Transmission Coefficient Analysis Floating Breakwater using Computational Fluid Dynamics (CFD)

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Abstract: Breakwater is one of the coastal structures that was built with the aim to protect the coastal area against waves. This structure is generally designed to protect ships and facilities at the Port. Breakwaters that are often applied are conventional breakwaters such as the rubble mound type. Climate change that causes tidal variations and sea level height which tends to change at any time, as well as unsuitable soil conditions to receive large structural loads will be costly and more economical if using floating breakwater. Over time, the demand for floating breakwater development increased so that scientists and engineers did a lot of research development both in physical experiments and numerical models. In this study numerical simulations will be conducted by exploring the porous shape of floating breakwater from the Christensen experiment. The aim is to get the most optimal transmission coefficient. Numerical simulations using the Computational Fluid Dynamics (CFD) method with the help of Flow 3D Software. Validation is done first between numerical tests and experiments to get a valid approach before exploring the development of shape.

1 INTRODUCTION

Breakwater is one of the coastal structures that was designed to protect ships, marine ecosystems, port facilities, and for coastal protection against waves. Conventional breakwater is generally used in shallow water and the geometry is bottom founded. Unconventional breakwater is known as floating breakwater for the deeper the water. However, there are several advantages using a Floating Breakwater (FB). For example, more environmentally friendly to pollution and sedimentation problems because it does not inhibit water circulation (Dai et. al, 2018), a little effort to move another location (Christensen et. al, 2018). When sea water level (SWL) rises due to tides or climate change, FB can adjust so that is more economical than bottom founded. Further, floating breakwater may be the only solution for high load structures to poor soil conditions.

Floating breakwater (FB) was the first applied in 1811 to protect marinas and ships against waves at the port of Plymouth, England (Hales, 1981). Starting in 20th century, the demand of floating breakwater increased to anticipate infrastructures development of ocean space. So, Scientist and Engineers did a great developing FB research either experimentally, numerically, or combination of both. Most research is usually done on various geometric shapes, configurations, or bilge keels of FB on the wave characteristics.

Experimentally and numerically of floating breakwaters have been studied. For instance, (Christensen et al., 2018) conducted physical experiments and numerical modeling to evaluate transmission, reflection, and performances of Regular Pontoon (RG), WP, and WP-P100. The study showed that wing plates (WP) reduced the motions of floating breakwater, while wing plates and porous media (WP-P100) reduced the refection and transmission most effectively. (Ji Chunyan et al., 2018) conducted experimental study for a dual rectangular pontoon floating breakwater with two treatments (single-row and double-row). The result indicated that double-row floating breakwater significantly reduced transmission especially for short-period wave than single-row floating breakwater. (Cho, 2011) investigated transmission of incident waves interacting with vertical porous side plates using matched eigenfunction expansion method (MEEM). (Wang and Sun, 2010) conducted experimental study of a porous floating breakwater with fabricated large numbers of diamond-shaped blocks to reduce

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transmitted wave height and mooring force. (Dong et al., 2008) conducted two-demensional physics model test on three types of structures: the single box, the double box, and the board net floating breakwaters. The result showed that transmission coefficient depend on the width of board, and the length of the mooring chain lying on the sea bottom. (Rahman et al., 2006) conducted numerical study of single pontoon floating breakwater to estimate the nonlinear dynamics using the volume of fluid (VOF) method.

This paper presents numerical study or simulation to analysis transmission coefficients using computational fluid dynamics (CFD) method. The basic geometry is regular ponton floating breakwater that modified in several notched shape on the side of structure. Data parameters and numerical model verifications based on the result of experiments that conducted by (Christensen et al., 2018).

2 NUMERICAL SIMULATIONS

2.1 Floating Breakwater Geometry

Floating breakwater geometry is based on Regular Pontoon (RG) experiment test conducted by (Christensen et al., 2018). The experiment conducted two-dimensional physical model test where cross-sections were tested and analysed in wave flume. The data parameters are shown in Table 1 and illustrated in Figure 1. Furthermore, the experimental model will be developed on porous shape on side plates with numerical simulations using computational fluid dynamics (CFD) to optimalization wave transmission. The developed shapes can be seen in Figure 2.

