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PHYSICAL MODELING FOR MEASURING THE EFFECTIVENESS OF SINGLE CURTAIN PILE FOUNDATION BREAKWATER IN INTERMEDIATE WATER DEPTH

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ABSTRACT: A combined Curtain and Pile Foundation's breakwater called the Single Curtain Pile Foundation Breakwater (SCPFB), was designed to dissipate wave energy in an intermediate water depth instead of constructing a rubble mound-type breakwater. (C_T). The physical modeling of the SCPFB ~~is~~ was conducted at the Ocean Wave Research Laboratory in Institut Teknologi Bandung in a 2D wave flume to measure the breakwater's transmission coefficient in the intermediate water depth condition The waves generated in the wave flume were monochromatic. The scaling applied the principle of Froude similarity, where the Froude number of the model equaled to the Froude number of the prototype. Wave heights and wave periods data were observed by both visual observation and wave probes. The incoming wave heights and transmitted wave heights before and after the SCPFB, respectively, were measured and processed to obtain the C_T . The relationships between C_T and non-dimensional variables such as the relative incident wave steepness, water depth, and curtain draft were obtained. Comparisons with similar research are shown.

Keywords: Intermediate water depth, single curtain pile foundation breakwater, transmission coefficient.

1. INTRODUCTION

The construction of a rubble mound-type breakwater in front of a harbor with an intermediate water depth can be costly. A pile-type breakwater may overcome the cost issue while maintaining the maximal function to dampen the wave energy. The configuration of the breakwater can be seen in Fig.1 and is called a Single Curtain Pile Foundation Breakwater (SCPFB). The SCPFB is a breakwater consisting of piles and barriers on top of piles facing the waves. The curtain is attached to the pile while part of the curtain is submerged under the water level. The depth of the curtain under the water level is called the draft and is denoted by S. The waves dissipate through partly due to the blockade of the curtain-draft. The remaining wave energy enters the chamber behind the curtain and is dissipated there. In order to identify the effect of the draft height below the curtain on the wave dissipation rate, the curtain on the SCPFB model is designed to slide easily up and down.

The effectiveness of the SCPFB is determined by observing the transmitted waves compared to the incident waves. The ratio between transmitted waves and incident waves is the transmission coefficient C_T . The smaller the transmission coefficient, the better the SCPFB is. The SCPFB model was tested at the Ocean Wave Research Laboratory at Institut Teknologi Bandung, Bandung, Indonesia.

Previous research conducted by Kyung-Duck *et al.* [1] describes the hydrodynamic characteristics of a curtain-wall-pile breakwater, a part of which is a vertical wall and piles, similar to the SCPFB. They carried out the modeling in the region of $0.8< kh < 4.2$, which is the intermediate to deep water condition, where k is the wave number and h is the water depth. Kyung-Duck *et al.* [1] also compared the physical model with the analytical model solution using the velocity potential with a kinematic and dynamic boundary condition at the single curtain and applying regular waves.

Koraim [2] observed the hydrodynamic characteristics of slotted breakwaters under regular waves. The breakwater consists of one row of vertical slots. He investigated the hydrodynamic behavior of the breakwater theoretically and experimentally under normal regular waves. A simple theoretical model based on an eigenfunction was developed. The wave transmission, reflection, energy loss, and the hydrodynamic force exerted on the breakwater was calculated for different values of the wave and structure parameters. The breakwater was found to reduce the amount of incoming wave energy to about 20–50%. He used a friction coefficient of 0.5.

Laju *et al.* [3] observed the energy dissipation rate on a single chamber system of a skirted pile breakwater bounded by pile-supported skirt barriers in the front row and another one in the back row. Numerical and physical models were used to study the hydrodynamic behavior. The

numerical model uses eigenfunction expansion of the potential velocity in 3 sections, in front, inside the chamber, and behind the back barrier. The physical model was conducted in the condition of $1 < kh < 2.6$, which is in the intermediate water depth condition. To get the maximum wave energy dissipation rate of up to 50%, the chamber width has to be between 0.3 to 0.5 of the wavelength.

