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TWO-DIMENSIONAL PHYSICAL MODELING OF SINGLE CHAMBER SKIRT BREAKWATER (SCSB)

Azis Ali Wibowo[1], *Harman Ajiwibowo[2], Andojo Wurjanto[3], and Anugrah Yazid Ghani[4]

[1,2,3,4]Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia

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ABSTRACT: Gravity-type breakwaters such as the rubble mound type are ineffective in intermediate-depth and deep waters due to high construction costs. In intermediate-depth and deep waters, the skirt-type breakwater is one of the best alternatives due to the low construction cost because the breakwater structure is consists of a pile at the bottom part and a skirt wall in the upper part of the structure. To assess the effectiveness of the skirt type breakwaters, two-dimensional physical modeling conducted on the wave flume in Ocean Engineering Laboratory at Bandung Institute of Technology, Indonesia. In this study, a Single Chamber Skirt Breakwater (SCSB) model structure was investigated. The relationship between the transmission coefficient, (C_T) and the reflection coefficient (C_R) with environmental and structure variables are examined. The physical modeling concluded that SCSB is effective in intermediate depth in the region of 1.5<kh<2.0. In this region, the value of C_T and C_R are optimum where the C_T value is 0.28-0.49, and the C_R value is 0.28-0.52.

Keywords: Single chamber skirt breakwater, Transmission coefficient, Reflection coefficient, Intermediate-depth, Deep water.

1. INTRODUCTION

In intermediate-depth and deep waters, gravity-type breakwaters such as the rubble mound type are ineffective due to high construction costs. The skirt-type breakwater is one of the best alternatives to be applied in an intermediate depth and deep waters region. In this study, physical modeling of a SCSB model structure was investigated to assess the effectiveness of the skirt type breakwaters. The relationship between the transmission coefficient (C_T) and the reflection coefficient, (C_R) with environmental and structure variables are examined. The research was carried out in the wave flume in the Ocean Engineering Laboratory at Bandung Institute of Technology, Indonesia.

This research is based on the previous study, Ajiwibowo [1] studied Single Curtain Pile Foundation Breakwater (SCPFB) by using the transmission coefficient (C_T) parameter to assess the effectiveness of the structure. The research concludes that The SCPFB performs well in intermediate to deep water. The research suggested continuing the research in the range of $kh>\pi$.

Ajiwibowo [2] conducted 3D physical modeling to calculate the effectiveness of Perforated Skirt Breakwater (PSB) by quantifying the transmission coefficient (C_T), the research concludes that the PSB is effective for a short wave period and suggested using the 3D physical model to validate any numerical model.

Suh et al. [3] studied the hydrodynamic characteristics of a curtain-wall-pile breakwater. The research carried out in a large-scale wave flume (104 m length, 3.7 widths, and 4.6 m depth) produces the region of intermediate to deep water (0.8< kh < 4.2). The research compared the physical model with the analytical model solution using the velocity potential with a kinematic and dynamic boundary condition and applying regular waves. The research concludes that the pile-supported vertical wall breakwater always gives smaller transmission and larger reflection than a curtain wall breakwater with the same draft.

Ajiwibowo [4] conducted 2-D physical modeling to measure the effectiveness of Perforated Skirt Breakwater (PSB) by quantifying the transmission coefficient (C_T). The PSB is effective to dampen the wave energy 30-70% for short wave. The draft of the skirt and length of the chamber has a significant influence on the value of C_T.

Koraim [5] observed the hydrodynamic characteristics of slotted breakwaters with regular waves. The breakwater consists of one-row vertical slots. The research investigated the hydrodynamic behavior of the breakwater theoretically and experimentally. A theoretical model based on an eigenfunction was developed to validate the experiment. The wave transmission, reflection, energy loss, and hydrodynamic force exerted on the breakwater calculated for different values of the wave and structure parameters. The breakwater was found to reduce incoming wave energy to about 20–50%.

Laju et al. [6] studied the hydrodynamic performance of pile-supported double skirt breakwater. Numerical and physical models of previous research were used to study hydrodynamic behavior. The mathematical model uses the eigenfunction expansion theory for linear wave. The physical model was conducted in the condition of $0.2 < kh < 2.0$, which is in the intermediate depth condition. The research concludes the required submergence of the skirt may vary between 0.2 to 0.5 for a chamber width equal to one-third of predominant wavelength to achieve transmission less than 50% for $kh \geq 1$. The transmission of waves depends on the maximum submergence of skirt breakwater. The reflection is found to rely on the submergence of the front skirt breakwater. A porous front skirt, as well as differential submergence of skirts, reduces reflection without much increase in transmission.

