Two-Dimensional Characteristics of Wave Action as a Preliminary Study for Physical Modelling of Gabion-Type Breakwater Stability

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Two-Dimensional Characteristics of Waves as an Initial Study for Physical Modeling of Gabion-type Breakwater Stability

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Abstrak

In the initial stage of research on physical modeling of gabion-type breakwater stability, preliminary experiments on simulated wave generation in various variations of wave deviation and variations in water depth in the wave channel in the laboratory have been carried out. The purpose of this research is to understand the wave characteristic model that will be used in the simulation of the gabion type breakwater physical model. The research was conducted on a tilting flume type regular wave channel with a length of 15 m, a width of 30 cm and a glass wall height of 45 cm. The regular wave flume is equipped with adjustable stroke and variator to obtain variations in wave height and period. Wave generation simulation was conducted with stroke (St) variations of 7 cm, 8 cm and 9 cm, while variations for wave period (T) were 1 second, 1.1 second and 1.2 second and water depth (d) was 20 cm, 25 cm and 30 cm. The generated wave height was recorded with a data logger through 3 wave probes placed at the base, center and end of the flume. Data logger calibration was performed to convert the generated voltage unit into length unit. The relative depth (d/L) obtained is in the range of 0.132 - 0.192 so that the experiment conducted is modeling the transitional sea with Airy wave theory. The deeper the water the more volatile and the bigger the waves formed. The reflection coefficient (Kr) that occurs is quite large, ranging up to 0.3. An empirical approach Hi/St = Cf. kd/2 is obtained, where Cf is the flume coefficient with a value of 1.45. This approach can be used to design the model wave height required for physical modeling simulations.

Keywords: physical model waves, stroke, water depth, flume coefficient.

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1. Introduction

Physical model studies are physical imitations of real-world system problems on a smaller, similar or larger scale. The model to be tested must be adjusted to its prototype if it is desired that the behavior of the model is similar to the behavior of its prototype. Physical modeling is necessary because the application in the laboratory is not exactly the same as the conditions in the field so that by paying attention to the effect of the provision will minimize the laboratory effect. The objectives of physical modeling include: 1. To predict the possibilities that will occur after the structure is built. 2. To determine or predict the appearance of the hydraulic building and its effect on the environment.

The basics of modeling is to reshape the problem in the prototype on a smaller scale (model), so that the events (phenomena) in the model are similar to those in the prototype. The relationship between the model and the prototype is derived by scale. Scale is the ratio between the value of a parameter in the prototype and the value of that parameter in the model. For each parameter has its own scale and the magnitude is not the same. Similarity or congruence between the prototype and the physical model can be obtained if the suitability of the model is determined by how possible hydraulic congruence such as geometric congruence (length, width, height), kinematic congruence (velocity, flow), and dynamic congruence (related to force) in nature can be replicated in the model.

Research on breakwater buildings using physical model simulation is aimed at understanding the behavior of ocean waves towards breakwater. The research objective is to find the relationship of stability parameters of gabion type breakwater with influential parameters. Why is the gabion arrangement chosen as a breakwater? This is because it is difficult to get a quarry that provides natural stone with a large size. It is known that the commonly used approach to calculate the required stone weight based on wave height is the Hudson Formula as described in the theory section. As an approach to understanding and preparing the physical model of gabion-type breakwater stability in this study, the preliminary test results presented in this article are the results of simulating the formation of model waves that will be used in the stability test of the gabion structure model as a breakwater. The characteristics of the model wave in the flume are identified and formulated empirically to be used as an approach to determine the dimensions of the wave height and period that are appropriate for various wave-related physical model studies and one of them is the gabion-type breakwater stability study to be carried out. The dependent parameter is the generation wave height (H_i), while the independent variables are the stroke length (S_t), the rotational speed of the wave generating machine disk or variator (vt), and the water depth in the flume (d).

