

Performance of Using Porous Floating Cylindrical Breakwater with Different Porosities as a Wave Energy Dissipater in Experimental Study

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ABSTRACT

Floating breakwaters are commonly used to protect shorelines, marine structures and harbors from wave attacks. Through the physical model test method, the wave energy dissipation performance by using porous floating cylindrical breakwater under regular waves. The objective of this research is to study the effect of using a horizontal cylindrical pipe with different diameters and different percentage of porosities acting as a wave energy dissipater, working as a single pipe or as a group. Which contains five different models with diameters (2 inch, 3 inch, 4 inch, (3&4 inch together) and (2, 3 & 4 inch together), by choosing different percentage of porosities as (15, 30 & 50%) to achieve maximum energy dissipation with minimum transmitted energy. The experiments were carried out in a recirculating open channel flume located at the Hydraulics Engineering Laboratory, Higher Institute of Engineering in El Shorouk City.

INTRODUCTION

As a wave resisting structure, breakwaters are widely used in port fairways, bathing places, wharves a yachts, and its structural form has great influence on ship navigation, water exchange, wave attenuation and wave reduction in offshore engineering. Traditional gravity breakwaters in deep-water areas are faced with problems such as high foundation requirements, difficult construction and high cost in very deep water. The floating breakwater is made up of floating bodies and mooring systems, which owns a lot of advantages. It is conducive to the water exchange, and has little influence on the sediment and the ecological environment. The cost is less affected by water depth, the foundation is more adaptable, and the construction is relatively convenient. It is more suitable for sea areas with high tidal range, soft soil bed and deep waters. Therefore, the floating breakwaters has broad application prospects. In recent years, many researchers proposed many new types of floating bodies, the cage floating breakwater, the square box-truss-mooring-type floating breakwater, the double pontoon floating breakwater, the net-board floating breakwater, the wave dissipation performance, hydrodynamic performance, the mooring force and wave pressure of floating breakwaters are mainly studied in experimental and numerical ways. Many experimental and theoretical studies have been done for determining the efficiency of vertical submerged or emerged permeable or impermeable types of breakwaters. **Dalrymple et al, (1991)** examined the reflection and the transmission coefficients from porous structures under oblique wave attack. **Wang and Sun, (2010)** examined a porous breakwater where the structure was fabricated with large numbers of diamond-shaped blocks arranged to reduce transmitted wave height and the mooring force. Their results showed that the porous FB reduced transmission of a large part of the incident wave energy through dissipation rather than reflection of the wave energy. The effect of the porous media on the incoming waves has in recent years gained attention with the use of advanced numerical models as discussed for example by **Garcia et al., (2004)**, **Jacobsen et al., (2015)**, **Jensen et al., (2014)**, **Losada et al., (2005)**. The single

pontoon FB reflects rather than dissipates the wave energy, **Abul-Azm, (1993)** analyzed the linear wave potential near submerged thin barriers using the Eigen Function Expansion to determine the breakwater efficiency. **Erik et al., (2018)**, attaching wing plates to the floating breakwater significantly reduced the motion, which was also anticipated. When the porous sides were attached the motion of the Floating Breakwater increased compared to the (WP) cross section, but the wave transmission was reduced. **Isaacson et al, (1996)**, carried out an experimental investigation on the reflection of obliquely incident waves from a model rubble-mound breakwater of single slice. N Zheng et al., (2018), the wave dissipation performance and mooring force of porous floating breakwater under regular waves are analyzed and compared with the traditional pontoon floating breakwater. **Heikal and Attar, (1997)**, examined the efficiency of an impermeable, vertical thin submerged breakwater sited on sloping impermeable bed experimentally and numerically by using the Eigen Function Expansion method **Twu et al, (2001)**, studied theoretically, using the Eigen Function Expansion method, the problem of wave transmission over a rectangular and vertically stratified with multi-slice porous material. **Zhichao et al., (2018)**, study of the wave-dissipating performance of a four-layer horizontal porous-plate breakwater. **Stamos and Hajj, (2001)** developed a new method to separate incident and reflected wave components. Then the method is applied to perform a parametric study to compare the reflection and transmission characteristics of flexible and rigid breakwaters. **Stamos et al, (2003)** conducted a parametric experimental study to compare the reflection and transmission characteristics of submerged hemi-cylindrical and rectangular rigid and water-filled flexible breakwater models. **Ting et al, (2004)** investigated how the porosity of submerged breakwaters affects non-breaking wave transformations. Eight model geometries each with six different porosities, from 0.421 to 0.912, were also considered. **Sidek and Wahab, (2007)** experimentally investigated the effects of porosity of submerged breakwater on non-breaking wave transformations. A hollow framework-shaped test model was used. Three models each with three different porosities ranging from 0.40 to 0.80 were used in that experiment. **Womera, (2011)** investigated the interaction between waves and rectangular submerged impermeable breakwater. A two-dimensional numerical model based on the SOLA-VOF method was proposed. **Vahid and Fatemeh, (2011)** developed an experimental solution for evaluation of transmission coefficients of water waves through single perforated sheets and upright perforated wave filters. **Wu et al, (2012)** conducted experimental and numerical interactions. The Effect of Porosity of Submerged and Emerged Breakwater on wave transmission. From the review of many related published literature in this field, it is acknowledged that more information are needed from both in the laboratory and the field for the efficient application, development and design of promising vertical porous structures as coastal engineering solutions in the field. In this study, experimental investigation has been carried out in a two dimensional wave tank to understand the effect of porosity in vertical thick submerged and emerged porous breakwaters under wave action. In summary, through the research of many floating breakwaters, the wave dissipation performance of floating breakwater under long wave action is the focus. In order to increase the effects on long waves, some percentage of porosities in the body of the floating cylindrical breakwater by opening holes in it on both sides of the model to dissipate more wave energy. It is also be called porous floating cylindrical breakwater. In this paper, the transmission and dissipation coefficients can be calculated and also choosing the favorite percentage of porosity and the best diameter for achieving minimum transmitted energy.

