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Wave Transmission of Tandem Breakwater with Various Angles of Wave Attack

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Abstract— ***This paper explains the study of wave transmission of a tandem breakwater physically modelled with various angles of wave attack. Tandem breakwater is an arrangement of a conventional rubble mound breakwater sheltered by a submerged breakwater located at some distance. The experimental works were carried out in a wave basin with dimensions of 25 m length, 18 m width and 1.2 m height. Setting still water depth of 0.45 m, 0.50 m and 0.60 m, waves with T=2.05 sec, 2.20 sec and 2.50 sec were generated from a piston type multi element wave maker. Multi directional waves were generated with angle of wave attack of 0, 15, 30 and 60 degree. Wave gauge was located at eight different positions to record water level and by using the measured data, the wave transmission, K_t was calculated. Besides the effect of various angle of wave attack, the effects of relative distance between submerged and rubble mound breakwater towards wave transmission was investigated. Experiments are done for two breakwater structures with different spacing (X/d = 8.33-15.56) and for various heights (h/d = 0.42-0.56). The results show that for angle of wave attack of 0 degree, the wave height attenuation (WHA = 1- K_t) achieved are 24.5% (0.45m), 20.7% (0.50m) and 10.4% (0.60 m), respectively. WHA are increasing along with the increasing of angle of wave attack but it is declining with increasing of water depth. The highest WHA is for the depth of 0.45m and at the angle of 60°, which is 55.02%. The values of K_t for X/d = 10.0-13.33(6 m) are more approaching to 0 compare to X/d = 6.67-8.89(4 m). K_t drops with an increase in H/gT^2 and increase in relative depth, d/gT^2 as submerged breakwater is efficient in breaking the steeper waves.***

Index Terms— ***Tandem breakwater, Wave attack, Wave height attenuation, Wave transmission.***

I. INTRODUCTION

Breakwaters are coastal structures, which are widely used for providing shelter from the wave action. Breakwaters protect shorelines from erosion by mitigating wave damage and conventionally emerged breakwaters have been used [1]. Submerged breakwaters are constructed with their crests submerged in the water and functioning to control the erosion near the beach [2]. The advantages of submerged breakwater are cost effective and fast installation compared to emerged breakwater [3]. These type of breakwaters are capable for defending at present existing breakwater and as a restoration structure for an impaired breakwater ([4].

For submerged breakwater, the wave transmission coefficient, K_t is a very important parameter that needs to be considered. The definition of wave transmission coefficient, K_t is given as the ratio below [5]:

$$K_t = \frac{H_t}{H_i}$$

(H_t) is the transmitted wave height and (H_i) is the incident wave height at the breakwater seaward. There are a few factors that affecting wave transmission and can be categorized into two part. The first part is the characteristics of the submerged breakwater; the geometrical structure, permeability and porosity, free board (R_c) or (F), crest width (B), slope of the structure and nominal diameter, (D_{n50}). The second part includes the hydraulics parameters; depth of water, (h), wave height (H), wave steepness and wave period, (T). ([5], [6], [7]. Figure 1 shows the structure of submerged breakwater with all the parameters.

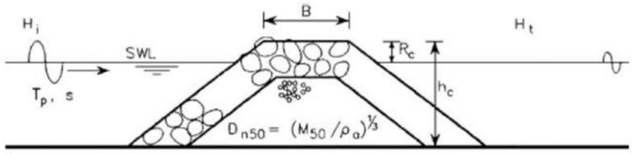

Figure 1: Submerged breakwater characteristics ([8]

A combination of submerged breakwater built at a forward facing of a traditional rubble mound breakwater is termed as tandem breakwater. The space between the both structure (submerged and the main breakwater) has developed the tranquillity zone. A natural energy dissipation will happen in this area causing reduced waves stretching the main breakwater [9]. A study was done to investigate the strength of a common rubble mound breakwater sheltered by a submerged breakwater in front of it [10]. The results shows that with usage of submerged breakwater, the damages for the protected breakwater is decreased by 40-100% when comparing to single breakwater (not using submerged breakwater).

II. LITERATURE REVIEW

A mathematical model is a very complex process to achieve, including determining the wave transmission over a submerged structure of the tandem breakwater. That is why physical model is still important and valid for the researchers to study the performance of breakwaters quantitatively. ([11]. The main important non-dimensional input parameters used are relative crest height (h/d), wave

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steepness (Hi/gT^2), relative crest width (B/L), relative submergence (F/H_i), relative depth (d/gT^2) and relative breakwater spacing (X/d), the spacing between main breakwater and submerged structure.

