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Design and Construction of Flap Type Wave Maker Using Servo-Motor Equipped with The Reducer for Generating Waves in 3-D Wave Tank

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ABSTRACT
Laboratory physical models in ocean engineering field are beneficial methods to conduct various research experiments. One of the most important equipment in the ocean engineering laboratory is a wave maker to generate and mimic the actual ocean wave. This research aims to design and construct a wave maker to generate waves on the wave tank with the dimensions of 7.5 m x 15 m x 1 m. The selected type of wave maker is a flap with hinged at the bottom, which is driven by a 3-phase motor 5 HP and gearbox reducer WPA 80 with a ratio of 1:40. The flap was connected to pulley B1-12 by shaft. There are three designs of wave maker system, i.e., stroke length of 0.5 m and the gearbox reducer with ratio 1: 40; stroke length of 0.5 m and the gearbox reducer with v-belt and pulley; stroke length of 0.05 m and the gearbox reducer with ratio 1: 40. The performance of the wave maker shows that the third design is more satisfying and suitable than the two others. However, the absorption structure must be added from both ends of the wave tank to reduce the wave reflection.

Keywords: *Flap wave maker design, 3-dimensional wave tank, stroke length analysis.*

1. INTRODUCTION

According to the Convention on the Law of the Sea (UNCLOS) in 1982, the area of the Indonesian seas is about 3,257,357 km^2[1]. Each coastal province has a territorial sea of up to 12 nautical miles measured from the baselines. The sea and coastal areas can be developed in many ways, such as the construction of ports, residential, beach tourism, aquaculture, tidal farming, and others. One of the provinces in Indonesia that has a very long beach is West Kalimantan, with a coastline length of about 1,300 km [2].

Coastal planning and development activities require complex studies and analysis. One of the important and indispensable studies is to conduct research on laboratory-scale physical modelling for various purposes, for example, regarding the effect of waves on the safety of the Cilegon PLTU intake [3], the performance of breakwaters to protect the port facility [4,5], shoreline stability [6], ship stability [7], and others. In addition, the wave propagation process also impacts the coastal structures [8]. Wave energy in the ocean is an abundant source that must be utilized to generate electricity. Moreover, laboratory experiment regarding to model the wave energy device has become a widespread issue because of green and blue economy implementation [9]. Therefore, wave maker is one of the most important experimental tools and plays a central role in the ocean engineering field [10].

To conduct laboratory experiments, particularly for physical modelling of wave transformation, at least we must have two important components, i.e., wave tank and wave maker. The wave maker is complex and very expensive because it is commonly manufactured by an institution in a foreign country. In addition, designing the wave maker is also difficult due to the complexity of the system itself. This situation hinders research development in the ocean engineering field using physical modelling methods. Therefore, it is vital that the ocean engineering department must have a supporting device that can carry out physical modelling tests to mimic the actual wave propagation conditions.

Previous researchers have carried out a simple piston type of wave maker for flume [11]. It is found that determining the stroke length is not as simple as using the formula proposed by Galvin [12]. Another researcher showed that the wave height and wavelength did not correspond to the length of stroke [13]. Recently, a new wave generation device with a rotary valve-controlled cylinder system was also introduced and implemented for flap and piston type of wave maker in the flume by scientists [10]. This new type can generate a different regular wave form only by adjusting the distance of the wave paddle. However, the research mentioned above are only applied at two-dimensional wave tank. Research for designing and constructing a simple wave maker for a 3-dimensional wave tank is still not further studied. Moreover, the references for making the wave maker, particularly in a simple form, for a three-dimensional wave tank are very limited. Therefore, a study of making wave maker still has a room to be further investigated. The flap type of wave maker with hinged at the bottom for simulating wave propagation in the wave tank will be designed and constructed.