EXPERIMENTAL WORK

The experimental work was conducted in a wave flume 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 tests were carried out in a wave flume in the Hydraulic laboratory at the Higher Institute of Engineering, in El Shorouk City. The flume is 12.00 m long, 0.50 m wide, and the sidewalls are 0.60 m high, see Fig. (1). The sidewalls of the flume consisted of a 12.00 panels of glass each one meter, to enable for following the motion of the Floating Breakwater as shown in figure (2). The flume was equipped with a piston-type wave maker at one end and a wave absorber before it and a wave absorber at the other side of the flume. The water depth in the flume was fixed to 30 cm, as a maximum water depth in the flume.

Wave period and wave length are measured by Sonic Wave Sensor XB as shown in figure (3).



Figure (1) General view of the wave flume

DESIGN OF THE PHYSICAL MODELS

The physical model consists of five models of a hollow cylindrical horizontal floating pipes with different diameters (2", 3", 4", (3" & 4" together) and (2", 3" & 4" together), changing the porosity from (15, 30 and 50 %), it rested on a wooden floating base with dimensions of 45 cm long, 16 cm width and 7 cm height, which tied to the base of the flume by four anchors. The horizontal pipe hanging over two vertical sides of height 14 cm. Water depth was constant at 30 cm) with different wave heights, lengths and periods. By testing these models to evaluate the performance of each model for dissipate the incident wave energy and also to calculate wave coefficients (C_t , C_r and C_d), also the maximum possible transmitted energy. Finally, comparison these tested models by a same solid pipes, **El saie, (2019)**. Also the figures (2, 3, 4, 5, 6, 7 & 8) contains some of the tested models with different porosities.



Fig. (2) Model one with P = 30 %

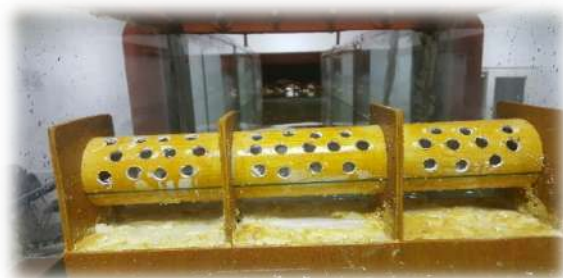


Fig. (3) Model two with P = 30 %

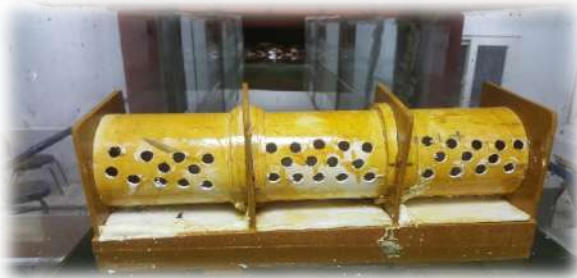


Fig. (4) Model three with P = 50 %



Fig. (5) Model four with P = 15 %



Fig. (6) Model five with P = 15 %



Fig. (7) Model five with P = 30 %

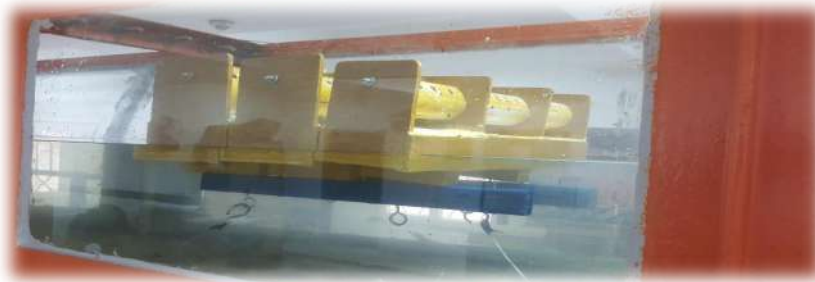


Fig. (8) Side view of model five tied with anchors

MEASUREMENTS AND RESULTS

By testing these models in the wave flume and measure the wave heights before and after these tested models by using Sonic Wave Sensor XB, measurements and calculated coefficients (Ct, Cr & Cd) as shown in the following tables.

Tables (1, 2, &3) for $\varnothing = 2$ inch & P = 15, 30 & 50%.

Table (1) Measured and calculated data for $\varnothing = 2$ inch & P = 15%

Porosity 15 %, $\varnothing = 2''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	9.04	0.21	139.37	0.072	0.8989	0.0209	0.4376	80.80
	9.01	7.90	0.20	122.34	0.074	0.8767	0.0219	0.4805	76.87
	7.96	6.89	0.18	106.55	0.075	0.8660	0.0231	0.4996	74.99
	7.34	5.99	0.17	90.23	0.081	0.8154	0.0227	0.5784	66.50
	6.15	4.82	0.15	69.25	0.089	0.7844	0.0242	0.6198	61.52

Table (2) Measured and calculated data for $\varnothing = 2$ inch & P = 30%

Porosity 30 %, $\varnothing = 2''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	9.27	0.18	139.37	0.072	0.9216	0.0183	0.3876	84.94
	9.01	8.13	0.17	122.339	0.074	0.9018	0.0191	0.4317	81.33
	7.96	7.20	0.16	106.548	0.075	0.9044	0.0202	0.4263	81.79
	7.34	6.24	0.15	90.231	0.081	0.8495	0.0198	0.5272	72.17
	6.15	5.10	0.13	69.254	0.089	0.8294	0.0212	0.5583	68.78