2. Literature Review

2.1. *Waves and their Impact on the Beach*

Ocean waves play an important role in shoreline formation and coastal ecosystems. Waves cause erosion, sedimentation, and changes in beach shape over time as well as disturbance to harbor ponds. There are many problems on the coastline caused by daily waves and storm surges, but there are two that are related to the planned research, namely:

a. Beach erosion/abrasion

The impact of waves on a beach can vary depending on the strength, frequency and type of waves, as well as the geographical characteristics of the beach itself. Figure 1. shows an example case of damage to a beach and beach infrastructure due to wave erosion and abrasion.

Figure 1. Examples of coastal erosion and abrasion due to waves

Beach Erosion occurs when waves erode beach material and carry it downstream and break down sediments from the beach and transport them to the sea. Strong and frequent waves cause abrasion or erosion of soil and rocks on the shore. Large waves coming from storms or extreme weather can accelerate the erosion process. Waves with high speeds carry more energy, which increases the potential for erosion. Poorly designed breakwaters or structures can accelerate erosion in certain areas. The impact of beach sediment loss is that the beach space narrows, reducing the available land area in coastal areas. There is also damage to coastal infrastructure as severe erosion can damage roads, buildings and other facilities near the shoreline. Coastal ecosystems are disturbed as coastal erosion reduces the natural habitat for coastal organisms, such as coastal vegetation and marine biota. Storm surge impacts where coastal facilities are submerged. Rising seawater due to storm surge can cause widespread flooding in coastal areas. Like regular waves, storm surge can also transport sediment, causing dramatic changes to the shoreline.

b. Sediment Transport and Shoreline Change

Ocean waves carry sediments (sand, mud, gravel) and deposit them in other areas, forming new beaches or extending existing beaches. Lateral flow of sediment along the shore caused by waves arriving at a certain angle, resulting in the movement of material along the shore. This phenomenon is important in the formation of deltas, spits and tombolos. Over a long period of time, shoreline changes will occur that impact the utilization of coastal areas and waters as shown in Figure 2.

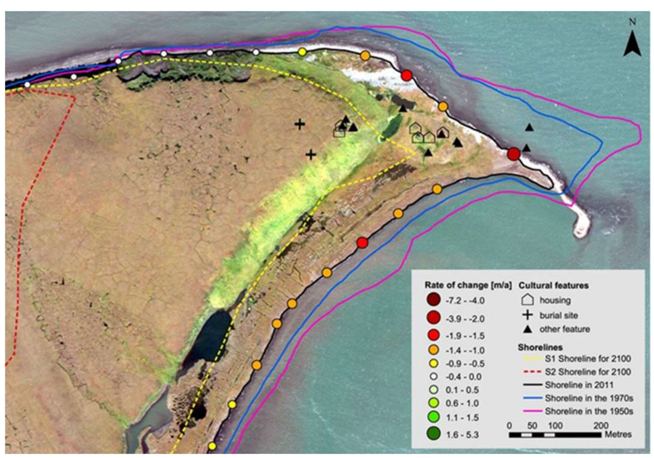

Figure 2. Examples of shoreline changes include former Niaqulik settlements, shoreline changes over time, and projected future changes (Irrgang et al., 2018).

The impact of shoreline formation/geomorphology and change, where sediment-bearing waves can create various coastal features such as dunes, deltas or lagoons. A common term is dynamic beaches, which can change shape seasonally or annually depending on the movement and deposition of sediment by waves.

2.2. *Beach Protection with Breakwaters*

There are 5 ways to protect the beach, namely: 1. Reducing wave energy with breakwater before the wave reaches the beach, 2. Reducing the rate of beach sediment transport with groin and training jetty, 3. Strengthening the coastal wall with sea wall and/or revetment, 4. Natural protection with vegetation and sand dune, 5. Replenishing eroded beach with sand from other sources. The associated coastal protection of this research plan is a rubble mount type breakwater. Figure 3 shows an example of a rubble mount type breakwater (Leo C Van, 2016).