Suh et al. [7] conducted research with modified the pile in the curtain-wall pile breakwater in [3] to become circular, and developed a mathematical model and validated it with a physical model. The research found that the increasing curtain wall draft and decreasing pile's gaps will increase the reflection coefficient. And the same configuration also decreases the transmission coefficient.

Wurjanto et al. [8] observed the effectiveness of perforated skirt breakwater with two and three chambers in long wave conditions (shallow water) by measuring the transmission coefficient. The research found that the perforated skirt breakwater with three chambers is more effective than two chambers. The width of the chamber also influences the effectiveness of breakwater, and it was found that the transmission coefficient is increasing while the width of the chamber decrease. The transmission coefficient also decreases if the draft of the skirt increasing.

2. SCALING AND DIMENSIONAL ANALYSIS

2.1 Scaling

The scaling method uses the Froude similarity principle [9], as written in Eq. (1) and Eq. (2).

$$(\boldsymbol{F_r})_{\boldsymbol{prototype}} = (\boldsymbol{F_r})_{\boldsymbol{model}} \tag{1}$$

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

where
F_r = Froude Number
v = flow velocity
g = gravitational acceleration
L = length dimension

From the consideration of laboratory capacity, a scale of 1:12 is determined. The prototype and model of the structure and environment variables are stated in Tables 1 and 2.

Table 1 Structure variables

Structure Variables					
Variables	Symbol	Prototype		Model	
Draft of the skirt	s_1	3.00	m	25.00	cm
	s_2	2.00	m	16.70	cm
Chamber width	L_c	4.60	m	55.00	cm

Table 2 Environment variables

Environment Variables					
Variables	Symbol	Prototype		Model	
Water depth	h	9.60	m	80.00	cm
		8.40	m	70.00	cm
		7.20	m	60.00	cm
Incident wave height	H_I	1.20	m	10.00	cm
		1.80	m	20.00	cm
		3.60	m	30.00	cm
		4.20	m	35.00	cm
Wave period	T	1.00	s	3.46	s
		1.50	s	5.20	s
		2.00	s	6.93	s
		3.00	s	10.39	s
		4.00	s	13.86	s
		5.00	s	17.32	s

2.2 Dimensional Analysis

Dimensional analysis is carried out to produce dimensionless parameters that will be controlled and affect the results of the experiments. Dimensional analysis is calculated by using the Buckingham pi method [9].

The dimensionless variables equation as the results of the Buckingham Pi method is stated in Eq. (3) and Eq. (4).

$$C_T = \Pi\left(kh,\ \frac{H_I}{L}, \frac{s}{h}\right) \tag{3}$$

$$C_R = \Pi\left(kh, \frac{H_I}{L}, \frac{s}{h}\right) \tag{4}$$

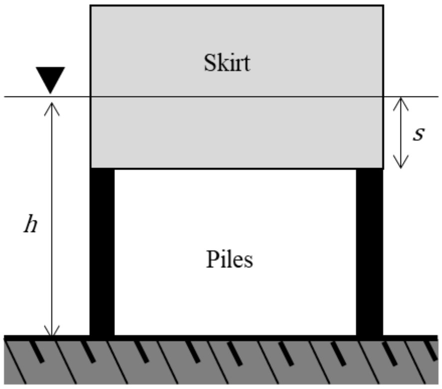
where
C_T = transmission coefficient
C_R = reflection coefficient
$k = \frac{2\pi}{L}$ = wave number

The dimensionless variables to be studied in this research is the correlation between transmission and reflection coefficient (C_T and C_R) with relative depth (kh) and wave steepness (H_I/L).