Value of K_t varies between 0 and 1. If the value of K_t is 0, its indicate that there is no transmission occurred due to the impermeable or high breakwaters. If there is no reduction in wave height, the K_t will be 1 ([12]. Wave height attenuation (*WHA*) can be expressed as (1- K_t) x 100. Cox and Clark [13] applied the tandem breakwater concept. A breakwater defenced by a submerged structure were built to protect a marina harbour. They applied the relative breakwater spacing (*X/d*) ranging from 3.49 to 5.81 for a tandem breakwater experiments where a maximum wave height attenuation of 32% was resulted. A research conducted by K. G. Shirlal and Subba Rao [14] had used breakwater spacing (*X/d*) ranging from 3.33 to 4.29 and produced a maximum of 25% wave height attenuation. Another study conducted by Shirlal et. al. [10] using (*X/d* =2.5–13.33) and various relative heights (*h/d* = 0.625–0.833) for the submerged breakwater parameter. Relative widths (*B/d* = 0.25–1.33) were used in the tests. The results attained show that with relative width (*B/d*) = 0.6–0.75 and relative distance (*X/d*) of 6.25–8.33 breaks all the entering waves hence the energy is dissipated and waves are getting weaker. This makes the breakwater safe from massive damage.

Most of the researches for wave transmission are using 2D flume and this only involve wave that is perpendicular to the structure in the flume. ([15]. A study was done to measure the wave transmission with the influence of wave attack that is not perpendicular to the structure. From the study it was found that the values of wave transmission Kt are decreasing when there is an increase of incident angle of wave attack [16], [17].

III. MATERIALS AND METHODS

The completely experimental work is carried out in a wave basin at the National Hydraulic Research Institute of Malaysia (NAHRIM) where a traditional rubble mound breakwater and submerged breakwater are placed in it as shown in Figure 2. The basin was 25 m long, 18 m wide and 1.2 m deep. Figure 3 shows the arrangement of the wave gauges for the measurement of the incident and transmitted wave. Wave paddle is located at one end and at the other end, a wave absorber was installed to minimize the wave reflection impact. Figure 4 is the actual view of the tandem breakwater in the wave basin. While Table 1-3 are the characteristics value for the conventional and submerged breakwater used in the tandem breakwater system.

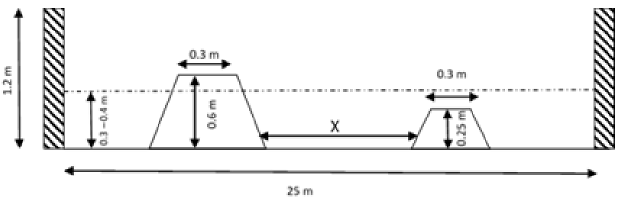

Figure 2: Side view plan

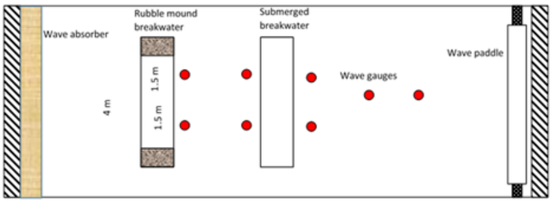

Figure 3: Top view plan

Figure 4: Wave basin with tandem breakwater

Table 1 : Wave characteristics

Characteristics	Value
Wave height, *H*	0.15m, 0.18 m and 0.20 m
Wave period, *T*	2.05s, 2.20s and 2.50s
Number of waves, *N*	1000 waves
Angle of wave attack, θ	0°, 15°, 30° dan 60°
Water depth, *d*	0.45 m, 0.50 m and 0.60 m

Table 2: Characteristics for conventional breakwater model

Characteristics	Value
Model scale	1 : 20
Height	*H* = 0.70 m
Crest width	*B* = 0.30 m
Length	*L* = 4 m
Slope ratio	1 : 2
Armour layer	Quarry stone and mortar cube
Nominal diameter, D_{n50}/D_n	0.050 m – Stone 0.049 m – Cube
Weight, W_{50}	270-300 gm – Stone 282 gm – Cube

Table 3: Characteristics for submerged breakwater model

Characteristics	Value
Model scale	1 : 20
Height	*h* = 0.25 m
Crest width	*B* = 0.30 m
Length	*L* = 4 m
Side slope	1 : 2
Material	Quarry stones
Nominal diameter, D_{n50}	0.03 m
Weight, W_{50}	150-200 gm
Porosity	0.45