The state of the art from this study lies in designing a simple wave maker for a three-dimensional wave tank with a simple mechanism using ordinary components and materials such as an actuator (flap), servo-motor with 5HP, and the reducer. Moreover, determining the stroke length of the flap is critical to mimic the regular and sinusoidal waves.

This paper aims to design and construct a simple wave maker for flap type to generate waves in the wave tank in the laboratory of ocean technology at the Faculty of Engineering, Tanjungpura University. Moreover, this paper also determines the scale factor that is suitable to conduct the physical modelling of wave propagation based on the dimensional analysis.

2. MATERIAL AND METHODS

2.1 Working Principle of Flap Type Wave Maker

The equation used to design wave makers refers to the formula proposed by Galvin [12]. The formula is derived based on water volume displaced by piston or flap type of wave maker that equals the length of stroke (S) multiplied by the water depth (h). Particularly for the flap type wave maker with hinged at the bottom, the volume of water displaced by the wave maker would be less by a factor of 2, i.e., $(H/S) = kh/2$, where H and k are wave height and wave number, respectively. Theoretically, the ratio of wave height to the stroke length can be determined by using formula as follows:

$$\frac{H}{S} = \frac{4\ \sinh(kh)}{2\sinh(2kh) + 2\mathrm{kh}}\left[(sinh\ (kh) + \frac{1 + cosh(kh)}{kh}\right] \quad (1)$$

2.2 Physical Model Calculation for Wave Maker

The wave generated in the wave tank requires geometric, kinematic, and dynamic similarity to mimic the actual condition, where a scale factor of the model in the laboratory can be determined according to the limitation and capability of the wave tank and wave maker [14,15].

The geometrical and kinematic similarity is the similarity of shape and motion between the model and prototype, respectively, while the dynamic similarity corresponds to the similarity of forces. In physical modeling for wave simulation, the dynamic similarity between the model and prototype can be achieved if the geometric and kinematic similarity is fulfilled.

In the case of free-surface flows such as river and wave motion modeling implemented in the physical model laboratory, gravity effects are predominant. Therefore, the Froude number is the most important force that must be counted to achieve dynamic similarity. The Froude number is defined as the ratio of inertia and weight of fluid [16].

2.3 Materials and Installation Design

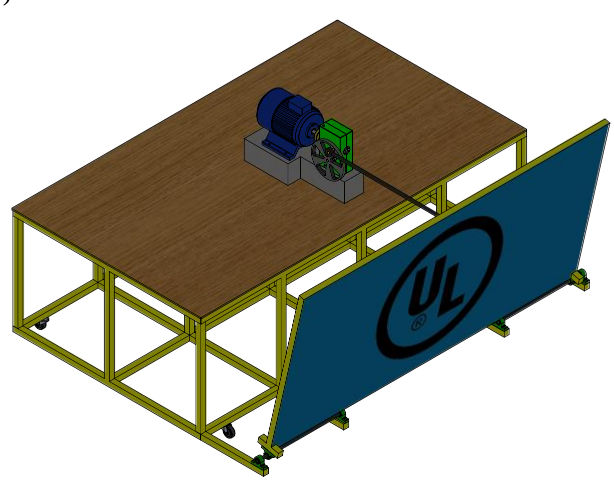
There are six main components of flap type wave maker, i.e., actuator (flap), motor, gearbox reducer, pulley, rod, and frame. Flap type wave maker is characterized by an actuator that is driven by the electric-mechanics systems [17]. The flap of wave maker is hinged on the bottom of the wave tank. The main mover is a servo-motor that turns a pulley equipped with the gearbox reducer to decrease the speed of the pulley rotary. The pulley is connected to the flap actuator through the rod. The latter motion is transferred to the flap through the rod. The design of hinge flap type wave maker can be illustrated in Fig. 1.