Table (3) Measured and calculated data for $\varnothing = 2$ inch & P = 50%

Porosity 50%, $\varnothing = 2''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	9.52	0.14	139.37	0.072	0.9467	0.0138	0.3218	89.63
	9.01	8.33	0.13	122.339	0.074	0.9240	0.0144	0.3822	85.37
	7.96	7.33	0.12	106.548	0.075	0.9203	0.0152	0.3910	84.69
	7.34	6.33	0.11	90.231	0.081	0.8618	0.0149	0.5070	74.27
	6.15	5.20	0.10	69.254	0.089	0.8453	0.0160	0.5341	71.45

Therefore figure (9) describe the relation between coefficient of dissipation (Cd) and (Hi/L) for $\varnothing = 2.0$ inch with different percentage of porosity.

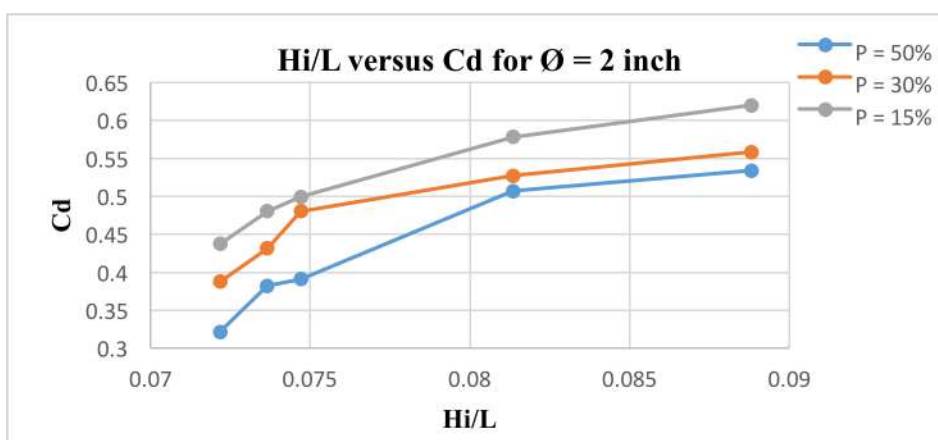


Fig. (9) Cd versus Hi/L for $\varnothing = 2.0$ inch & P = (15, 30 & 50 %)

Also, figure (10) shows the percentage of energy transmitted with different wave steepness Hi/L for $\varnothing = 3.0$ inch and different porosities.

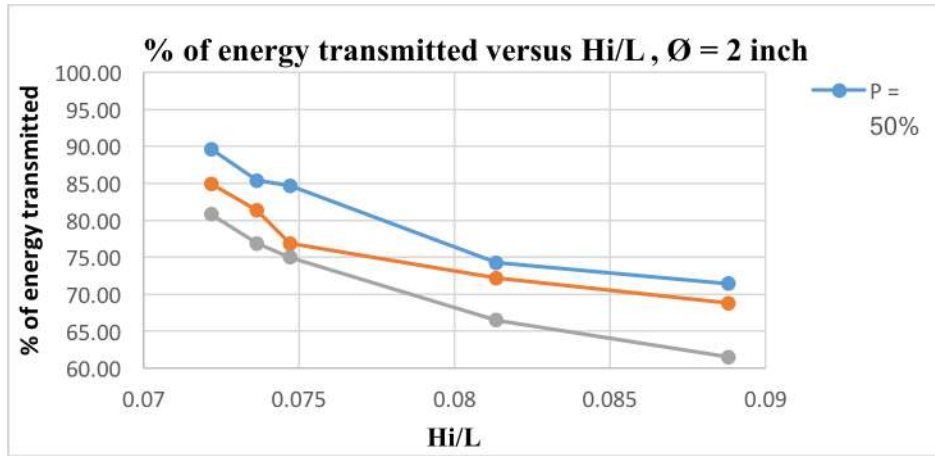


Fig. (10) % of energy transmitted versus Hi/L for Ø = 2.0 inch & P = (15, 30 & 50 %)

Therefore, tables (4, 5 &6) also for measured heights of waves and the calculated wave coefficients for Ø = 3 inch & P = 15, 30 & 50%.

Table (4) Measured and calculated data for Ø = 3 inch & P = 15%

Porosity 15 %, Ø = 3"	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	8.93	0.23	139.37	0.072	0.8880	0.0227	0.4594	78.8465
	9.01	7.83	0.22	122.34	0.074	0.8685	0.0239	0.4950	75.4370
	7.96	6.76	0.20	106.55	0.075	0.8495	0.0253	0.5269	72.1690
	7.34	6.04	0.18	90.23	0.081	0.8235	0.0250	0.5668	67.8125
	6.15	4.88	0.17	69.25	0.089	0.7932	0.0270	0.6083	62.9194

Table (5) Measured and calculated data for Ø = 3 inch & P = 30%

Porosity 30 %, Ø = 3"	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	9.3721	0.23	139.37	0.072	0.9316	0.0225	0.3627	86.79
	9.01	8.1256	0.21	122.339	0.074	0.9018	0.0237	0.4314	81.33
	7.96	7.1255	0.20	106.548	0.075	0.8952	0.0251	0.4450	80.13
	7.34	6.2459	0.18	90.231	0.081	0.8509	0.0248	0.5247	72.41
	6.15	5.0254	0.16	69.254	0.089	0.8171	0.0267	0.5758	66.77

Table (6) Measured and calculated data for Ø = 3 inch & P = 50%

Porosity 50 %, Ø = 3"	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	9.84	0.20	139.37	0.072	0.9777	0.0200	0.2092	95.58
	9.01	8.62	0.19	122.339	0.074	0.9563	0.0210	0.2917	91.45
	7.96	7.45	0.18	106.548	0.075	0.9353	0.0223	0.3530	87.49
	7.34	6.66	0.16	90.231	0.081	0.9067	0.0220	0.4213	82.21
	6.15	5.37	0.15	69.254	0.089	0.8734	0.0237	0.4865	76.27

Therefore figure (11) describe the relation between coefficient of dissipation (Cd) and (Hi/L) for Ø = 3.0 inch with different percentage of porosity.