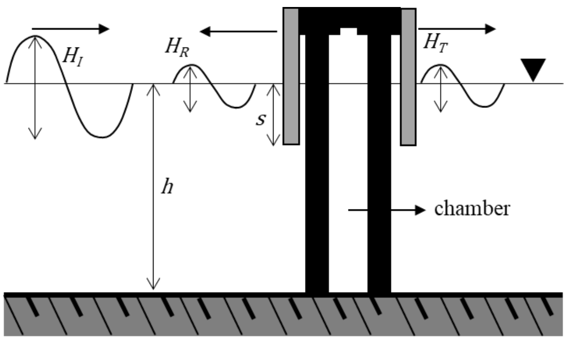
3. METHODS

3.1 Models

The SCSB is made from steel and consisting of piles and a skirt chamber on the top of piles facing the waves. The skirt chamber has no porosity, and it is attached to the upper part of the pile, while part of the skirt chamber is submerged under the water level. The waves dissipate through partly due to the blockade of the chamber draft. The configuration of the SCSB model is described in the sketch of definition in Fig.1 and perspective view in Fig.2.



(a) Front view of SCSB



(b) Side view of SCSB.

Fig.1 Definition sketch of Single Chamber Skirt Breakwater (SCSB)

where

h = water depth
s = draft of the skirt
H_I = incident wave height
H_T = transmitted wave height
H_R = reflected wave height

3.2 Laboratory Capacity Test

The laboratory capacity is calculated based on the capacity of the wave flume (dimension of the wave flume) and the capacity of the wavemaker in generating the waves. The capacity of wave flume is calculated based on its dimensions, and the wave flume has a length of 40 m, a height of 1.5 m and a width of 1.2 m.

The capacity of the wavemaker was also tested. It was found that the wavemaker is effectively capable of generating wave heights up to 35 cm and wave periods of up to 7 seconds.

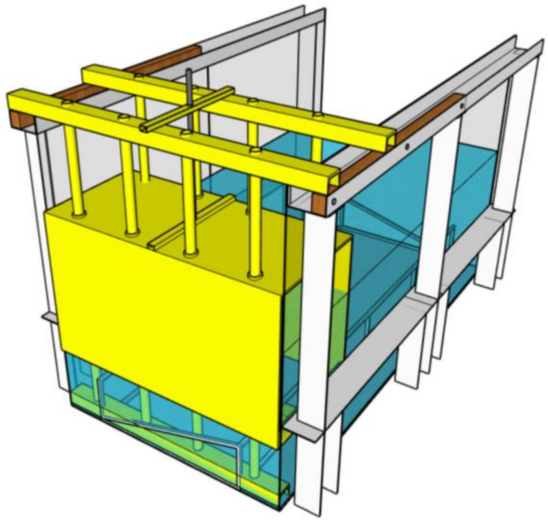


Fig.2 Perspective view of Single Chamber Skirt Breakwater (SCSB)

3.3 Wave Gauges Calibration

Wave gauges calibration is conducted by comparing the results of visual observation with the results of data recordings from the wave gauges in each of the experiment scenarios. From the comparison of visual data and recorded data, the wave gauges coefficients of calibration in every wave gauges are obtained (Table 3).

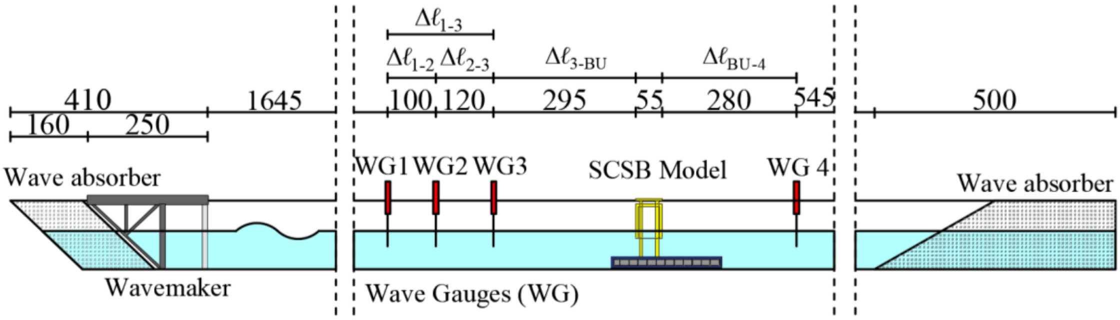
Table 3 Value of coefficients of calibration

Water depth (h) [cm]	**Coefficient calibration**			
	WG1	**WG2**	**WG3**	**WG4**
60	0.024	0.023	0.027	0.023
70	0.033	0.033	0.036	0.034
80	0.041	0.040	0.044	0.039

3.4 Wave Flume Setup

Wave flume setup is conducted to placing the SCSB model, wave absorber, and wave gauges in the proper position, the wave flume setup is depicted in Fig.3.