2.4 Methods

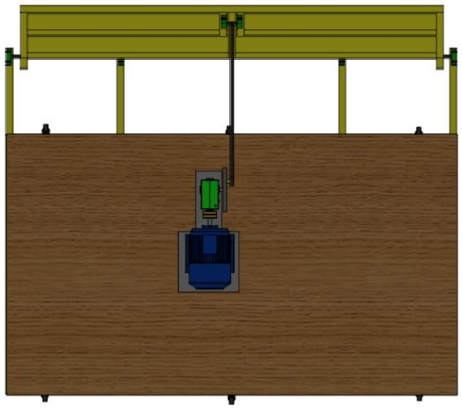
The wave tank dimension has 15 m length, 7.5 m width, and 1 m depth. The dimension of the flap is 2.44 m in width and 1.22 m in height. The dimension of table frame is 2.6 m x 1.5 m x 1 m. The length stroke of the flap is 0.7 m, with a water depth of 0.78 m. Thus, the displaced water volume (V=Shb) is 1.332 m^3, where b is the width of the flap.

Wave maker is designed using motor electricity as the main driver, coupling, gearbox as reducer, pulley, and rod as a connector to the flap. The electro-motor with specification 5 HP and 3 phases is chosen as main mover. In addition, we use gearbox reducer WPA 80 with 1498 rpm to reduce the speed using a ratio of 1:40, yielding 37.45 rpm. The pulley dimension that is connected to the rod is B1-12.

(a)



(b)



(c)

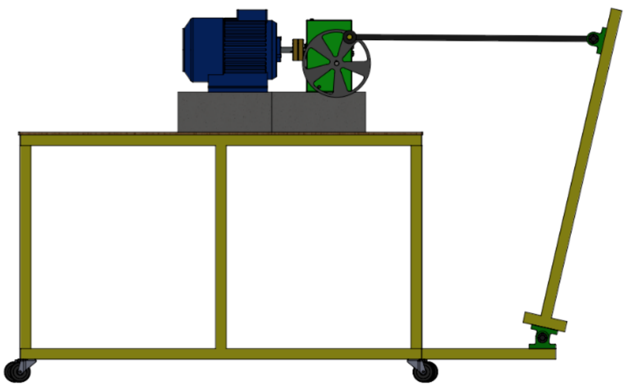


Figure 1. (a) Pictorial view of the first design flap type wave maker; (b)Top view; (c) Side view

There are three designs of wave makers that must be tested to review the performance and behavior of generated waves. The first design has a stroke length (S) of 0.5 m, a pulley diameter of 254 mm, and a speed ratio of 1:40 with 37 rpm. In the second design, the stroke length is 0.5 m and reduce the speed ratio to 1:80 with 19 rpm by using the v-belt-and-pulley of speed reducer with a ratio of 1:2. The third design, we reduce the stroke length (S) from 0.5 m to 0.05 m and change the pulley diameter from 254 mm to 127 mm with 30 rpm.

Three designs of wave maker were tested and will be checked to be evaluated regarding the parameters, which consist of a generated wave, reflection phenomena at both sides, i.e., upstream and downstream, and stability of table frame. Wave height will be measured manually using a conventional meter gauge. The rotation per minute (rpm) will be measured by a tachometer. If the performance of wave maker and behavior of the generated wave is not satisfied, then it will be redesigned to solve the problems.

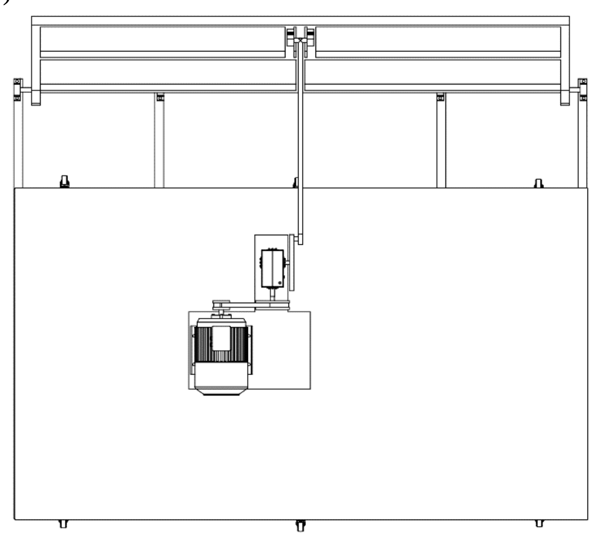
3. RESULT AND ANALYSIS

Figure 2 shows the first type of flap type wave maker after being laid on one side of the longitudinal direction of the wave tank.