Kyung-Duck *et al*. [4] modified the pile in the curtain-wall pile breakwater in [1] to become circular, and developed a mathematical model and validated it with a physical model. They found that the increasing curtain wall draft and decreasing pile's gaps will increase the reflection coefficient. And the same configuration will decrease the transmission coefficient.

2. MODEL SETUP

The prototype of the SCPFB can be seen in Figs.1, 2, and 3.

2.1 Models

The model is placed inside a 2D wave modeling flume. The wave flume is glass-wall flume measuring 40 m in length, 1.2 m in width and 1.5 m in height. A piston-type wave generator is at one end and a sloping beach is set up at the other end. There are 5 resistance-type wave probes, and an 8-channel DAS (Data Acquisition System) to record the wave data as seen in Fig.4.

Fig.4 shows the placement of the model and the wave probes in the middle of the wave flume. *S* denotes the curtain draft, which can be adjusted by sliding up and down. Three wave probes are set in front of the SCPFB and 2 probes are set behind the SCPFB. Probe 1 and Probe 4 record the incident and transmitted waves, respectively.

2.2 Scaling

The scaling method uses the Froude similarity principle as written in Eqs. (1) and (2).

$$\left(F_r\right)_{\text{prototype}} = \left(F_r\right)_{\text{model}} \tag{1}$$

$$F_r = \frac{v}{\sqrt{gL}} \tag{2}$$

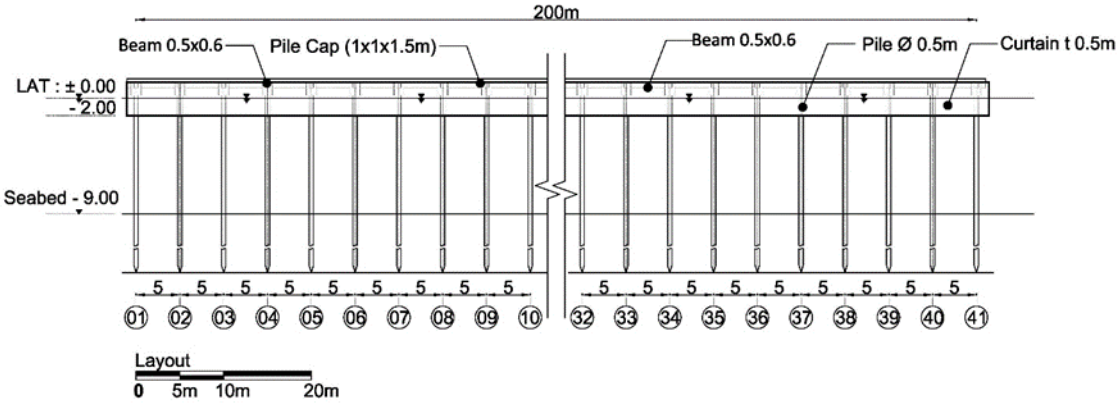

Fig.1. Single Curtain Pile Foundation Breakwater (Front View)