Table 1: Regular Pontoon Dimensions.

No	Geometry	Dimensions [m]
1	Length (L)	0.58
2	Width (W)	0.46
3	Draft (D)	0.31
4	Height (H)	0.39

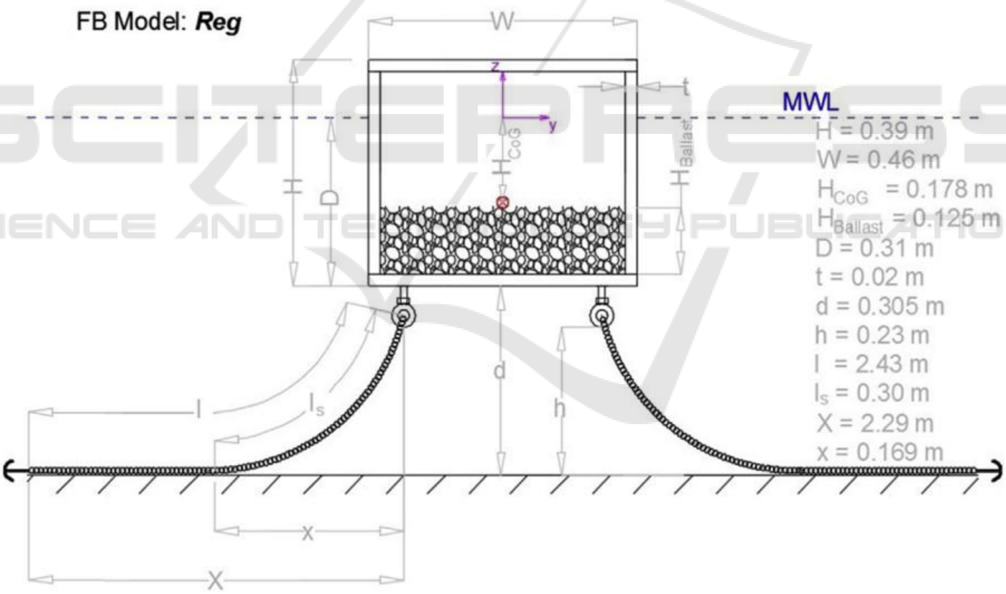
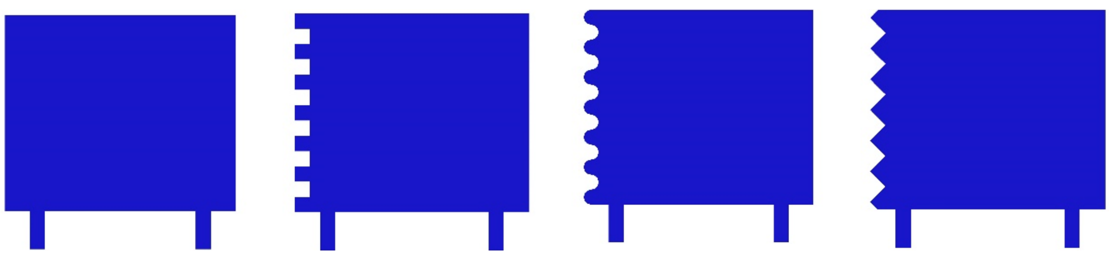


Figure 1: Basic Cross-section Regular Pontoon FB.



(a) (b) (c) (d)

Figure 2: Developed Model Floating Breakwater (Notched Shape).

2.2 Data Parameters

The data were composed of wave parameters that are scaled. The scale is assumed to use Froude scalling by 1:65. Froude scalling was considered valid as long as viscous effects are negligible. The 2^{nd} stokes wave was used on this simulation. Table 2 shows conditions for numerical simulations.

2.3 The Wave Flume

The flume is 28 m long, 0.6 m wide, 0.8 m high, and 0.615 m initial surface elevation. The flume was filled water with density of 1000 kg/m^3. The flume was equipped with wave maker at one and wave absorber at the other end. Where, the floating breakwaters were placed almost cover the entire width of flume to reduce the effect of sidewalls. See, Fig. 3 for ilustraton.