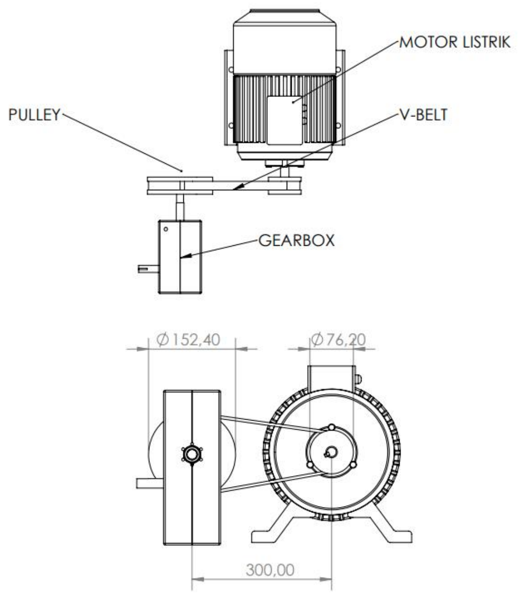
Figure 2. The first type of flap wave maker after being constructed

In a running test of the wave maker, the performance of the first design shows that the wave can be generated successfully. However, the experiment test shows that the table frame is unstable and exhibits float. In addition, the flap movement from backward to forward is too fast for the certain wave tank dimension. Due to the unsatisfaction of the first design, it must be adjusted. Therefore, the second design is modified to overcome some drawbacks. In this case, the parameter that must be modified is the ratio of gearbox reducer from 1: 40 to 1: 80 by adding V-belt-and-pulley of speed reducer with the ratio of 1:2. The modified system of flap wave maker as the second design can be seen in Figure 3.

(a)



(b)



(c)

Figure 3. (a) The second design of flap type wave maker; (b) Gearbox reducer for second design; (c) Second type of flap wave maker after being constructed

The equation below is used to calculate the v-belt length of the gearbox reducer for the second design [18].

$$L = 2C + 1.57\,(D + d) + \pi \frac{(D - d)^2}{4C} \qquad (2)$$

Where L is v-belt length, C is the distance between the two axis, D and d are diameter of gearbox pulley and motor pulley, respectively. If the distance between the two axis (C) is 0.3 m, and D and d are 0.1524 m and 0.0762 m, then the v-belt length is 0.974 mm or 38 in.

The second design examines whether it is working correctly or not by evaluation from similar parameters as mentioned in the previous section. The third design is similar to the first design, but the diameter of the pulley is reduced from 304.8 to 127 mm. Table 1 shows the calculation of the *H/S* ratio to determine the stroke length. The period of wave height is determined based on the RPM.

Table 1. Calculation of H/S ratio based on the wave tank dimension

Parameter	Result
h (m)	0.78
H (m)	0.05
L (m)	6.24
k (m^{-1})	1.00
H/S	2.16
S (m)	0.0231

Table 2 summarize the performance of three designs of wave maker. Qualitative and quantitative parameters must be analyzed to determine the final design.

The quantitative parameters are satisfied from three designs, but the third design has been improved compared to the first and second designs for the qualitative side. The stability of the frame, wave reflection, and generated wave height are satisfying for the third design.

