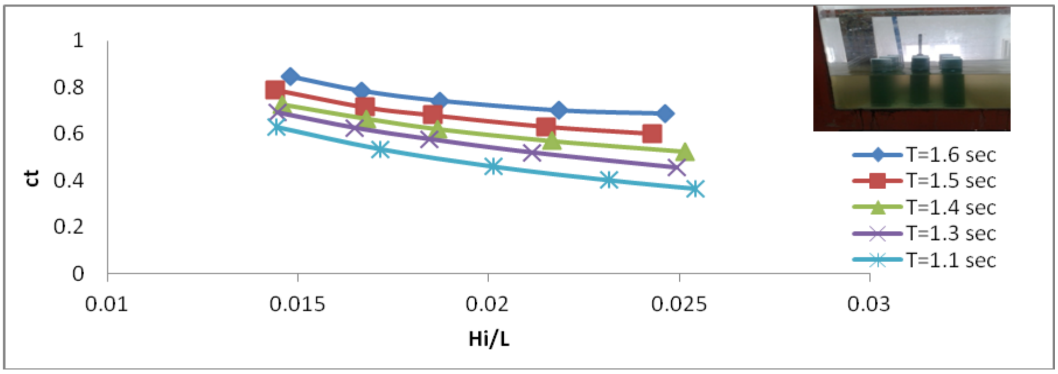

Figure 12: Relation between C_t and H_i/L For solid staggered piles(D=5 cm, angle=45^o)

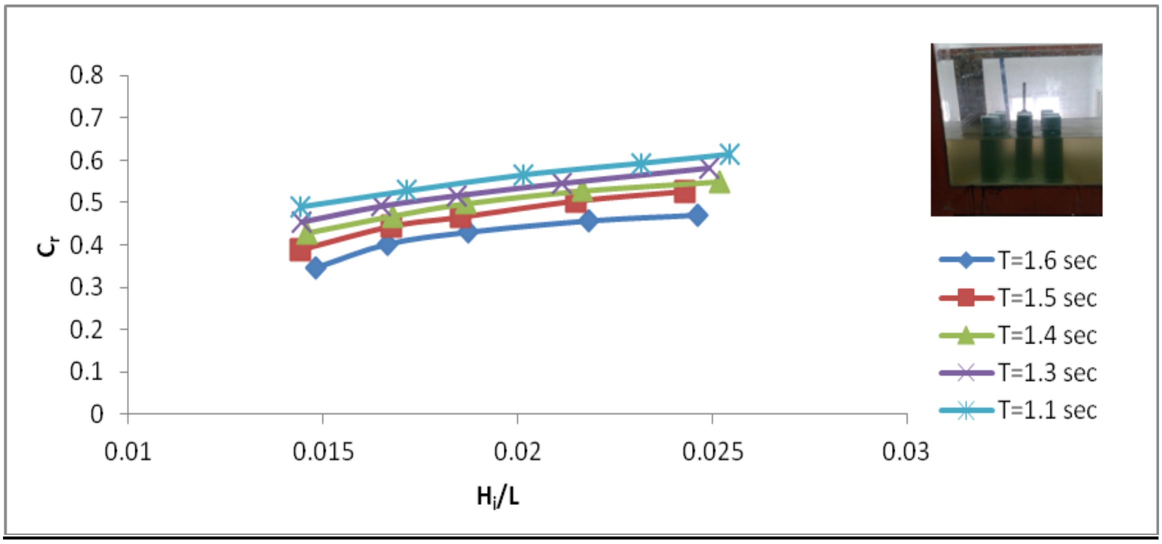

Figure 13: Relation between C_r and H_i/L For solid staggered piles (D=5 cm, angle=45^o)