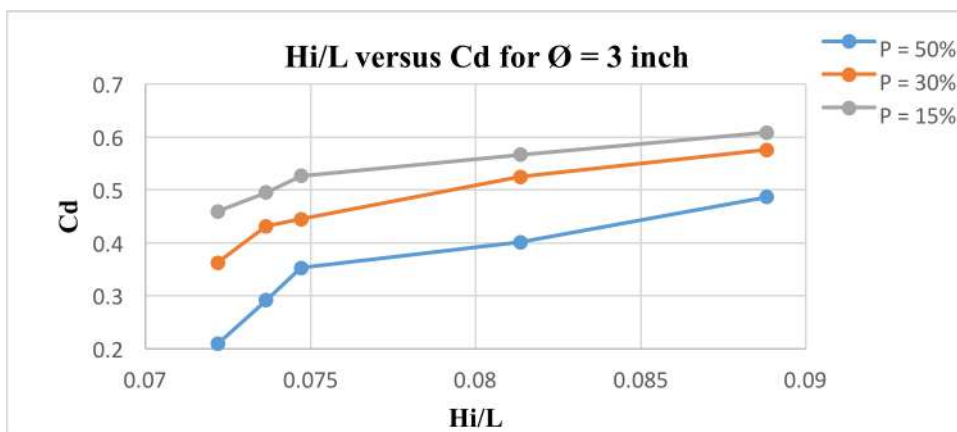


Fig. (11) Cd versus Hi/L for Ø = 3.0 inch & P = (15, 30 & 50 %)

Also, figure (12) shows the percentage of energy transmitted with different wave steepness Hi/L for Ø = 3.0 inch and different porosities.

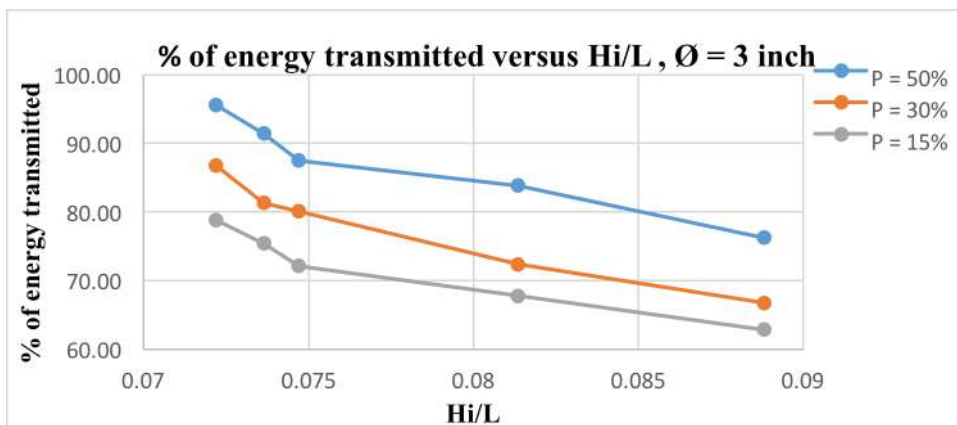


Fig. (12) % of energy transmitted versus Hi/L for Ø = 3.0 inch & P = (15, 30 & 50 %)

Similarly, tables (7, 8 &9) also for measured heights of waves and the calculated wave coefficients for Ø = 4 inch & P = 15, 30 & 50%.

Table (7) Measured and calculated data for Ø = 4 inch & P = 15%

Porosity 15 %, Ø = 4"	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	8.766	0.22	139.37	0.072	0.8714	0.0219	0.4901	75.93
	9.01	7.644	0.21	122.339	0.074	0.8484	0.0231	0.5289	71.97
	7.96	6.625	0.20	106.548	0.075	0.8322	0.0246	0.5539	69.26
	7.34	5.714	0.18	90.231	0.081	0.7784	0.0244	0.6273	60.59
	6.15	4.457	0.16	69.254	0.089	0.7247	0.0264	0.6885	52.52

Table (8) Measured and calculated data for $\varnothing = 4$ inch & P = 30%

Porosity 30 %, $\varnothing = 4''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	9.1888	0.21	139.37	0.072	0.9134	0.0210	0.4065	83.43
	9.01	8.0124	0.20	122.339	0.074	0.8893	0.0221	0.4568	79.08
	7.96	6.8458	0.19	106.548	0.075	0.8724	0.0235	0.4883	73.96
	7.34	6.1025	0.17	90.231	0.081	0.8159	0.0234	0.5777	69.12
	6.15	4.672	0.16	69.254	0.089	0.7597	0.0253	0.6498	57.71

Table (9) Measured and calculated data for $\varnothing = 4$ inch & P = 50%

Porosity 50 %, $\varnothing = 4''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	9.64	0.18	139.37	0.072	0.9586	0.0180	0.2840	91.90
	9.01	8.32	0.17	122.339	0.074	0.9333	0.0190	0.3585	85.36
	7.96	7.29	0.16	106.548	0.075	0.9156	0.0202	0.4017	83.83
	7.34	6.29	0.15	90.231	0.081	0.8564	0.0200	0.5160	73.34
	6.15	4.82	0.13	69.254	0.089	0.7973	0.0217	0.6032	61.52

Therefore, figure (13) describe the relation between coefficient of dissipation (Cd) and (Hi/L) for $\varnothing = 4.0$ inch with different percentage of porosities.