2.4 Wave Measurements and Analysis

The objective of this study was to obtain the transmission coefficient (C_T), the ratio of transmitted wave height (H_T) to incident wave height (H_i). See equation 1 below:

$$C_T = H_T / H_i \tag{1}$$

Measurement of transmitted and incident wave heights were represented by surface elevation using wave gauges. 4 wave gauges were placed on the incident side, while 3 wave gauges were placed on the lee side. See figure 4.

2.5 Mooring System

The mooring lines were installed only to keep floating breakwater on position. The mooring system have an effect on the performances of stability and the mooring forces, but in this study no analysis of both. There are four mooring lines on each corner of floating breakwater, two on each side of the cross-section. The submerged weight of the mooring line was w =0.589 N/m. The mooring line made from polyethylene (PE) with density of 880 kg/m^3 and diameter of 0.01 m. The dimension of mooring line was illustrated on figure 1.

Table 2: Parameters Wave Data.

No.	Wave Length	Wave Period	Frequency	Depth Ratio	Wave Height
	L[m]	T[s]	f[Hz]	h/L[]	$H_{\{2\%\}}$
1	1.174	0.868	1.152	0.524	0.023
2	1.883	1.116	0.896	0.327	0.036
3	2.252	1.240	0.806	0.273	0.041
5	3.333	1.613	0.620	0.185	0.052
6	4.024	1.861	0.538	0.153	0.055

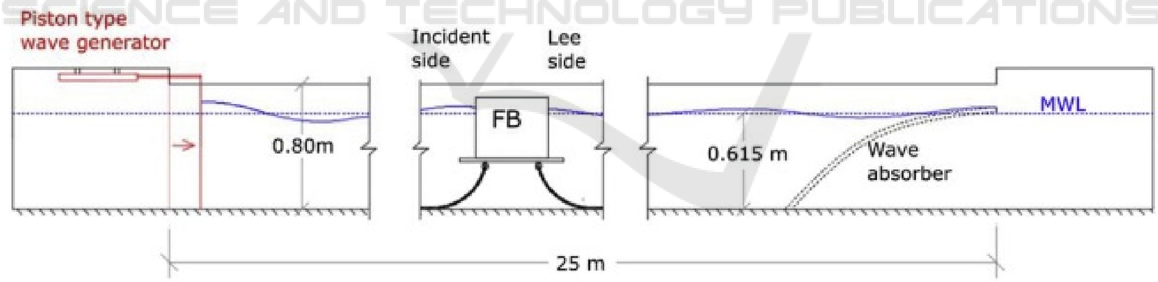


Figure 3: Sketch of the wave flume.

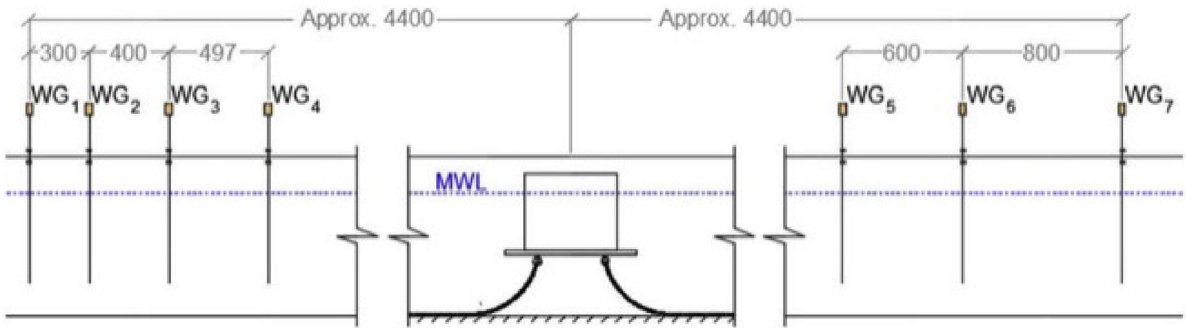


Figure 4: Position Wave Gauges in Unit [mm].