The wave absorber is placed behind the wavemaker and behind the model at the end of wave flume. Four wave gauges are used, wave gauges 1,2, and 3 are placed in front of the model and used to record reflected wave. Wave gauge 4 is placed



(dimension are in cm)

Fig.3 wave flume setup

behind the model and used to record the transmitted wave.

The SCSB model is placed in the middle of the wave flume. Piston type wave maker is used to generate a specified wave type. Wave maker determined and run with using specified software and data recording also controlled and run using the specified data acquisition system.

3.5 Wave Gauges Position

The position of the wave gauges (Fig.3) arranged to resolved the spectra of the incident and reflected wave in the effective range of resolution [10]. The distance between two wave gauge which produces the effective range of spectral analysis (resolution) arranged according to Eq. (5).

$$0.05 < \Delta\ell / L < 0.45 \qquad (5)$$

where
$\Delta\ell$ = the distance between two wave gauges (m)
L = wavelength (m)

In regular wave analysis, the wave gauges are positioned closest to $0.2L$ from the model [10]. For transmission analysis, the data of H_I is calculated using the data which is recorded from wave gauge 1, 2, and 3. The data of H_T is using the wave height which is recorded from wave gauge 4. For reflection analysis, the data of H_I and H_R are calculated using the data which is recorded from wave gauge 1-2, wave gauges 2-3, and wave gauges 1-3.

4. EXPERIMENTS

The experiment was conducted with 144 scenarios as described in Table 4. The scenarios are permutation results of the structure (draft of the skirt) and environmental variables (water depth, incident wave height, and wave period).

5. DATA ANALYSIS

The data recorded from the wave gauges are processed through the zero mean processes. The selection of time interval data to be analyzed is chosen, i.e. the time-lapse in the wave record that has not been affected by the reflected waves. The selected interval data are analyzed for wave transmission and reflection analysis. The result of the analysis is a nondimensional graph of C_T and C_R versus kh, s/h, and H_I/L.

Table 4 Scenarios of the experiment

Variables	Symbol	Model		Number of Scenarios
Draft of the Skirt	s_1	25.00	cm	2
	s_2	16.70	cm	
Water depth	H	80.00	cm	3
		70.00	cm	
		60.00	cm	
Incident Wave height	H_I	10.00	cm	4
		20.00	cm	
		30.00	cm	
		35.00	cm	
Wave Periode	T	1.00	s	6
		1.50	s	
		2.00	s	
		3.00	s	
		4.00	s	
		5.00	s	

5.1 Wave Transmission Analysis

Transmission Coefficients (C_T) is obtained from the ratio of the average of transmitted wave height to the average of incident wave height as shown in Eq. (6).