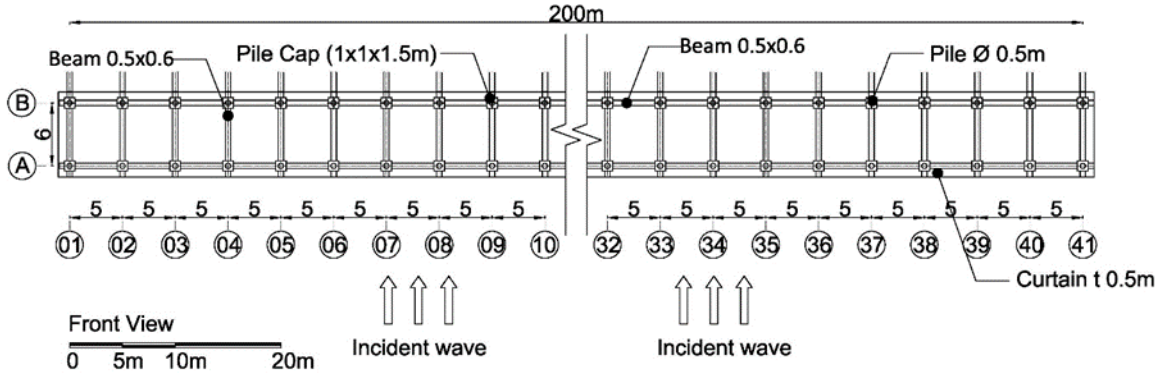

Fig.2. Single Curtain Pile Foundation Breakwater (Top Vie**w)**

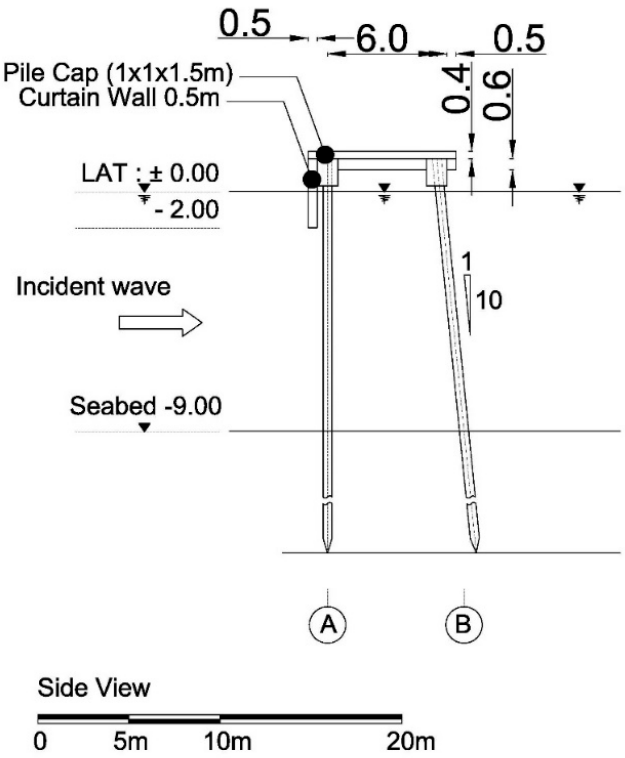

Fig.3. Single Curtain Pile Foundation Breakwater (Side View)

where

F_r = Froude number
v = Flow velocity
g = Gravitational acceleration
L = Length characteristic of object

2.3 Dimension Analysis

The non-dimensional parameters that will be observed in the experiment are obtained from the dimensional analysis. From the dimensional analysis, the transmission coefficient depends on non-dimensional parameters as follows:

$$C_T = \frac{H_t}{H_i} = \Pi\left(\frac{H_i}{gT^2}, \frac{S}{H_i}, \frac{h}{H_i}, \frac{P}{H_i}, \frac{D}{H_i}\right) \quad (3)$$

where

H_i = incident wave height
H_t = transmitted wave height
h = water depth
S = panel draft
P = pile spacing
D = pile diameter
g = gravitational acceleration
T = wave period

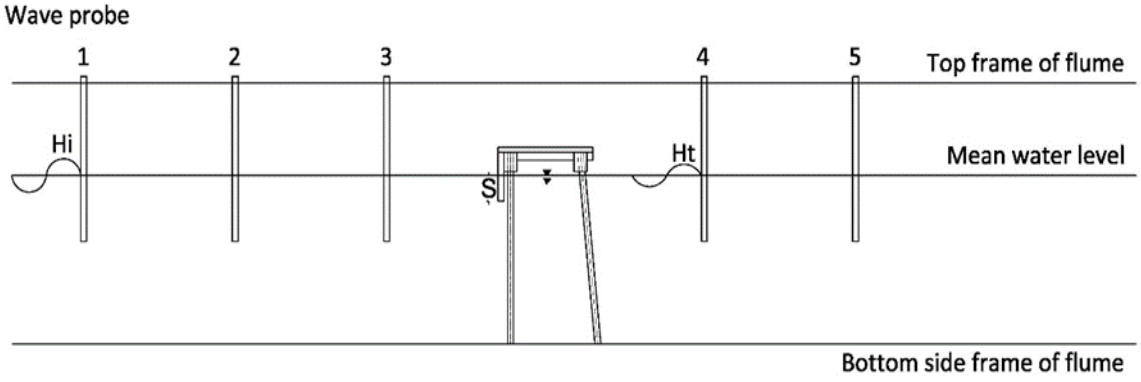

Fig.4. Placement of model and wave probes at the flume

The experiment focuses on the effectiveness of the SCPFB related to the water depth and curtain draft, while P and D are held constant, thus C_T modifies to,

$$C_T = \Pi\left(\frac{H_i}{gT^2}, \frac{S}{H_i}, \frac{h}{H_i}\right) \quad (4)$$

Equation (4) can be written as,

$$C_T = \Pi\left(\frac{H_i}{gT^2}, \frac{S}{h}, kh\right) \quad (5)$$

where k is the wave number.