Table 2. The qualitative and quantitative parameters of flap type wave maker performance

Parameters	First design	Second design	Third design
Pulley Reducer diameter (mm)	-	76.2 to152.4	-
Pulley diameter of stroke (mm)	304.8	-	127
RPM	37	19	37
Period (sec)	1.62	3.16	1.62
Wave height (m)	0.07-0.12	0.05-0.07	0.05-0.07
Behavior of generated wave	Not regular/ sinusoidal	Not regular/ sinusoidal	Regular and sinusoidal
Stability of table frame	Not stable	Not stable enough	Stable
Wave reflection	Very strong	Strong	Weak

4. DISCUSSION

Test results demonstrate that the wave maker can generate waves in the wave tank with dimensions of 1 m x 15 m x 7.5 m, where the water depth is 0.78 m. Therefore, the volume of water in the wave tank is 87.75 m^3. The performance from the first design of flap type wave maker has a powerful energy but produces many turbulences around the wave tank, particularly at the table frame. As a result, it causes the instability of the table frame, creating many reflections behind the flap and on the opposite side. Moreover, the dimension of the wave tank is also limited. Therefore, the wave height is also influenced by the wave reflection. These interferences also cause the generated wave cannot mimic the sinusoidal wave smoothly. The instability of the frame is probably affected by the length of the stroke, where the longer the stroke, the more unstable the table frame. Moreover, the wave reflection is influenced by the interference of waves from the two sides of the wave tank. The interference wave is mainly because there is no absorption structure.

The first design then needs to be modified by adding a gearbox pulley with a ratio 1:2 to achieve ratio 1:80. The purpose of adding a gearbox pulley is to reduce the speed of the motor driver to be customized based on the dimensions of the wave tank. The performance is improved, although the stability and reflection have still occurred. The causes of instability and reflection of the second design are similar to the first design.

The third design modified the drawbacks of the first and second design by changing the stroke length based on the equation mentioned in the previous section of material and methods to optimize the wave maker performance. The result from the calculation, as shown in Table 1, shows that the wave maker's stroke length (S) must be around 0.0231 m. Therefore, the pulley diameter must be changed over from 304.8 to 127 mm to achieve the stroke length of 0.0287 m. Nevertheless, after the trial test, the stroke length must be adjusted to 0.05 m to obtain a wave height in the range of 0.05 to 0.08 m.

The performance of the third design shows that the wave maker performed well. There are no disturbances such as wave reflection and the instability of the table frame. Therefore, the wave can be generated smoothly and relatively steady.

Based on the wave tank and wave maker limitation, the scale factor for the physical modeling test ranges from 1:80 to 1: 90, where the wave height can be generated ranging from 0.05-0.08 m with a period of 1.62 s. This kind of scale factor implies that the characteristic of wave propagation can be categorized as a short wave where the period is on the order of seconds [14].

It should be noticed that the wave maker only has a single period and limited wave height, so the dimension pulley diameter must be adjusted to change the period and wave height. The scale factor that can meet the requirement of dynamic similarity to carry out the physical model test ranging from 1: 80 to 1: 90 corresponds to the prototype of 5 m and 15 s for wave height and period in deep water, respectively.

In the future, the wave tank and wave maker at the laboratory of ocean technology will be equipped with the absorption structure to reduce the reflection. In addition, the wave gauge is also needed to measure the wave height. In addition, the floor of the wave tank will be replaced with an inclined form to be more realistic in mimicking wave transformation.

5. CONCLUSIONS

The three designs of the flap type wave maker with hinged at the bottom have been designed, constructed, and tested in the wave tank with the dimensions of 15 m x 7.5 m x 1m. The first design shows quite unsatisfactory with an unstable frame and the interferences from the wave reflection are high despite the wave can be generated. The second design shows improvement but still has many drawbacks. The third design denotes more satisfaction compared to others and is suitable for the dimension of the wave tank. The scale factor for the wave simulation model test is based on the wave tank dimension and wave maker design, ranging from 1:80 to 1: 90.

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