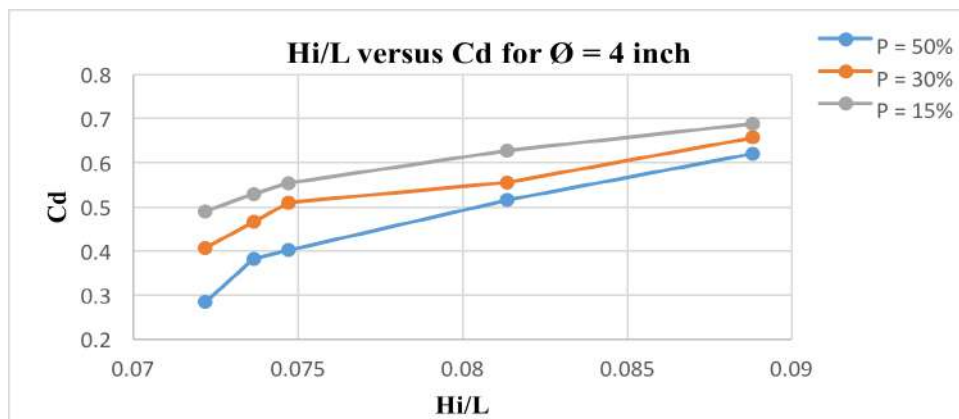


Fig. (13) Cd versus Hi/L for $\varnothing = 4.0$ inch & P = (15, 30 & 50 %)

Also, figure (14) shows the percentage of energy transmitted with different wave steepness Hi/L for $\varnothing = 4.0$ inch and different porosities.

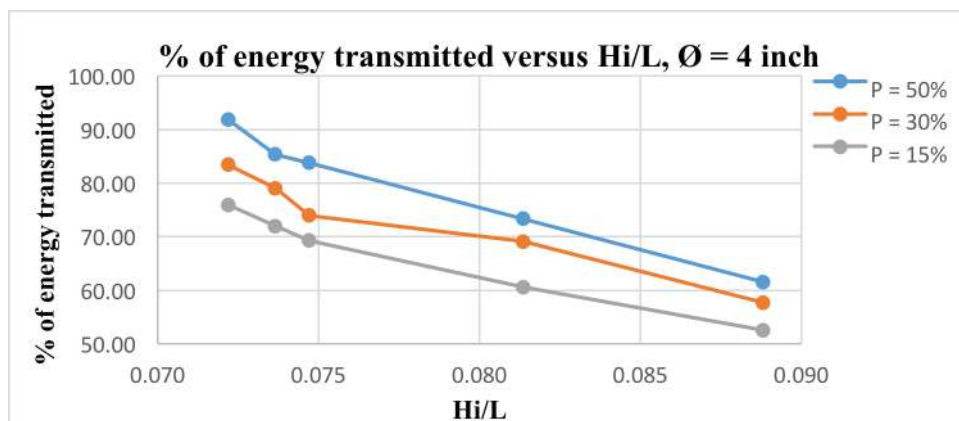


Fig. (14) % of energy transmitted versus Hi/L for $\varnothing = 4.0$ inch & P = (15, 30 & 50 %)

Therefore, tables (10, 11 &12) also for measured wave heights and the calculated wave coefficients for $\varnothing = 3$ & 4 inch & P = 15, 30 & 50%.

Table (10) Measured and calculated data for $\varnothing = 3$ & 4 inch & P = 15%

Porosity 15 %, $\varnothing = 3'' , 4''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	5.607	0.26	139.37	0.072	0.5573	0.0263	0.8299	31.06
	9.01	4.89	0.25	122.339	0.074	0.5562	0.0278	0.8306	29.53
	7.96	4.192	0.24	106.548	0.075	0.5267	0.0297	0.8496	27.74
	7.34	3.716	0.22	90.231	0.081	0.5063	0.0297	0.8619	25.63
	6.15	2.91	0.20	69.254	0.089	0.5064	0.0325	0.8617	22.43

Table (11) Measured and calculated data for $\varnothing = 3$ & 4 inch & P = 30%

Porosity 30 %, $\varnothing = 3'' , 4''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	5.8721	0.25	139.37	0.072	0.5837	0.0249	0.8116	34.07
	9.01	5.2032	0.24	122.339	0.074	0.5825	0.0263	0.8124	33.35
	7.96	4.3907	0.22	106.548	0.075	0.5516	0.0282	0.8336	30.43
	7.34	3.892	0.21	90.231	0.081	0.5302	0.0282	0.8474	28.12
	6.15	3.03	0.19	69.254	0.089	0.5304	0.0308	0.8472	24.18

Table (12) Measured and calculated data for $\varnothing = 3$ & 4 inch & P = 50%

Porosity 50 %, $\varnothing = 3'' , 4''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	6.16	0.21	139.37	0.072	0.6122	0.0213	0.7904	37.47
	9.01	5.29	0.20	122.339	0.074	0.6109	0.0226	0.7914	34.61
	7.96	4.66	0.19	106.548	0.075	0.5785	0.0241	0.8153	34.27
	7.34	4.08	0.18	90.231	0.081	0.5561	0.0241	0.8308	30.92
	6.15	3.21	0.16	69.254	0.089	0.5562	0.0263	0.8306	27.29

Also, figure (15) describe the relation between coefficient of dissipation (Cd) and (Hi/L) for $\varnothing = 3.0$ & 4.0 inch with different percentage of porosities.