2.4 Experimental Process

The experiment is conducted by varying the prototype parameters such as water depth (6–9 m), wave heights (1.5–2.6 m), and wave periods (4–14 secs). Since the generated waves are monochromatic, we take a simple approach for the analysis of C_T. Figs. 5 and 7 show the recorded data from wave probes 1 and 4, respectively.

Fig6 shows the data range for analysis, which is taken from t = 0 to t = 7 sec. This wave height data range is selected for analysis since these are still pure incident waves, not affected by disturbance from the reflected or boundary effect. Fig. 7 shows the recorded data from wave probe #4 after the zero-mean process. A data range of t = 8 to t = 15 sec for transmitted waves is also selected for the same reason as for the incident waves. Using the up-crossing method, we obtain the incident wave heights and take the average of the incident wave height to get $\overline{H_i}$ and the corresponding averaged transmitted wave height $\overline{H_t}$; then we obtain C_T.

3. RESULTS AND ANALYSIS

Figs.8 and 9 show the relation between the transmission coefficient and various parameters. As for the S/h = 0, the curtain bottom edge is right at the water level, thus S is 0, but there is still a wave dissipation mechanism occurring at the curtain. Part of the wave energy hits the curtain section above the water line.

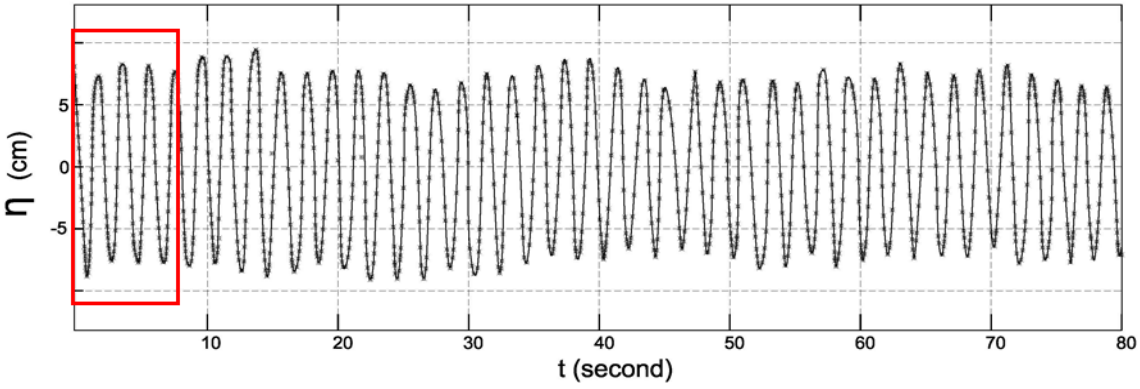

Fig.5. Recorded incident regular wave height data from wave probe #1, after zero mean process)