The incident waves are obtained from the zero

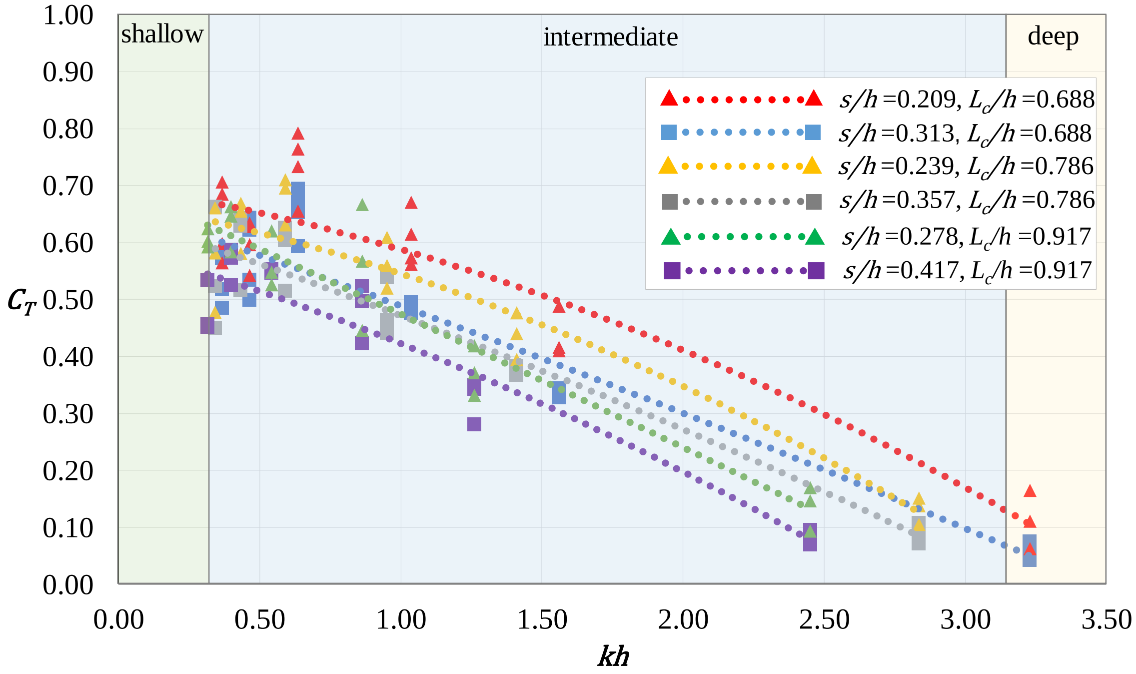


Fig.4 Graph of C_T vs *kh*

up crossing process of water level elevation record from the wave gauges in front of the model, and the transmitted waves are obtained from the wave gauges behind the model.

$$C_T = \frac{\bar{H}_T}{\bar{H}_I} \tag{6}$$

where

C_T = Transmission Coefficient

$\overline{H_I}$ = Average of incident wave height (m)

$\overline{H_T}$ = Average of transmitted wave height (m)

5.2 Wave Reflection Analysis

The wave reflection analysis is calculated based on a technique to resolve the incident and reflected waves from the record of composite waves [10]. The reflection coefficient is calculated based on the following Eq. (7) – Eq. (9).

$$C_R = \sqrt{\frac{E_R}{E_I}} \tag{7}$$

$$E_I = \int_{i=0}^{i=N} S_I(\omega)d\omega \tag{8}$$

$$E_R = \int_{i=0}^{i=N} S_R(\omega)d\omega \tag{9}$$

where

C_R = Reflection Coefficient

E_I = Incident wave energy

E_R = Reflected wave energy

$S_I(\omega)$ = Incident wave spectrum (m^2s)

$S_R(\omega)$ = Reflected wave spectrum (m^2s)

ω = Wave angular frequency (rad/s)

The incident and reflected wave spectrum are obtained from the component of the amplitude spectrum in the following Eq. (10) and Eq. (11).

$$S_I = \frac{\frac{1}{2}{a_{I_i}}^2}{\Delta\omega} \tag{10}$$

$$S_R = \frac{\frac{1}{2}{a_{R_i}}^2}{\Delta\omega} \tag{11}$$

a_{I_i} and a_{R_i} in Eq. 10 and Eq.11 are the components of the amplitude spectrum of the incident and reflected waves. The components of the amplitude spectrum are obtained from the following Eq. (12) and Eq. (13).

$$a_{I_i} = \frac{1}{2|\sin k_i \Delta\ell|}\left[\left(a_{2_i} - b_{1_i}\cos k_i \Delta\ell - b_{1_i}\sin k_i \Delta\ell\right)^2 + \left(b_{2_i} - b_{1_i}\cos k_i \Delta\ell + a_{1_i}\sin k_i \Delta\ell\right)^2\right]^{1/2} \tag{12}$$

$$a_{R_i} = \frac{1}{2|\sin k_i \Delta\ell|}\left[\left(a_{2_i} - b_{1_i}\cos k_i \Delta\ell + b_{1_i}\sin k_i \Delta\ell\right)^2 + \left(b_{2_i} - b_{1_i}\cos k_i \Delta\ell -\right.\right.$$