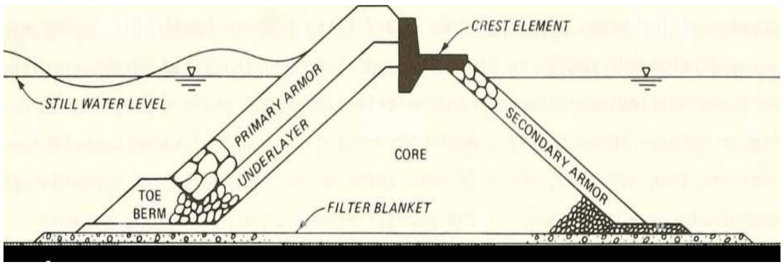

Figure 3. Rubble mount type breakwater (www.alamy.com)

Figure 3 shows a standard cross-section of a rock pile type breakwater (either natural rock, or artificial rock). There are 4 parts of the rock that make up this breakwater, namely core, underlayer, primary armor and secondary armor (Burcharth, 2019). The part that is directly facing the waves is the primary armor or called the protection layer. The main requirement that this layer must fulfill is that the stone must not move by the attack of the design wave. Design waves are waves with a height and wave period that represent waves in a certain return period (10 years, 20 years, 50 years etc.) depending on the designation. In the implementation of stone protection layers, natural and/or artificial stones are often used. To cope with high waves, sometimes a large stone size or weight is required. Sometimes it is very difficult to obtain natural stone of the recommended size as a result of design using the Hudson Formula, so artificial stone made of concrete or reinforced concrete is often used. But sometimes even this artificial stone remains a problem because the area is remote, difficult to lift equipment and concrete materials and expensive in cost. In this condition, alternative solutions are needed such as using geotubes and geobags made of geotextile material with sand filling and gabions that use woven stainless gabions.

Figure 4. Gabion, Geotube and Geobag type breakwater

From Figure 4, the leftmost is a gabion-type breakwater, the middle is a geotube and the right is a geobag. These three types of breakwater have advantages and disadvantages. The gabion breakwater has the advantage of using small stones and having pores that effectively reduce wave energy (Chaudhary et al., 2015). The disadvantage is the gabion wire material which generally still uses iron which is easily corroded. Geotubes and geobags have the advantage of being easy to install, but if the geotextile sheet is torn, it automatically loses its function and also does not have pores that effectively reduce waves.

The planned research is the development of gabion types with shapes other than box shapes to increase their interlooking value using high density polyethylene (HDPE) material. However, this paper still presents preliminary studies related to wave model studies that will be used in the physical model laboratory.

2.3. *Theoretical Foundation*

a. Waves in Nature & Wave Theory

Wind waves, hereafter referred to as waves, are fluctuations in sea level formed by wind blowing on the surface of the sea. The waves formed have important characteristics for civil engineering foundations, including wave height, wave period and wavelength. Waves are classified according to their water depth into three categories: shallow water, transitional water and deep water waves (Triadmodjo, 2014). The boundaries of the three categories are based on the ratio between depth and wavelength (d/L). The limitations of the three categories are further shown in Table 1. The boundaries of the wave theory are given in Figure 5.

Table 1. Boundaries of shallow, transitional and deep water waves

Wave Catagory	d/L	2πd/L	Tanh 2πd/L
Deepwater	> 0.5	> π	= 1
Transition	0.05 – 0.5	0.25 - π	Tanh 2πd/L
Shallow water	< 0.05	< 0.25	= 2πd/L

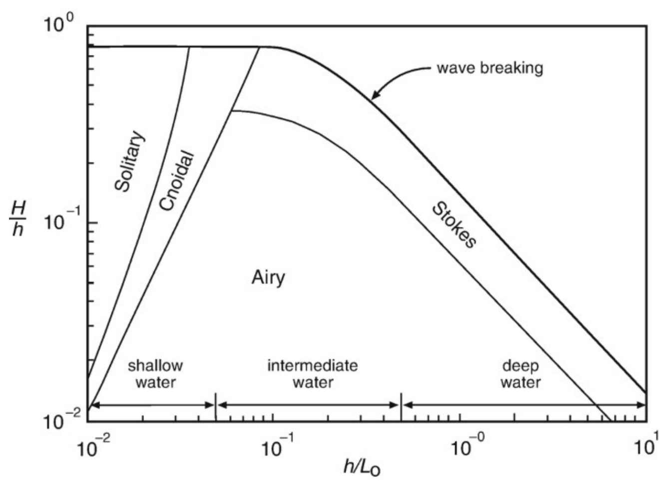

Figure 5. Area of use of wave theory in the relationship between d/gT2 and H/gT2.