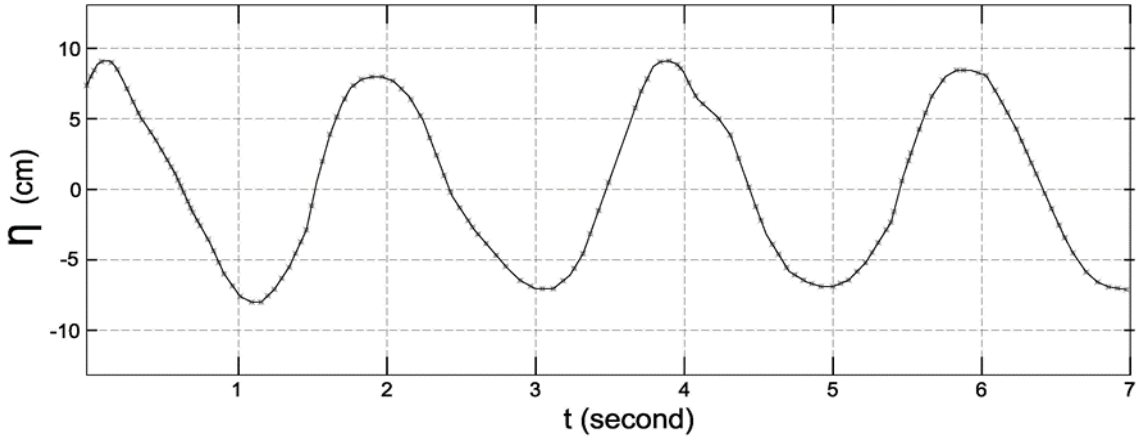

Fig.6. Recorded incident wave height data from wave probe #1, within selected data range

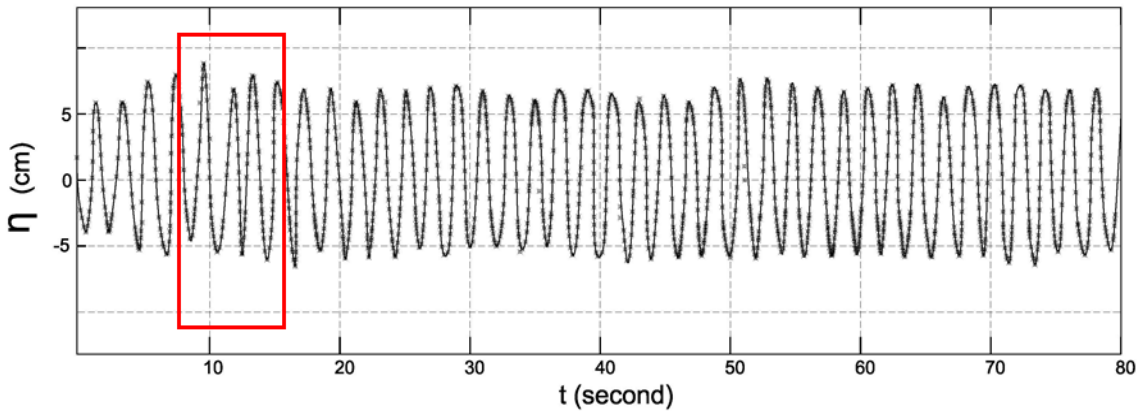

Fig.7. Recorded wave height data taken from wave probe #4. The selected data range is within t = 8 sec to 15 sec

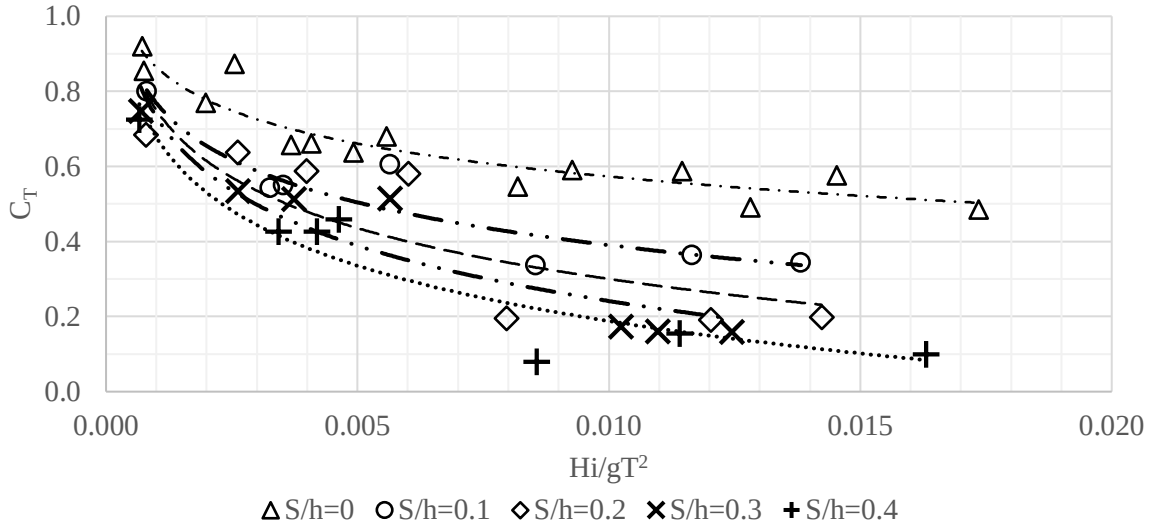

Fig.8. Results of C_T and the incident wave H_i/gT^2 for different relative curtain draft S/h