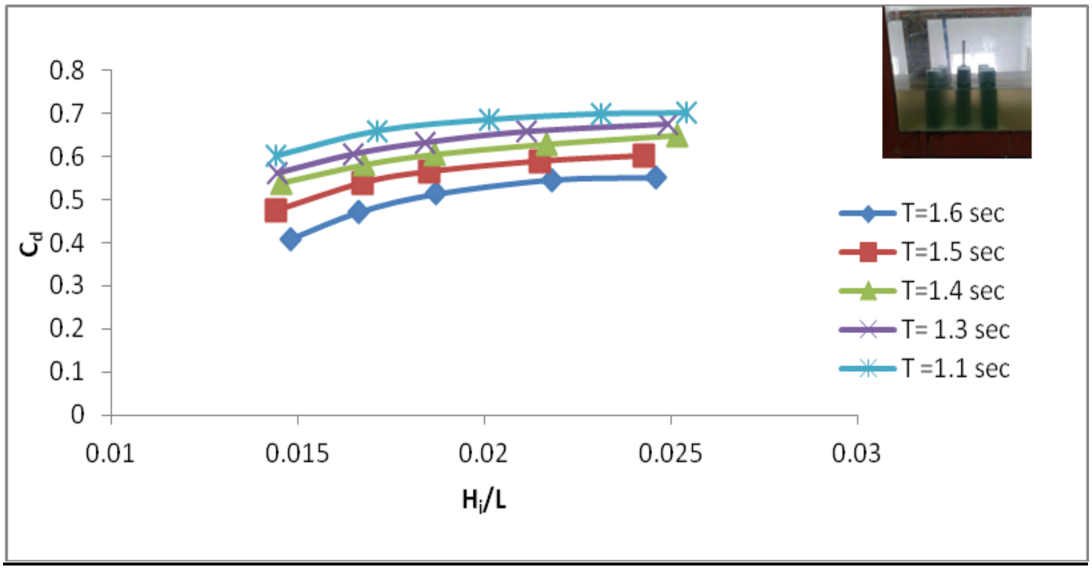

Figure 14: Relation between C_d and H_i/L For solid staggered piles (D=5 cm, angle=45^o)