2.6 Boundary Conditions

The purpose of boundary conditions was to determine model conditions that represented experiment conditions. See figure 5. Boundary conditions used in the model are as follow:

(1) Free surface (Wave): A wave boundary condition was defined at left (X Min). A surface wave entered the computational domain and propagated in the direction normal to the boundary. The wave was set 2nd stokes as wave generator represent the physical wave conditions at the boundary.

(2) Outflow: The outflow boundary condition was defined at right (X Max). It allowed users to numerically investigate the effects of wave interactions with structures. The capability permited a reduction in the extent of the computing mesh needed for accurate computations. A wave-absorbing layer used to reduce reflection of periodic wave at an open boundary.

(3) Symmetry: The symmetry condition was defined at front (Y Min), behind (Y Max), below (Z Min), and up (Z Max). No-slip conditions were imposed using the wall shear-stress options described in the Prandtl Mixing Length model. A symmetry condition can be specified as free-slip conditions that have a non-zero wall shear-stress.

2.7 Meshing

Mesh block was used to determine the area that modelled. The smaller mesh will be more detailed, but the output files will be larger and simulations run longer. Floating breakwater modelling used one mesh block with a meshing size of 0.04 m at total length (X-axis) is 28 m, total width (Y-axis) is 0.6 m, and total height (Z-axis) is 0.8 m.

3 RESULTS AND DISCUSSION

3.1 Validation

Validation is done by comparing the results of transmission coefficient of the (Christensen, 2018) study with the numerical study of the Computational Fluid Dynamics (CFD) aided by Flow 3D Software. Christensen has conducted study on three shapes of floating breakwater, but only one shape of floating breakwater validated in this study is Regular Pontoon (RG). The purpose of validation is to find out whether the numerical study conducted is in accordance with the experimental test. Validation is done in a simpler shape (RG). If validation are represented, then the development of the model can be done to more optimal shapes.

In this study, validation is based on comparison of the transmission coefficient of numerical test simulation and experimental test. The error rate refers to Mean Absolute Percentage Error (MAPE) theory. MAPE theory can be seen on table 3. As for validation results can be seen in figure 6. Based on MAPE theory, this study can be said to be validated and can be developed more optimal shapes.

Table 3: MAPE Theory.

No	MAPE Value	Prediction
1	MAPE ≤ 10%	High
2	10% < MAPE ≤ 20%	Good
3	20% < MAPE ≤ 50%	Reasonable
4	MAPE > 50%	Low

3.2 Transmission Coefficient Regular Pontoon (RG)

Regular Pontoon is one type of floating breakwater that was examined by (Christensen, 2018). In this section, the results of transmission coefficient of numerical simulation results can be seen in table 4. The transmission coefficient is obtained from the analysis of the output surface elevation results in

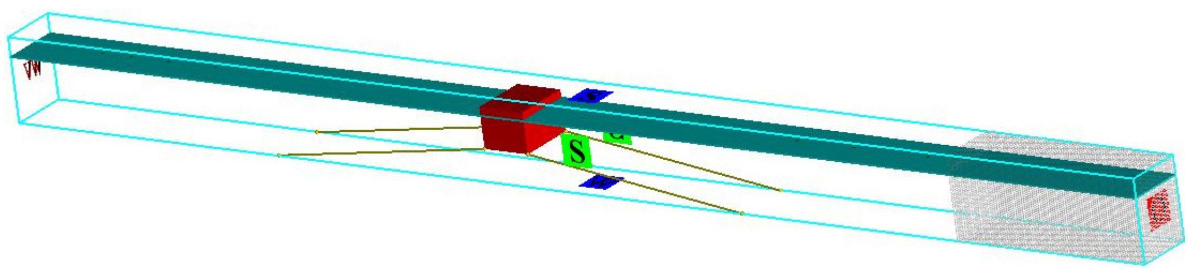


Figure 5: Boundary Conditions Model.