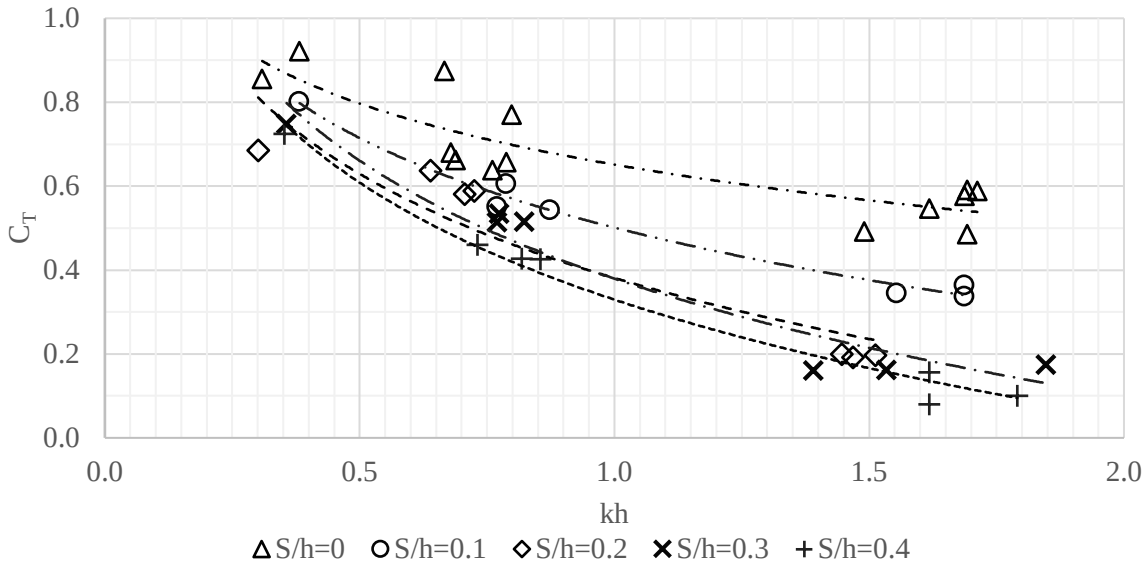

Fig.9. Result of C_T in terms of water depth condition kh

Parameter H_i/gT^2 is identical to wave steepness H/L, where L is the wave length. Fig.8 shows that the greater the wave steepness, the smaller the C_T or the SCPFB become more effective to dissipate energy. The trend seems asymptotical when the wave steepness becomes bigger. When S/h approaches the value of 0.4, the transmitted waves height is about 10% of the incident wave height. The SCPFB becomes effective.

Fig.9 shows the C_T vs the water depth condition. Shallow water waves are indicated by $kh < \pi/10$, and deep water waves are $kh > \pi$. Fig.9 shows that the water depth condition of the experiment is intermediate. From Fig.9, it can be seen that the SPCFB is more effective when applied in deeper water, as the bigger C_T results in smaller *kh*. The bigger the curtain draft, the smaller the C_T. If we look at the result, with the smaller *kh* (i.e. shallow water), the SPCFB does not perform well. However, more deep water condition experiments should be carried out.

4. COMPARISON WITH RELATED RESEARCH

The C_T results are compared with similar studies. Fig.10 shows the results of research by Kyung-Duck *et al.* [1] for the wave transmission coefficient on the uniform waves (regular waves) using the Curtain-Wall-Pile Breakwater. Kyung-Duck *et al.* have parameter *S* which is also the draft of the curtain, and *h* is the water depth, as seen in Fig.11.