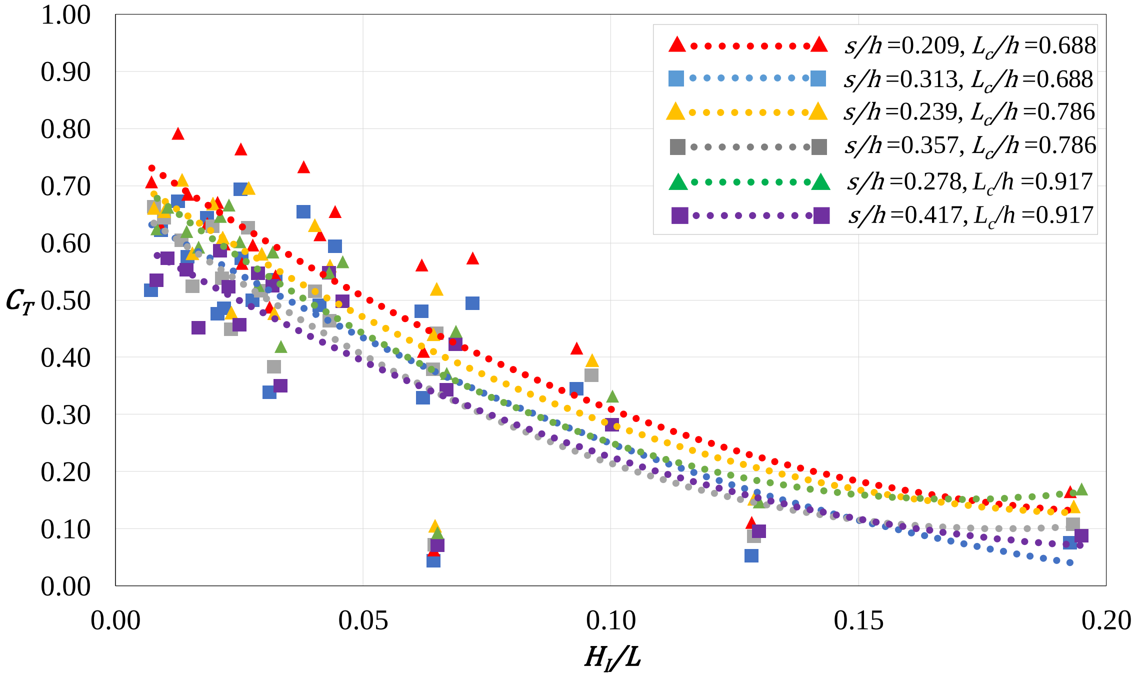


Fig.5 Graph of C_T vs H_I/L

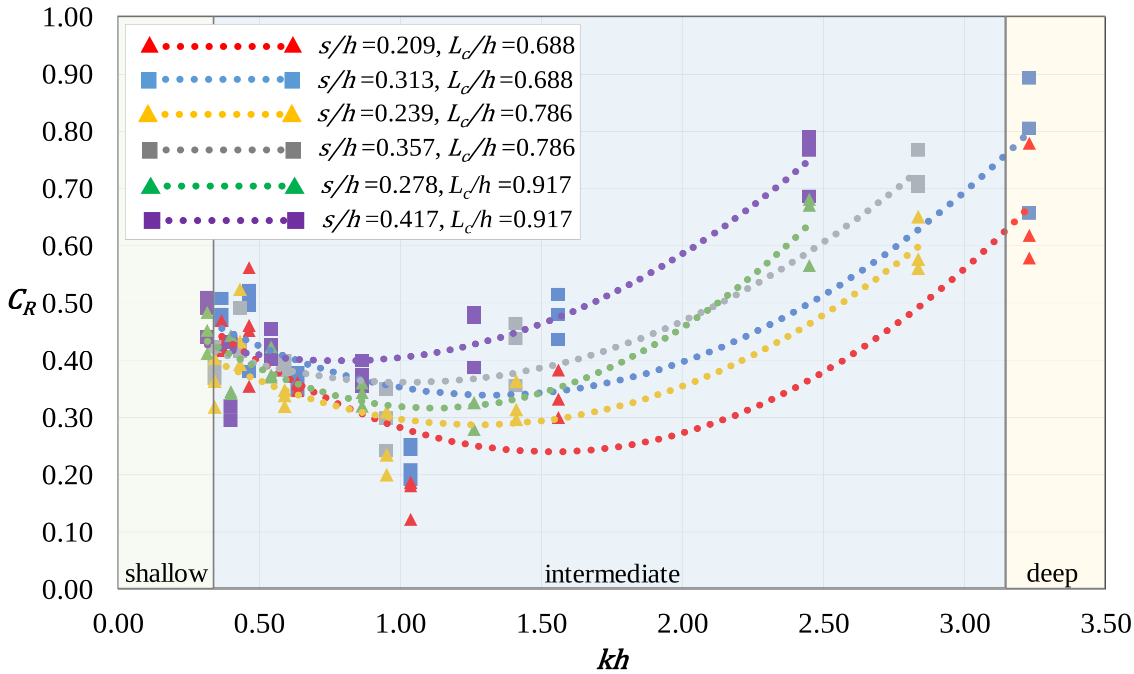


Fig.6 Graph of C_R vs kh

$$b_{1_i} \sin k_i \Delta\ell)^2\Big]^{1/2} \quad (13)$$

where

a_{1i}, b_{1i} = Fourier coefficient of WG1 data

a_{2i}, b_{2i} = Fourier coefficient of WG2 data

$k = \frac{2\pi}{L}$ = wave number (m^{-1})