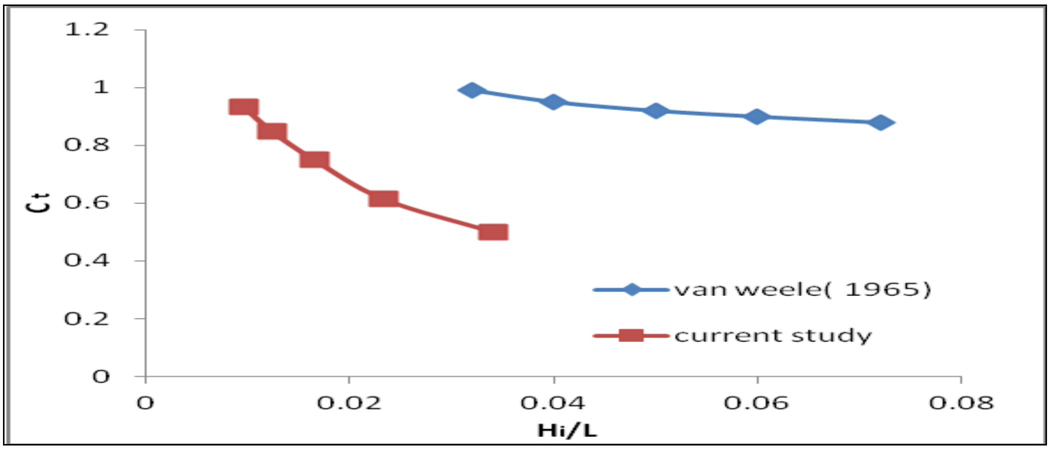

Figure 15: Comparison between present and previous studies

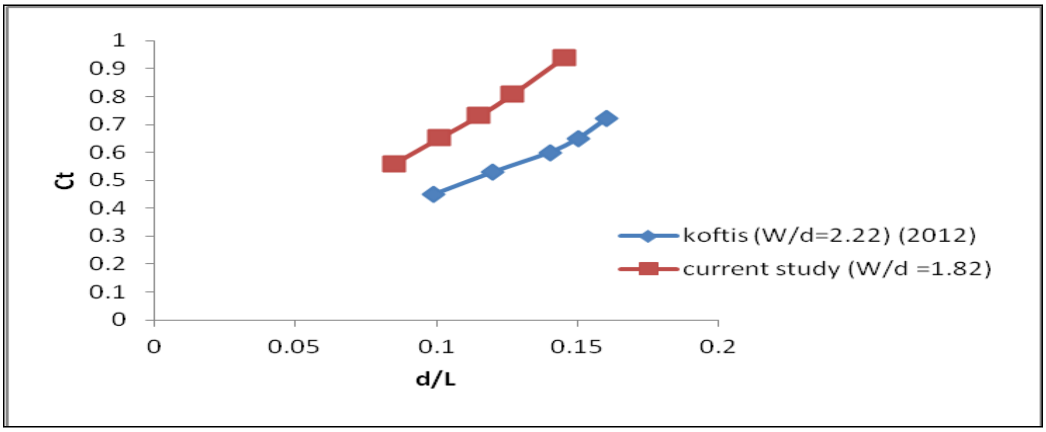

Figure 16: Comparison between results from the present study and results from [7].

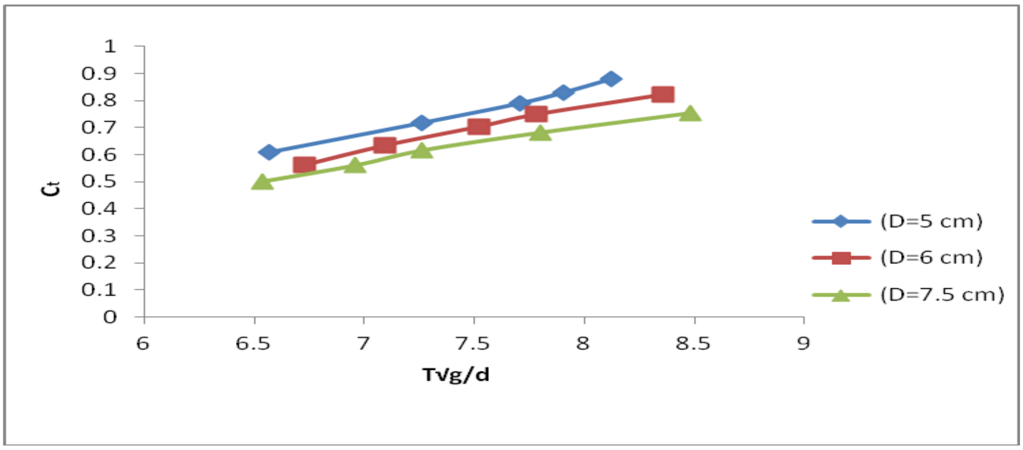

Figure 17: Relation between C_t and T√g/d For solid piles (D=5, 6,7.5 cm, angle=0^o)

Based on the calculations, the following was found:

- In case of the 0^o solid piles, wave energy was dissipated by 20 to 69 %.
- In case of the 0^o staggered piles, wave energy was dissipated by 20 to 60 %.
- In case of the 45^o staggered piles, wave energy was dissipated by 40 to 75 %.

6. Conclusions and recommendations

In this paper, experimental work for piles breakwaters was presented. The following conclusions can be drawn:

From the analysis of the results obtained through Laboratory experiments proved that the smaller the diameter pile was best results.

The following conclusions can be drawn:

- The smallest pile diameter provided the best performance as piles breakwater
- For the diameter (5 cm), wave transmission on pile is inversely proportional to wave steepness; therefore the approximately energy transmitted ranged between 50 to 90 % of the total energy.
- For the diameter (5 cm), wave reflection on pile is directly proportional to wave steepness; therefore the approximately energy reflected ranged between 15 to 45 % of the total energy.
- For the diameter (5 cm), dissipated energy on pile is directly proportional to wave steepness there for the approximately energy dissipation ranged between 15 to 65 % of the total energy.

Within the experimented range of parameters, it was clear that solid piles and the staggered possess an enormous capability of dissipating wave energy by a percentage that ranged between 20 to 75% Based on the above conclusions, it is recommended to implement a pilot project to investigate the efficiency of the proposed piles breakwaters configurations using a prototype scale.

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