Wave theory is developed into two types, namely small amplitude wave theory and finite amplitude wave theory. The small amplitude wave theory developed by Airy is based on the assumption that the wave height is very small with respect to the length or depth of the water, while the finite amplitude wave takes into account the magnitude of the wave height with respect to the length and depth of the water (Triadmodjo, 2014). The boundary conditions on the surface obtained from the Bernoulli equation with nonlinear terms (u2 + v2) that are ignored / linearized in the theory of small amplitude waves, can no longer be ignored in the theory of finite amplitude waves. Thus, finite amplitude wave theory is also called nonlinear wave theory (Triadmodjo, 2014). The wave theory that will be used in this study is Airy wave theory. The water level profile is a function of space (x) and time (t) which has the following form.

$$\eta\ (x,t) = \frac{H}{2}\cos(kx - \sigma t) \qquad (1)$$

Equation (1) shows that water level fluctuations are periodic with respect to x and t, and are sinusoidal and progressive waves traveling in the positive x-axis direction. The propagation speed (C) and wavelength (L) are given by the following equations (Triadmodjo, 2009).

$$C = \frac{gT}{2\pi}\tanh\frac{2\pi d}{L} = \frac{gT}{2\pi}\tanh kd \quad \text{......(2)}$$

$$L = \frac{gT^2}{2\pi}\tanh\frac{2\pi d}{L} = \frac{gT^2}{2\pi}\ tanh\ kd \quad \text{......(3)}$$

Where H = wave height, k = wave number (2π/L), x & t = position of the point under review in distance and time, σ = wave frequency (2π/T), d = water depth, T = wave period

b. Stabilitas Primary Armor

In the planning of a sloping-side breakwater, the grain weight of the protective stone (W) is determined, which can be calculated using Hudson's formula:

$$W = \frac{\gamma_r H^3}{K_D(Sr-1)^3 Cot\theta} \quad \text{......(4)}$$

Where, γr = specific gravity of stone, K_D = stability coefficient, Sr = relative specific gravity (γr/γa), γa = specific gravity of water and Cot θ = slope of the structure. Table 2 presents the KD coefficient values for quarry stone.

Table 2. K_D coefficient for natural stone type armor protection layer

Quarry Stone	Armor Unit (n)	Placement	Structured Trunk K_D Breaking Wave	Structured Trunk K_D Non-breaking Wave	Structured Head K_D Breaking Wave	Structured Head K_D Non-breaking Wave	Structured Head Slope Cotθ
Smooth rounded	2	Random	1.2	2.4	1.1	1.9	1.5 to 3.0
Smooth rounded	>3	Random	1.6	3.2	1.4	2.3	
Rough angular	1	Random		2.9		2.3	
Rough angular	2	Random	2.2	4.5	2.1	4.2	5
Rough angular	>3	Special	5.8	7.0	5.3	6.4	5

This approach will be used to design the weight of gabions per piece, which will then formulate the K_D coefficient. In the study of the physical model in the laboratory, in order to obtain accurate study results, preliminary experiments were carried out to study the characteristics of model waves that could be generated in the existing flume.

c. Waves in Physical Model Studies

Pembangkit Gelombang Tipe Flap dirancang untuk digunakan dalam penelitian pada gelombang laut transisi dan perairan dalam (lihat Gambar 6). Lebar flap dapat meyesuaikan saluran yang ada dan dapat digunakan secara individual dalam saluran yang sempit atau beberapa flap dapat digunakan bersama-sama dalam saluran yang lebih luas untuk menciptakan gelombang miring atau menyerap gelombang.