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Distance between conventional breakwater and submerged breakwater, *X*	4.0 m and 6.0 m

Table 4: Dimensionless parameter for wave and submerged breakwater

Characteristics	Value
Relative height, *h/d*	0.42-0.56
Relative width, *B/d*	0.5-0.67
Relative submergence, *F/Hi*	1.00-2.33
Relative distance, *X/d*	8.33-15.56
Wave steepness, H/gT^2	0.0024-0.0044
Relative depth, d/gT^2	0.0073-0.015

IV. RESULTS AND DISCUSSION

a) Effect of deep water wave steepness

Figure 5 shows the results of transmission coefficient K_t for different relative depth, d/gT^2 for the condition of 0° wave angle with the deep-water wave steepness parameter, H/gT^2. K_t decreases with an increase in H/gT^2 and relative depth, d/gT^2 as submerged breakwater is efficient in breaking the steeper waves. The wave height attenuation (*WHA* = 1- K_t) achieved are 24.5% for 0.00734-0.01092(0.45m), 20.7% for 0.00816-0.01213(0.50m) and 10.4% for 0.00979-0.01455(0.60 m), respectively. By considering all the depths, the K_t ranges from 0.76 to 0.99.

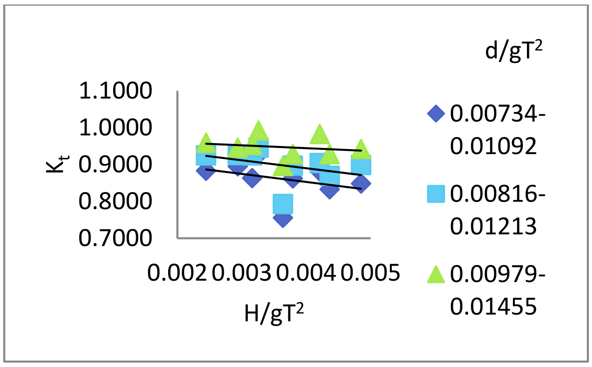

Figure 5: Variation of K_t values for different relative depth, d/gT^2

b) Effect of relative distance, X/d on wave transmission, K_t.

Figure 6 represents the comparison value of K_t for relative distance, *X/d* between 6.67-8.89(4 m) and 10.0-13.33(6 m). It is observed that for the *X/d* = 10.0-13.33(6 m) the values of K_t are more approaching to 0 which means the reduction of wave height is higher than *X/d* = 6.67-8.89(4 m) or higher wave attenuation. The submerged breakwater will break the incoming waves resulting in energy reduction. These waves then loose some more energy while circulating in the energy dissipation zone.

Results show that for *X/d* = 6.67-8.89(4 m) with relative depth, d/gT^2 = 0.00734-0.01092 the wave height attenuation (*WHA*) is 24.5 percent (maximum) while for 10.0-13.33(6 m) the *WHA* is 42.0 percent (maximum) with the same relative depth.

Research conducted by [10] found out that with *X/d* = 2.5–3.33, the waves were attenuated by a maximum amount of 18%. For *X/d* = 6.25-8.33 waves were attenuated for about 33% and 43% was obtained for *X/d* = 10-13.33.

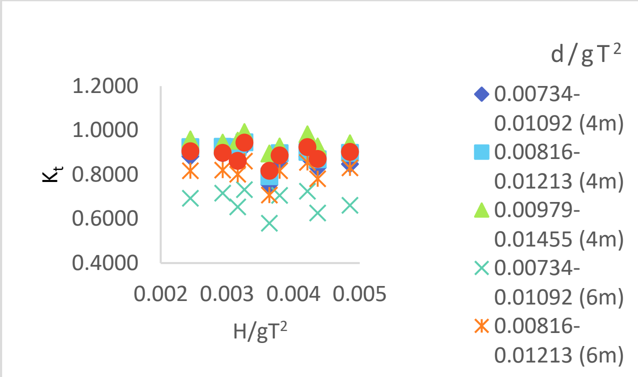

Figure 6: Comparison of K_t value for for relative distance, *X/d* between 6.67-8.89(4 m) and 10.0-13.33(6 m)

c) Effect of angle of wave attack, θ on wave transmission, K_t.

Figures 7, 8 and 9 shows the resulted K_t for relative distance, *X/d* = 10.0-13.3 (6 m) and with relative depth, d/gT^2 = 0.008904-0.013163(0.60 m), 0.007791-0.011518(0.50 m), 0.006678-0.009872(0.45 m) respectively. All the graphs indicate the decreasing value of transmission coefficient, K_t when the angle of wave attack, *θ* are increasing from 0° to 60°. The same pattern of graph also can be seen with *X/d* = 6.67-8.89(4 m).