Flow 3D software. Surface elevation data used to analyze the transmission coefficient are obtained from wave gauge 1 (in front of the structure) and wave gauge 5 (behind the structure). Surface elevation data is converted into wave height using Wave Analysis (WAVAN) software. Then, to get the transmission coefficient the calculation is according to formula (1). The results of regular pontoon coefficient transmission are shown in table 4.

3.3 Transmission Coefficient Development Notched Shape

It is still planned to analyze the transmission coefficient of porous shapes floating breakwater. There are 3 exploratory shapes of porous floating breakwater, see figure 2. In this analysis, it used Flow 3D software such as what was done in getting the transmission coefficient of without porous shape floating breakwater (RG).

4 CONCLUSIONS

Four porous shapes of floating breakwater will be examined in experimentally and numerically. But, still planned. The porous shape is placed in lee side and back side of the structure. The basic shape of the structure is regular box. This experiment was conducted by (Christensen, 2018) in a wave flume in the hydraulic laboratory at the Technical University of Denmark. As well as numerical simulations carried out by the authors by taking Christensen's experimental data. Numerical analysis using

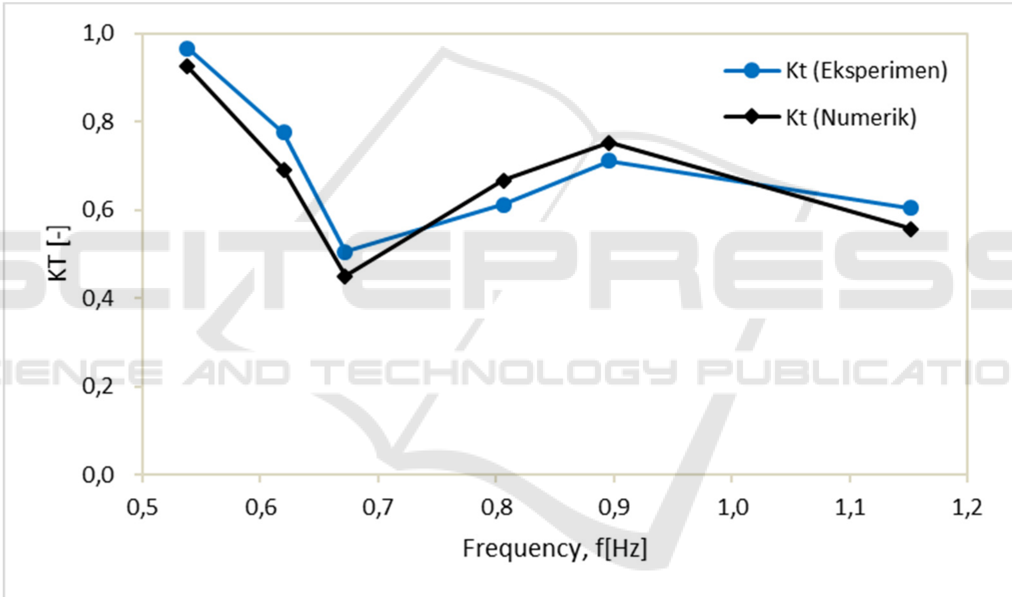


Figure 6: Validation Results.

Table 4: Value of Validation Results.

No	Data Input		H_I	H_T	$C_{T\ (experiment)}$	$C_{T\ (numeric)}$	Error (%)
	H [m]	T [s]					
1	0,0230	0,8680	0,0353	0,0197	0,6046	0,5581	8,3370
2	0,0360	1,1160	0,0329	0,0248	0,7114	0,7538	5,6248
3	0,0410	1,2400	0,0491	0,0328	0,6125	0,6680	8,3117
4	0,0490	1,4880	0,0521	0,0235	0,5054	0,4511	12,0483
5	0,0520	1,6130	0,0589	0,0408	0,7756	0,6927	11,9677
6	0,0550	1,8610	0,0498	0,0461	0,9673	0,9257	4,4936
Mean Absolute Precentage Error (MAPE)							**8,4638**

Computational Fluid Dynamics (CFD) method with the help of Flow 3D software. The aim is to optimize the transmission coefficient by exploring the porous shape, due to limited experiments. Previously, validation was done between numerical and experimental.

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