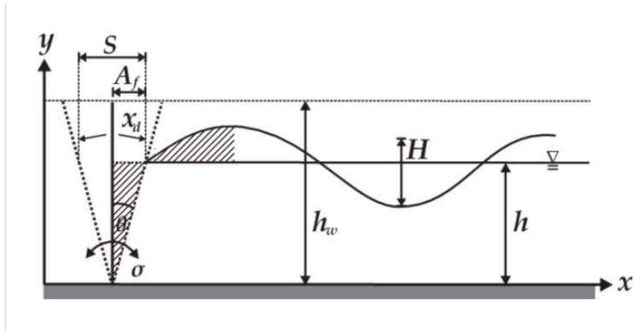

Figure 6. Flap type wave generator

For flap type wavemaker, the relationship between wave height, stroke length, and water depth is given as:

$$\frac{H}{St} = \frac{kd}{2} \quad \text{.....(5)}$$

Where, k is wave number and d is water depth.

In the study of physical modeling, there are criteria that need to be met, namely geometric congruence, kinematic congruence and dynamic congruence (Yuwono, 2021). Geometric congruence is a congruence where the shape in the model is the same as the shape of the prototype but the size may not be the same. Kinematic congruence is a congruence that fulfills geometric congruence and the comparison of velocity and acceleration of flow at two points on the model and prototype in the same direction is the same. A dynamic congruence is a congruence that satisfies both geometric and kinematic congruence criteria. The comparison of the forces acting on the model and prototype for the entire flow in the same direction is equal. The forces are inertial force, pressure force, weight force, frictional force, and friction force.

In general, coastal physical phenomena solved by hydraulic models meet the criteria of dynamic congruence according to the Froude number condition, because the physical processes that occur are determined by the force due to the acceleration of the earth's gravity (Hughes, 1993). The Froude number (Fr) and the scale relationship between Fr model and Fr prototype is 1. Model testing to determine the reflection and transmission coefficients of wave energy in this study was carried out with undistorted models where the length scale is equal to the height scale.

3. Research method

The research was conducted in a regular wave channel type tilting flume measuring 15 m long, 30 cm wide and 45 cm high glass wall. The regular wave flume is equipped with a wave generating machine with adjustable stroke and variator to obtain variations in wave height and period and an absorber at the end of the flume.

Figure 7. Wave Generation Tank (*Wave Flume*)

Wave generation simulations were conducted with variations in stroke (S_t) of 7 cm, 8 cm and 9 cm, while the variators for wave period (T) were 1 second, 1.1 second and 1.2 second and water depth (d) was 20 cm, 25 cm and 30 cm. The generated wave height was recorded with a data logger through 3 wave probes placed at the base, center and end of the flume. Calibration of the data logger was carried out to convert the resulting voltage units into length units. The relationship between variables was analyzed using dimensionless parameter regression. The results of dimensional analysis are presented in the form of graphs and equations that can generalize all variables involved in the relationship between parameters.

4. Results and Discussion

The results and discussion of the research are organized towards the research objectives to formulate the relationship of wave generation height and reflection coefficient with the determining variables, namely stroke length (*St*), the amount of time variator or wave period (T) and water depth (d). But before that, it is necessary to organize the discussion in stages starting from the calibration of the measurement instrument (probe), comparison of the characteristics of the generated waves, the effect of wave reflection on the experimental flume, the effect of stroke size (*St*) on wave height (*Hi*), the effect of water depth (d) on wave height (*Hi*), the joint effect of stroke, variator and water depth both on wave height (*Hi*) and on wave reflection coefficient (*Kr*).

4.1. Calibration and Wave Characterization in the Flume

The instrument for measuring wave water level fluctuations is a sensor rod called a wave probe with voltage measurement units. Therefore, the instrument was calibrated by measuring the change in elevation in length (cm) for each change in elevation measured and in volts by the instrument. Figure 5 shows an example of changes in wave height in volts (before conversion) and wave height in length (cm) after conversion.