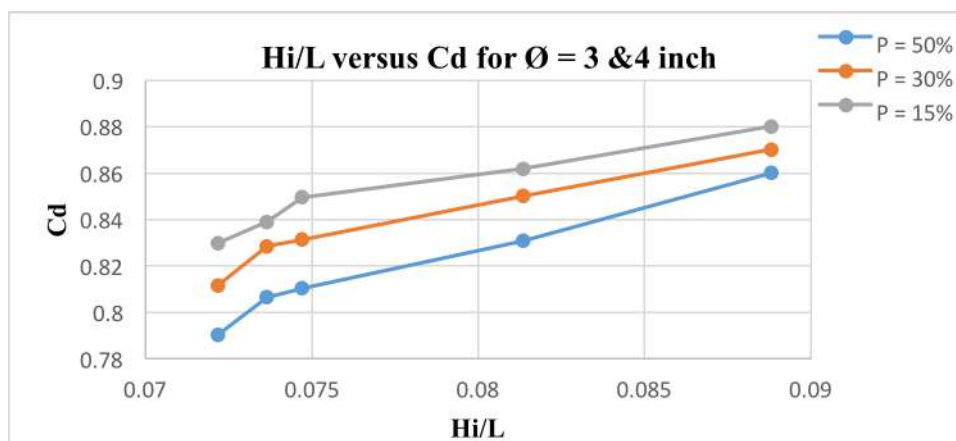


Fig. (15) Cd versus Hi/L for $\varnothing = 4.0$ inch & P = (15, 30 & 50 %)

Therefore, figure (16) shows the percentage of energy transmitted with different wave steepness H_i/L for $\varnothing = 3.0$ & 4.0 inch and different porosities.

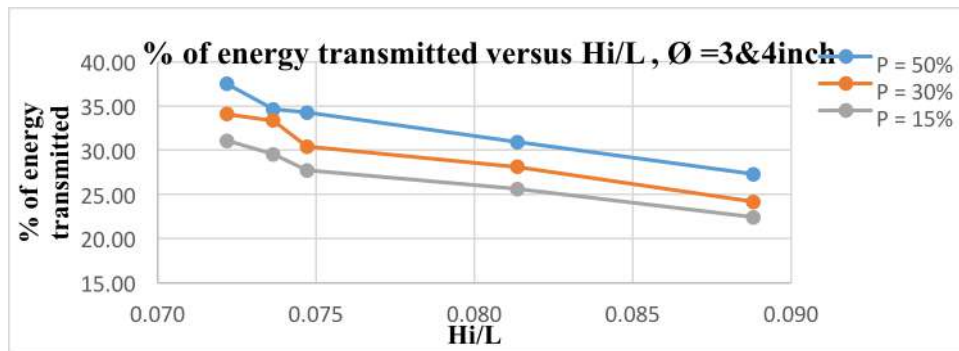


Fig. (16) % of energy transmitted versus H_i/L for $\varnothing = 3.0$ & 4.0 inch & $P = (15, 30 \text{ \& } 50 \%)$

Similarly, tables (13, 14 & 15) also for measured heights of waves and the calculated wave coefficients for $\varnothing = 3.0, 4.0$ & 4.0 inch & $P = 15, 30$ & 50% .

Table (13) Measured and calculated data for $\varnothing = 2.0, 3.0$ & 4.0 inch & $P = 15\%$

$P = 15\%, \varnothing = 2'', 3'', 4''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	4.976	0.29	139.37	0.072	0.4947	0.029	0.8686	24.47
	9.01	4.201	0.28	122.339	0.074	0.4731	0.031	0.8805	21.71
	7.96	3.672	0.27	106.548	0.075	0.4613	0.033	0.8866	21.28
	7.34	3.294	0.25	90.231	0.081	0.4487	0.034	0.8930	20.14
	6.15	2.703	0.23	69.254	0.089	0.4395	0.037	0.8975	19.31

Table (14) Measured and calculated data for $\varnothing = 2.0, 3.0$ & 4.0 inch & $P = 30\%$

$P = 30\%, \varnothing = 2'', 3'', 4''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	5.1518	0.27	139.37	0.072	0.5121	0.0267	0.8585	26.23
	9.01	4.4132	0.26	122.339	0.074	0.4898	0.0284	0.8714	23.99
	7.96	3.8014	0.24	106.548	0.075	0.4776	0.0306	0.8781	22.81
	7.34	3.368	0.23	90.231	0.081	0.4646	0.0309	0.8850	21.06
	6.15	2.798	0.21	69.254	0.089	0.4550	0.0341	0.8899	20.70

Table (15) Measured and calculated data for $\varnothing = 2.0, 3.0$ & 4.0 inch & $P = 50\%$

$P = 50\%, \varnothing = 2'', 3'', 4''$	Hi (cm)	Ht (cm)	Hr (cm)	Length (cm)	Hi/L	Ct	Cr	Cd	% energy transmitted
	10.06	5.36	0.23	139.37	0.072	0.5325	0.0228	0.8462	28.35
	9.01	4.65	0.22	122.339	0.074	0.5093	0.0243	0.8603	26.73
	7.96	4.01	0.21	106.548	0.075	0.4965	0.0262	0.8676	25.41
	7.34	3.55	0.19	90.231	0.081	0.4830	0.0264	0.8752	23.33
	6.15	2.91	0.18	69.254	0.089	0.4730	0.0292	0.8806	22.38

Also, figure (17) describe the relation between coefficient of dissipation (C_d) and (H_i/L) for $\varnothing = 2.0, 3.0$ & 4.0 inch with different percentage of porosities.