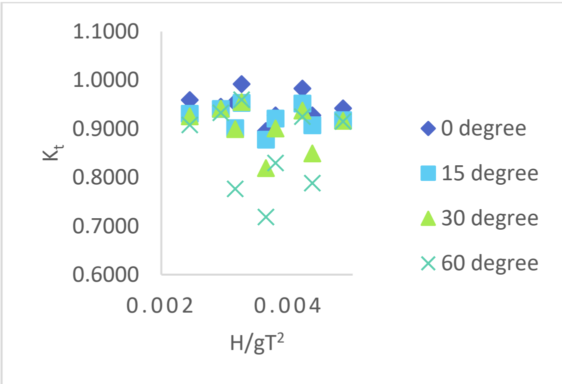

Figure 7: (*X/d* = 6.67-8.89, d = 0.6m)

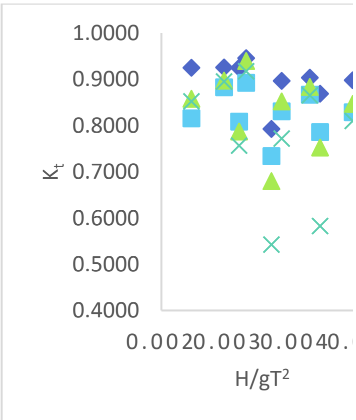

Figure 8: (*X/d* = 6.67-8.89, d = 0.5m)

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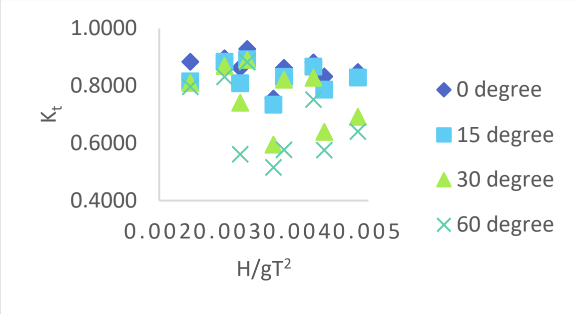

Figure 9: (*X/d* = 6.67-8.89, d = 0.45m)

Table 5 presents the results of *WHA* for relative distance, *X/d* = 10.0-13.3 (6 m). It shows that *WHA* are increasing along with the increasing of angle of wave attack but it is decreasing with increasing of water depth. The highest *WHA* is for the depth of 0.45m and at the angle of 60°, which is 55.02%. Table 6 shows the results for the relative distance, *X/d* = 6.67-8.89 (4 m). The highest *WHA* is also for the depth of 0.45m and at the angle of 60° that is 48.46%.

Table 5: Wave height attenuation for relative distance, *X/d* = 10.0-13.33 (6 m)

	Wave height attenuation (*WHA*) (%)			
d/gT²	0°	15°	30°	60°
0.00734-0.01092 (0.45m)	42.00	47.89	48.60	55.02
0.00816-0.01213 (0.50m)	29.24	29.98	34.82	45.16
0.00979-0.01455 (0.60m)	18.19	22.91	23.43	39.21

Table 6: Wave height attenuation for relative distance, *X/d* = 6.67-8.89 (4 m)

	Wave height attenuation (*WHA*) (%)			
d/gT²	0°	15°	30°	60°
0.00734-0.01092 (0.45m)	24.49	26.63	40.51	48.46
0.00816-0.01213 (0.50m)	20.73	23.75	32.05	45.73
0.00979-0.01455 (0.60m)	10.43	12.27	18.12	28.15

V. CONCLUSIONS

The physical model of tandem breakwater was built to study the wave transmission. Main aspects to be considered are the various angles of wave attack, wave height, water depth and wave period. The study and analysis of the results shows that wave height attenuation will occur with the installation of submerged breakwater. The wave height attenuation would increase if the distance between the submerged structure and main breakwater were increasing. The optimum spacing between the structures is found to be *X/d* = 10.0-13.3 (6 m). The highest *WHA* is for the depth of 0.45m and at the angle of 60°, which is 55.02% (*X/d* = 10.0-13.3 (6 m)) and 48.46% (*X/d* = 6.67-8.89 (4 m)) for the same depth and angle. This is due to as the length of the between breakwaters (*X*) increase, the submerged structure is functioning to break all the waves in to smaller waves and the rest of the energy from the waves will dissipate in the tranquillity zone.

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