From the comparison in Fig10, the results of the current research fall partly in the region of smaller kh, which is of shallower water. Comparisons of C_T within the same range of kh as Kyung Duck *et al.*'s results [1], that is, between kh = 0.8–1.8, for the same S/h = 0.4, there is a difference in the value of C_T. Let us recall that Kyung-Duck *et al.* [1] used the full-scale wave flume at OH Hindsdale Wave Research Lab at Oregon State University, Corvallis, Oregon, USA. The value of C_T has a difference of about 20 to 40%, where the scaled model gives smaller C_T. This is due to a scaling effect at some point. The scaling effect causes smaller transmitted coefficients. However, the trend is similar, which is the greater kh, the smaller C_T.

In the shallower water, the value of C_T resulting from the scaled model tends to approach the result from the full scale model. As we can see from Fig.13, for *kh* less than 1, the results of the scaled model tend to converge with the large scale model.

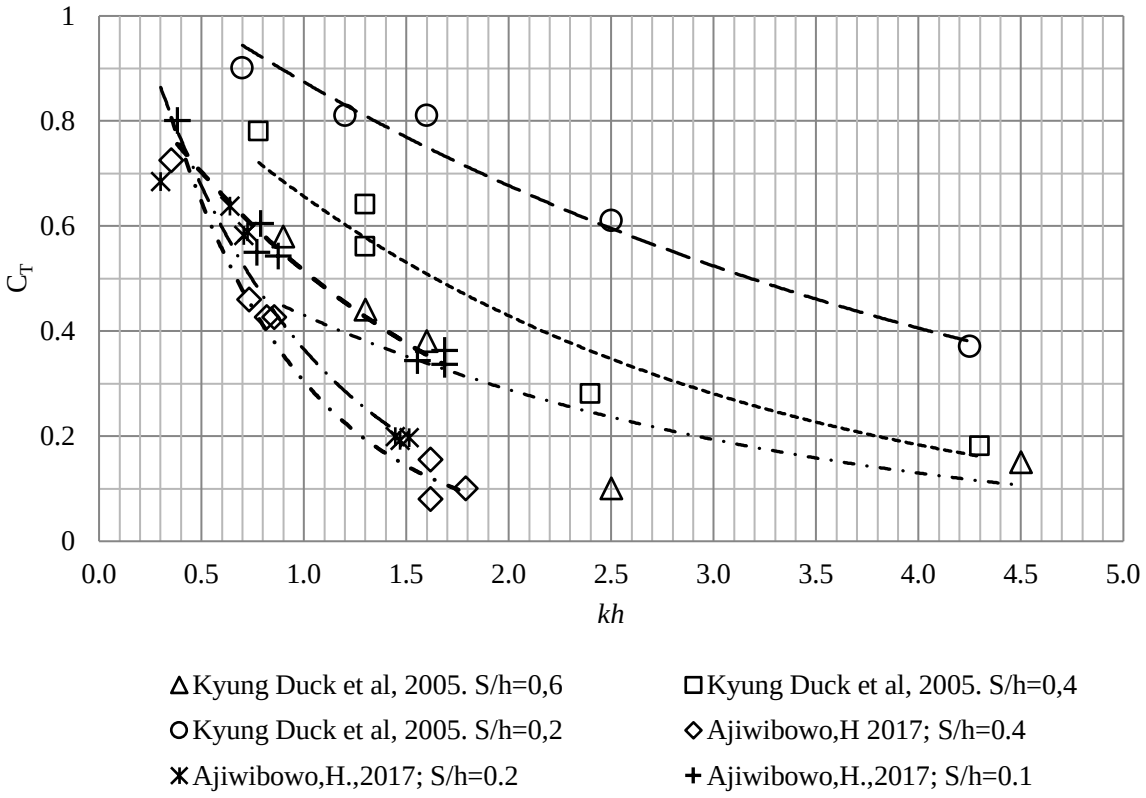

Fig.10. Comparisons with related research

5. CONCLUSION

The SCPFB performs well in intermediate to deep water. However, more deep water condition experiments in the range of $kh > \pi$ should be carried out. The SCPFB is almost 90% effective when applied with the curtain extended to almost half of the water depth in the intermediate water depth condition.

The scaling effect results in smaller transmission coefficient, C_T . However, for smaller kh, the results of the scaled model tend to converge with the results from the full-scale model. Thus for modeling using the scaled model, we should choose a larger rather than smaller scale.

6. ACKNOWLEDGEMENTS

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