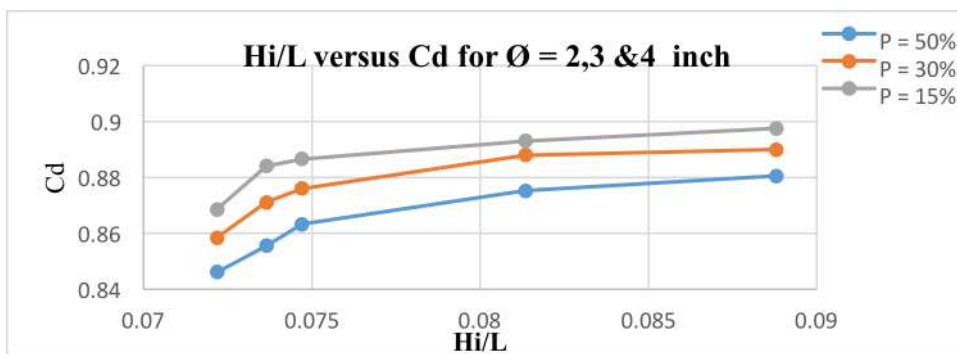


Fig. (17) Cd versus Hi/L for Ø = 2.0, 3.0 & 4.0 inch & P = (15, 30 & 50 %)

Therefore, figure (18) shows the percentage of energy transmitted with different wave steepness Hi/L for Ø = 2.0, 3.0 & 4.0 inch and different porosities.

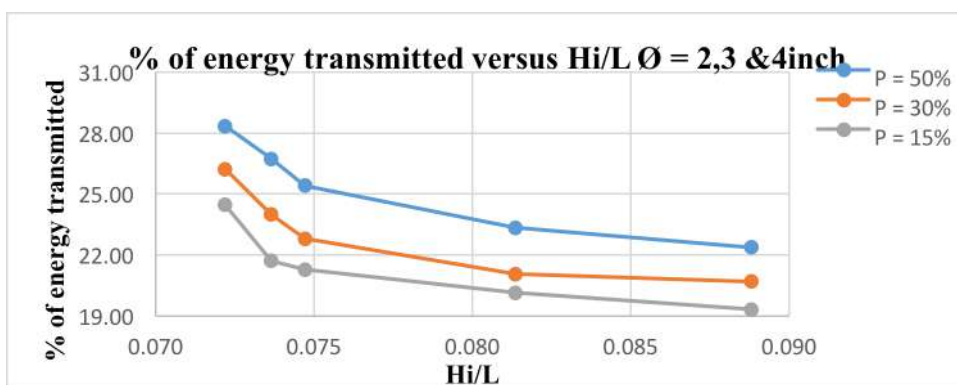


Fig. (18) % of energy transmitted versus Hi/L for Ø = 2.0, 3.0 & 4.0 inch & P = (15, 30 & 50 %)

Comparison with El Saie Y.M. (2019), that he was tested the same models but in the solid state who's porosity equal to zero. Therefore, figures (19, 20, 21, 22 & 23) shows the difference wave energy transmitted between the solid and porosities models.

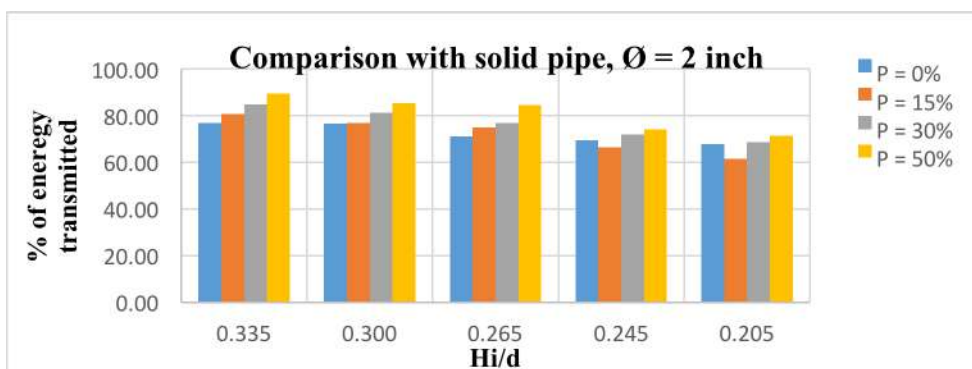


Fig. (19) Relation between % of energy transmitted and Hi/d for Ø = 2.0"

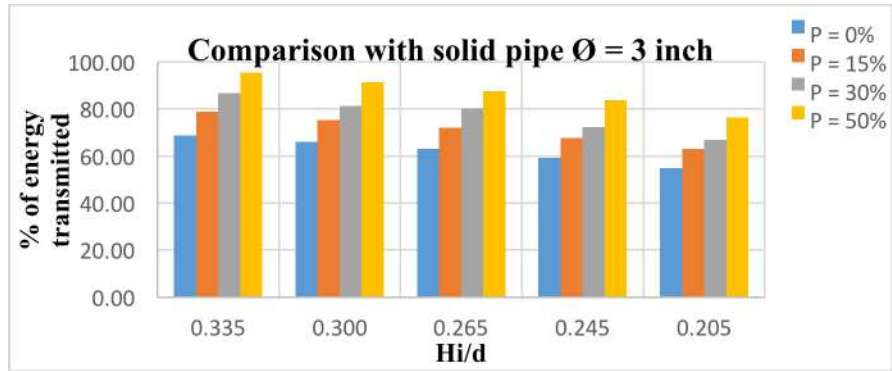


Fig. (20) Relation between % of energy transmitted and Hi/d for Ø = 3.0”