L = wavelength (m)

$\Delta\ell$ = distance of WG1 and WG2 (m)

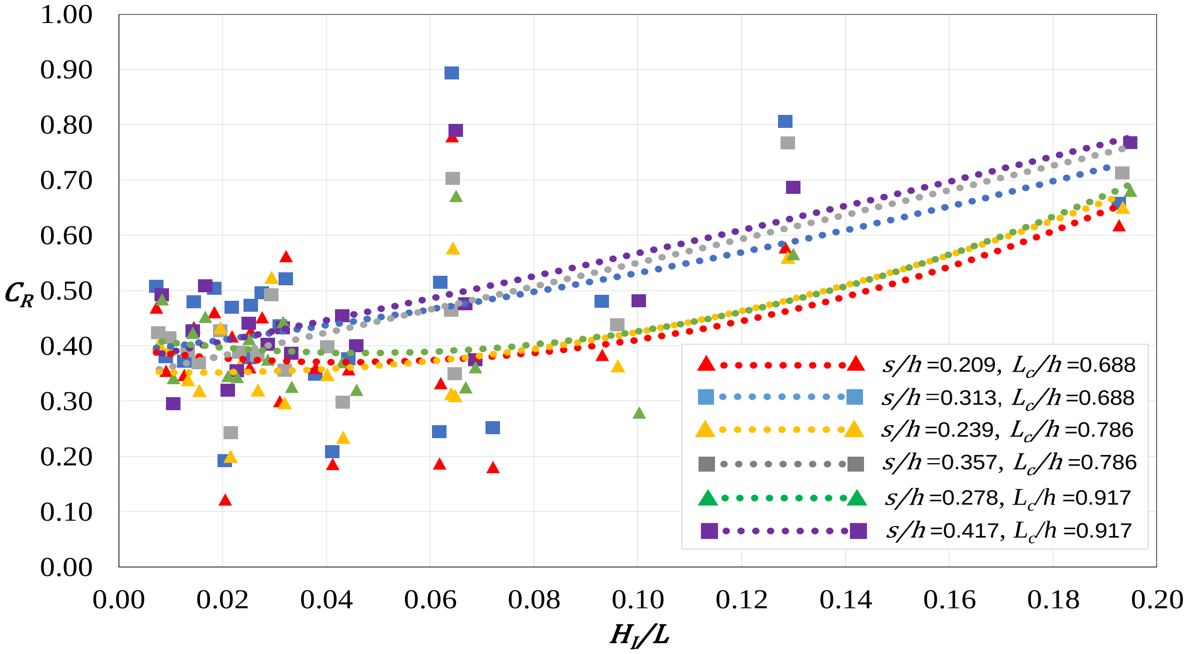


Fig.7 Graph of CR vs HI/L

6. RESULTS

The results of the analysis C_T and C_R are presented in Figs.4 to 8, which shows the relation between the transmission and reflection coefficient and various parameters. The results are presented in intermediate depth as indicated by $\pi/10<kh<\pi$, and deep water as indicated by $kh>\pi$.

6.1 Transmission Coefficient, C_T

The relation between C_T (Transmission Coefficient) and kh (relative depth) as a function of s/h (corresponding draft) and L_c/h (relative chamber width) are plotted in Fig. 4. As indicated by the figure, C_T decreases following the increases of kh. The value of C_T in deep water ($kh>\pi$) is 0.04-