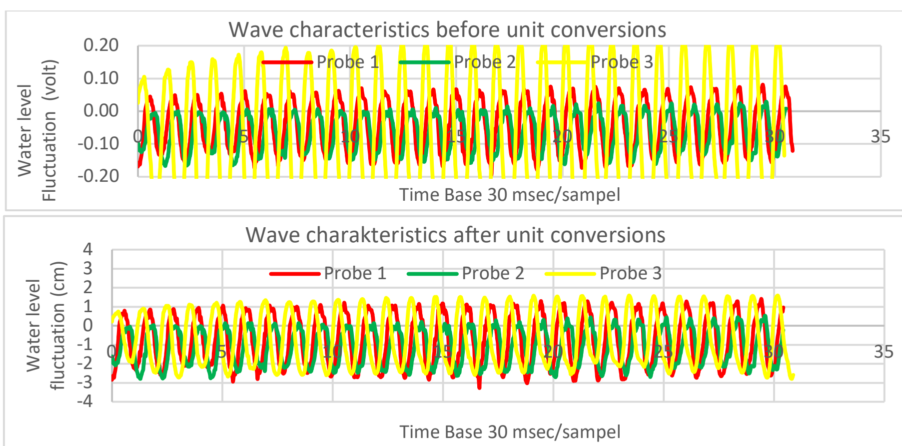

Figure 8. Example of waveform characteristics before calibration and after calibration.

There are 3 probes installed to measure the wave characteristics along the wave flume. One probe (Probe 1) is placed at the base of the flume to measure newly formed waves. The other two (Probe 2 and Probe 3) were placed at the center and end of the flume, respectively. The recorded waves at the three probes depict relatively uniform fluctuations from the first wave to the last wave. This provides an understanding that the wave characteristics with variations in St and Vt with the depth used have relatively little effect on wave reflection.

4.2. Wave Characteristics at Variation of Stroke

The wave height in the flume is adjusted by adjusting the stroke length, the greater the stroke the greater the wave height. Figure 9 presents the characteristics of the generated wave model based on the variation of stroke length at a fixed water depth and period.

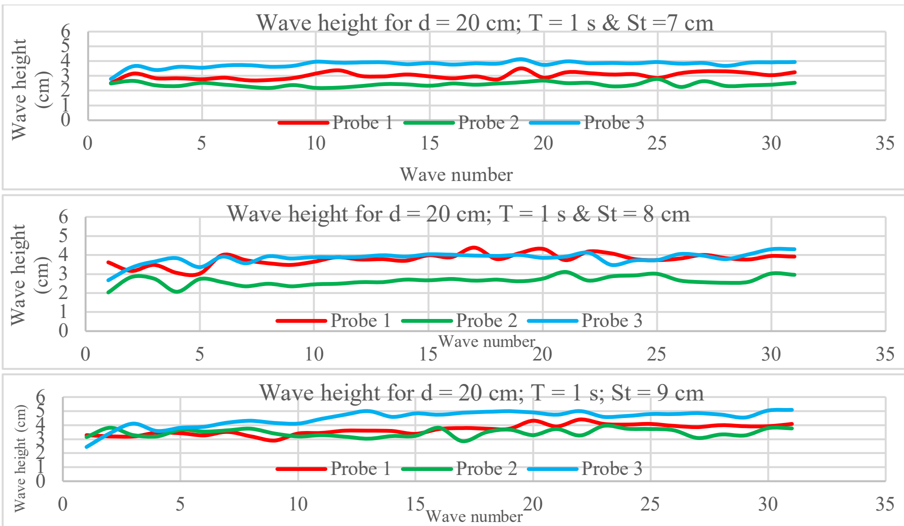

Figure 9. Characteristic wave height (Hi) in stroke variation at d = 20 cm with T = 1 s.

The three curves in Figure 9 show a wave formed with a height that only fluctuates slightly from the first wave to the end. The wave height ranges from 2 cm - 5 cm. The larger the stroke, the higher the wave height, although not significantly. Among the 3 probes that recorded, probe-3 measured the highest wave height. At d = 20 cm with T = 1 second or at d/L = 0.165, the wave characteristics do not fluctuate too much.

4.3. Wave Characteristics at varying water depth (d)

Wave characteristics in the Flume are also expected to be strongly influenced by variations in water depth (d). Figure 10 presents the characteristics of the generated wave model based on the variation of water depth (d) at a fixed period and stroke.