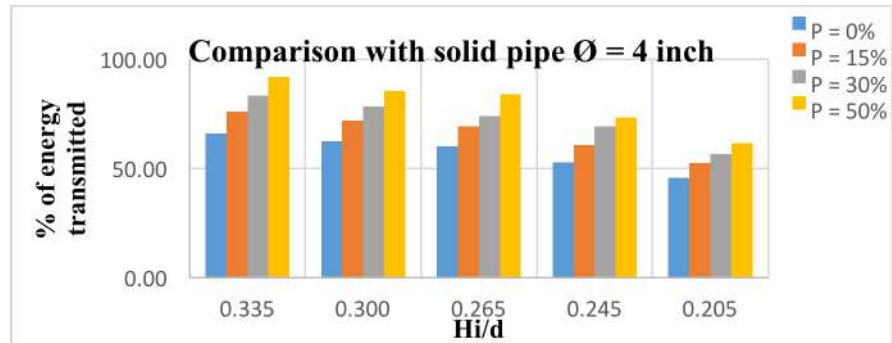


Fig. (21) Relation between % of energy transmitted and Hi/d for Ø = 4.0”

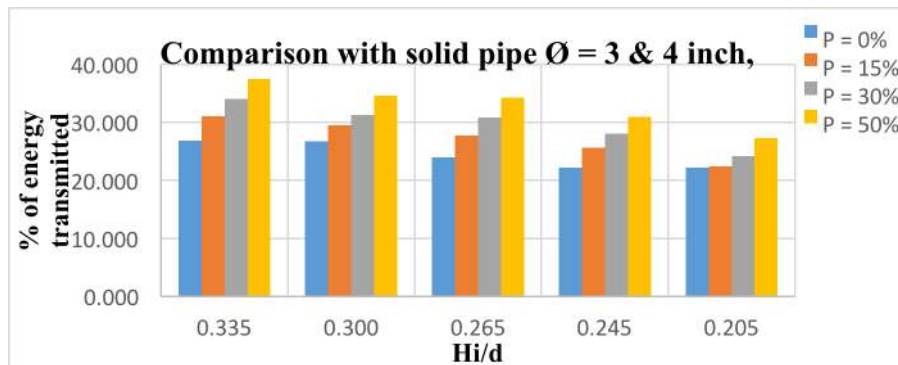


Fig. (22) Relation between % of energy transmitted and Hi/d for Ø = 3.0” & 4.0”

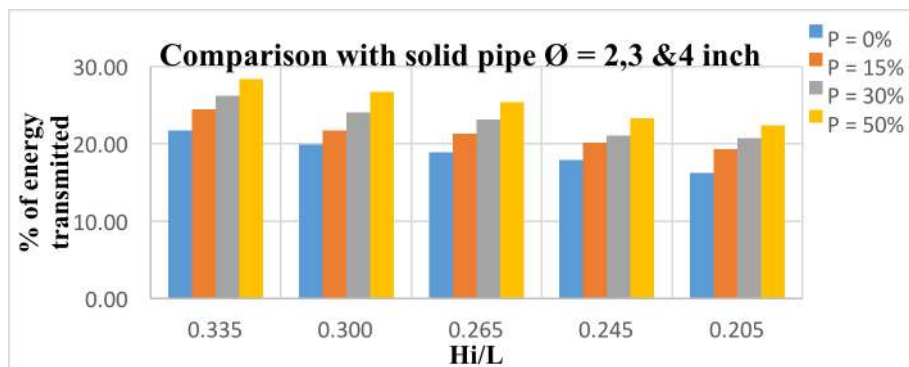


Fig. (23) Relation between % of energy transmitted and Hi/d for Ø = 2.0” , 3.0” & 4”

CONCLUSIONS

The main conclusions of this paper are as follows:

- The coefficient of dissipation C_d is directly proportional with the diameter of the horizontal floating pipes, also the coefficient of transmitted C_t is inversely

proportional with the diameter of the experimental floating pours models, with the difference wave steepness.

- The percentage of energy transmitted for the five models with $P = (15\%, 30 \& 50)$, and different wave steepness are approximately in average as follows:
 - * Model one ($\emptyset = 2.0$ inch), (72, 77.5 & 81.5 %).
 - * Model two ($\emptyset = 3.0$ inch), (71, 76 & 84 %).
 - * Model three ($\emptyset = 4.0$ inch), (63, 70 & 76 %).
 - * Model four ($\emptyset = 3.0 \& 4.0$ inch), (27, 29.5 & 32 %).
 - * Model five ($\emptyset = 2.0, 3.0 \& 4.0$ inch), (21, 23 & 26.5 %).
- The difference of changing (Cd) between models (1, 2, 3, 4 & 5) for porosities ($P = 15, 30 \& 50$) for minimum wave steepness is nearly 20% and in maximum wave steepness is approximately 10 %.
- For comparison with hollow solid pipes with porosity equal to zero for the same five models with $P = (15, 30 \& 50\%)$ and difference H_i/d the difference of energy transmitted is as follows:
 - * For $\emptyset = 2.0$ inch, (5, 11 & 13%).
 - * For $\emptyset = 3.0$ inch, (9, 14 & 22%).
 - * For $\emptyset = 4.0$ inch, (10, 16 & 24%).
 - * For $\emptyset = 3.0 \& 4.0$ inch together, (4, 9 & 12%)
 - * For $\emptyset = 2.0, 3.0 \& 4.0$ inch together, (3, 5 & 7%).
- Minimum porosity leading to maximum energy dissipation and minimum energy transmitted.

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