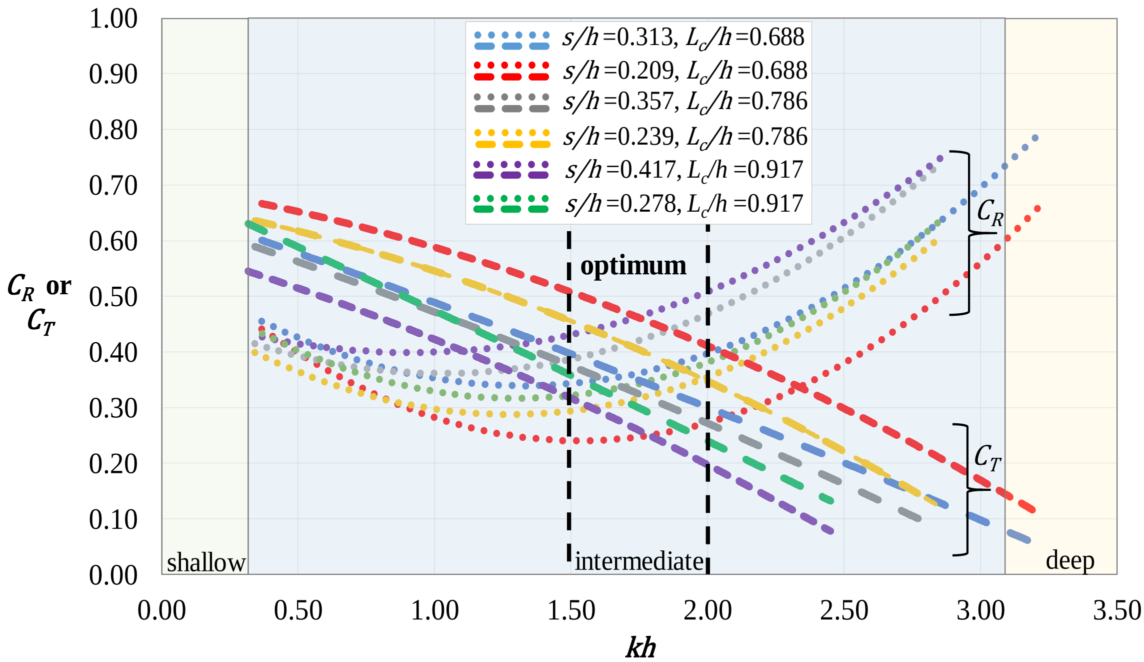


Fig.8 Graph of C_R or C_T vs H_I/L

0.17, while in intermediate depth ($\pi/10<kh<\pi$) is 0.07-0.79.

The draft of the skirt (s) also influences the C_T value. As s/h increases (by the same value of L_c/h), C_T decreases.

The relation between C_T (Transmission Coefficient) and H_I/L (wave steepness) as a function of s/h (corresponding draft) and L_c/h (relative chamber width) are plotted in Fig.5. As indicated by the figure, C_T decreases following the increases of H_I/L.

6.2 Reflection Coefficient, C_R

The relation between C_R (Reflection Coefficient) and kh (relative depth) as a function of s/h (corresponding draft) and L_c/h (relative chamber width) are plotted in Fig. 6. As indicated by the figure, C_R increases following the increase of kh. The value of the reflection coefficient in deep water ($kh>\pi$) is 0.58-0.89, while in intermediate depth ($\pi/10<kh<\pi$) is 0.12-0.79.

The draft of the skirt (s) also influences the C_R value. As s/h increases (by the same value of Lc/h), C_R increases.

The relation between C_R and H_I/L (wave steepness) as a function of s/h (corresponding draft) and L_c/h (relative chamber width) are plotted in Fig. 7. As indicated by the figure, C_R increases following the increases of H_I/L.

6.3 Optimum Performance of SCSB

The optimum performance of SCSB has occurred when the effectiveness of the SCSB is more than 50% or the value of C_T and C_R are less than 0.5. The optimum performance is obtained when SCSB applied to an intermediate depth in the region of $1.5>kh>2.0$ (Fig.8).

7. CONCLUSION

SCSB has optimum performance when applied to intermediate-depth in the region of $1.5>kh>2.0$. In the deep waters ($kh>\pi$), the C_T value is small, but the C_R value is high, this condition concluded that the SCSB does not apply to deep waters due to large wave reflections. This opposite value of the C_R and C_T needs to be considered in design the SCSB.

Corresponding draft (s/h) also has a significant influence on the value of C_T and C_R, the selection of draft dimensions needs to be well considered. As the value of *s/h increases*, the value of C_T decreases, but the value of C_R increases.

The value of the wave reflection in front of the SCSB can be reduced by adding perforation to the SCSB's front face. This research is recommended to be continued with perforated SCSB research.

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