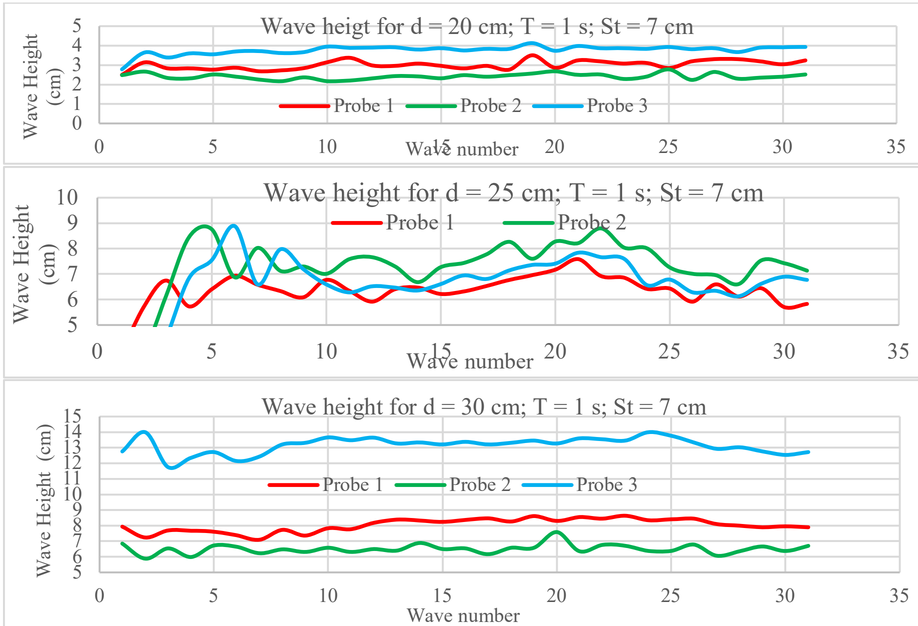

Figure 10. Effect of water depth (d) on wave height (Hi) at T = 1 s with St = 7 cm.

From the three curves in Figure 10, it can be seen that the greater the water depth, the greater the waves formed with the greatest increase occurring at the probe-3 location or at the end of the flume. Large fluctuations are shown at the middle depth (25 cm). Both conditions are thought to be influenced by the reflection of the waves that occur.

The prevailing wave theory is shown through the graph of the relationship between d/Lo and Hi/d as presented in Figure 11 and verified in Figure 5. Table 3 presents the values of d/L for different variations of wave period (T) and water depth (d).

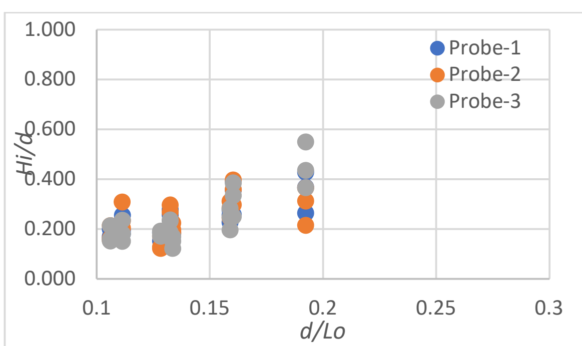

Figure 11. Experimental wave data map in relation to d/Lo with Hi/d

Tabel 3. Experimental d/L value

The *d/L* value								
d =20 cm			*d* = 25 cm			*d* = 30 cm		
T = 1 s	*T* = 1.1 s	*T* = 1.2 s	*T* = 1 s	*T* = 1.1 s	*T* = 1.2 s	*T* = 1 s	*T* = 1.1 s	*T* = 1.2 s
0.165	0.146	0.132	0.192	0.169	0.151	0.219	0.191	0.169

From the data shown in Figure 11, it can be seen that the range of wave data generated by the experimental scale is around 0.1 - 0.2 on the d/Lo scale and around 0.1 - 0.6 on the Hi/d scale. If we plot it into the graph of Figure 5, it is found that the set of wave data is in the Airy Wave Theory region. From Table 3, it is obtained that the experimental d / L values range from 0.132 - 0.192, so it is concluded that the waves formed are waves in the sea transition.

4.4. Wave Reflection

The wave reflections occurring in the flume are shown in Figure 8. all generated waves had their reflection coefficients calculated.

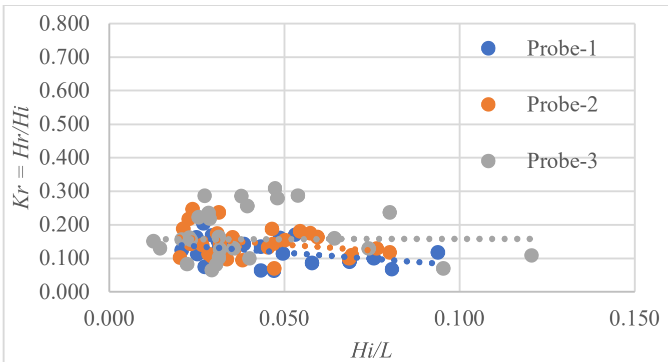

Figure 12. The range of reflection coefficient values occurring in the flume in relation to wave steepness (Hi/L) with Kr

From Figure 12, it can be seen that the greater the wave steepness value, the smaller the Kr value at Probe-1 and Probe-2. It is different at Probe-3 which shows a constant Kr value. The range of reflection wave height is quite significant with Kr values ranging from 0 to 0.3, especially at the end of the flume. This result corresponds to the characteristics of the wave formed at the end of the flume as shown in Figure 6.

4.5. Relationship between Wave Height (Hi) and Influence Parameters

The final result of this preliminary research is to understand the characteristics and formulate the relative wave height to stroke (Hi/St) generated in the wave flume located in the Coastal Engineering laboratory of the Department of Civil Engineering, Hasanuddin University in function of the variable wave period (T) and water depth (d). Referring to Equation (5), the dimensionless parameter relationship also uses Hi/St and kd/2, where k is the wave number. Figure 13 presents the relationship of kd/2, which is also the same as the theoretical H/S with Hi/St from physical modeling. The variable H equals Hi is the incident wave height and S or St is the stroke length.

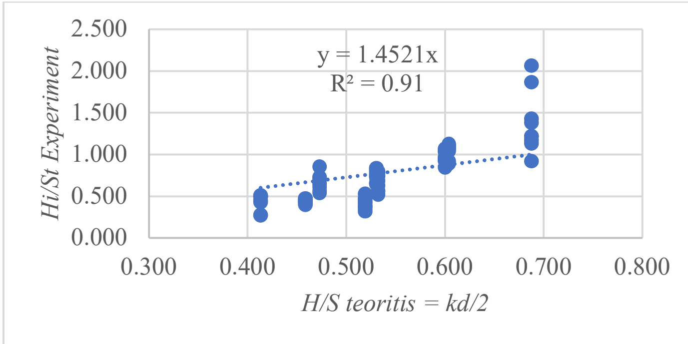

Figure 13. Theoretical H/S relationship with experimental Ht/St

From Figure 13, it can be concluded that the larger the kd value, the higher the Hi value. The parameter kd/2 is also the theoretical relative wave height to stroke (H/S). So if the comparison between Hi/St and H/S is described, it can be described as follows:

Hi/St = Cf. H/S atau Hi/St = Cf. kd/2 ……………………..………………………………….(6)

And then it can be written:

$$\frac{Hi}{St} = Cf.\frac{kd}{2} \quad (7)$$

Where, Cf is a constant with a value of 1.45. Cf will be referred to as the flume coefficient applicable to the wave flume used at the Coastal Engineering Research Laboratory, Department of Civil Engineering, Hasanuddin University, Indonesia. Equation (7) can then be used to determine the model wave height (Hi) that will be used for all physical modeling studies in the flume.

5. Conclusion

1) The preliminary experimental results show that the deeper the water the more fluctuating and the bigger the waves formed, with the greatest increase occurring at probe-3 depth of 25 cm, the waves are in the Aery Wave theory area with the value of Relative Depth (d / L) the experiment obtained 0.132 - 0.192 or the waves formed are in the transition sea.
2) The greater the Relative Depth (d/L) the smaller the wave reflection.
3) The relationship between Hi/L and Kr shows that the reflection coefficient (Kr) is quite large, ranging from 0 to 0.3.
4) An empirical approximation Hi/St = Cf. kd/2, where Cf is the flume coefficient with a value of 1.45 can be used to determine the modeled wave height (Hi).

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