Replication of wave and tidal sedimentation process on coastal Jakarta revealed by a flume tank experimental approach

J J Prayoga and O A Prasojo
Geoscience Study Program, Faculty of Mathematics and Natural Sciences (FMIPA), Universitas Indonesia, Depok 16424, Indonesia

Corresponding author’s email: octria.ad@sci.ui.ac.id

Abstract. The Tidal wave is one of the main factors that producing sedimentary structure and agent of erosion. Study further about it can help for local people living in the coastal area and for academic learning. The tidal wave was replicated using a flume tank. The sand used is fine-grained that taken from Sawarna beach. To obtain the quantitative Digital Elevation Model (DEM) was used. The DEM data were taken using a laser distance meter after the experiment. Reynold's Rule was used for scaling down the variable that happens in nature to the experiment scale. There are 3 significant changes as a result of this experiment. First, the sediment was sorted according to the grain size of the sediment. Second, the slope of the coast has changed which is measured by DEM. Third, the sediment structure was created which has a similarity with the one created by nature. So, the result was a proof that Reynold's scaling down methods can be used to scale down a sedimentary process that happens in nature. This research explains what exactly happens in the formation of a sedimentary structure.

Keyword: Tidal wave, coastal, scaling down, flume tank, sedimentary structure

1. Introduction
Sedimentary structures are important attributes of sedimentary rocks [1]. In Jakarta, tidal wave acts as the main factor producing a certain sedimentary structure such as wave ripple, current ripple and so on [2]. Sedimentation process that is caused by tidal wave occurs every day. This tidal wave has a 12-hour interval from high tide to low tide or vice versa [3].

This tidal wave is not only a factor in forming sedimentary structures but also as a factor in erosion in coastal areas. People who live in coastal areas must aware of this erosion for early mitigation. This research also aims to help in more detailed learning about the process of the formation of sedimentary structures for academic learning of geology majors [4].

This research is important both for academic and local people living in the coastal area. It proposed more detail process of sedimentary structures that are produced by a tidal wave. Based on previous findings, there is an abundant numerical model of tidal processes [5]. But this paper proposed a physical model using a flume tank experiment. The geoscience can learn not just from a book but also from the process how the sediment structures created using experiment with flume tank. Thus, the local people living in a coastal area could hopefully be better managed based on these findings.
2. Data and method

2.1. Experimental setup

First, we initiated preparations to make a flume tank which will be the main tool in this experiment. The first step was to design the flume tank. Flume tank had a size of 3 m × 1 m × 0.5 m. the flume tank could hold a volume of 1500 liters water (figure 1). The flume tank had 4 feet with 70 cm mounted on each corner. On the inlet of the tank, we used an iron plate that had a long hole in the center and on the outlet, on the left and right side we used glass. At the bottom of the flume tank, we used an iron plate that had a 2-inch hole which was intended as an outlet hole from this flume tank. At the corner of the inlet side, there were 2 hydraulic jacks that would be used to make slopes in the flume tank.

After making the flume tank, the next step was to create the outlet and inlet system. The sediment supply and water tank came from different places. This water tank was flowed using a water pump. When the water filling the tank, the sediment supply given to the water. The sediment was filtered in the outlet and the filtered water will flow to the drainage using a water pump.

The sediments that were used characterized as fine-grained sediments taken from Sawarna beach. The size of the d50 sand used was 175.59 μm this is a result of sieve analysis by LEMIGAS company using Laser Particle Size Analyzer. By using beach sand, we expect the result can approach or equal to the sedimentation process that occurs in nature.

In this research, measurements were also taken to obtain quantitative data. This measurement used a laser distance that can produce a Digital Elevation Model (DEM). The DEM data was taken after running the experiment, once after low tide and once after high tide. This was done to see the morphological changes experienced by the sediments. After the experiment, the flume tank was dried to see the layer structure that formed in the sediment.

2.2. Scaling down

Reynold’s rule is the rule used in this scaling down. Reynolds has 3 rule that must be fulfilled. Rule A is tidal velocity and tidal wave height must have the same ratio. The ratio comes from the experiment tidal divided by nature tidal. The Rule A can be written as,

\[
\text{Rule A: } \frac{\text{Tidal Velocity (experiment)}}{\text{Tidal Velocity (nature)}} = \frac{\text{Tidal Wave Height (experiment)}}{\text{Tidal Wave Height (nature)}},
\]

If the rule A condition meets, rule B can be applied. Rule B is the ratio of the tidal period and the ratio of horizontal scale divided by the ratio of velocity must be the same which could be written as follows:

\[
\text{Rule B: } \frac{\text{The Ratio of Horizontal Scale}}{\text{The Ratio of Velocity}} = \frac{\text{Tidal Period (experiment)}}{\text{Tidal Period (nature)}},
\]

Therefore, we can get the experiment tidal period time. Rule C is if rule A and B are fulfilled that the experiment tidal period is already the scaling downtime from nature.

\[
\text{Rule C: Tidal Period (experiment)} = \text{Period of the Model}
\]

The experimental wave height was 0.67 cm provided that the tidal wave height at north Jakarta is 0.25 m (rule A). Secondly, the ratios of the periods would be as the ratio of the horizontal scales divided by the ratios of the velocities [Reynolds 1887–1891]. To meet the rule B, the horizontal scale and tidal period of the experiment needed to be tuned accordingly. Real world tidal period is 43.200 s, and experimental period was 984 seconds. It gave a ratio of 43.200/984 = 43.9, which agreed with the horizontal scale of 1.95/513.6 m divided by the ratio of the velocity of 0.05/0.3 m/s. Reynolds [1887–1891] assimilates that the ratio 1/43.9 provides a time factor that directly translates...
experimental time to real time. In short, the theory of wave motion implies that when the velocity and wave height conditions agree (rule A), the tidal period and horizontal scale to velocity scale ratio of experiment and prototype should agree (rule C) [6]. This wave was made with a wave maker so that the wave frequency was constant. The wave that was created has a wave height of 0.67 cm at low tide (table 1) and 1.7 cm high tide (table 2) with a current speed of 0.08 m/s. the transition from low tide to high tide has an interval of about 16 minutes. It was done to replicate the real tidal on the coast of North Jakarta. By conducting this experiment, it is hoped that a sedimentary structure and a morphological change can be formed on the coast in the flume. The horizontal scale was obtained based on the distance between data retrieval points to the shoreline (figure 2) [7].

![Schematic design of flume tank used in this experiment.](image_url)

**Figure 1.** Schematic design of flume tank used in this experiment.

| Table 1. Scaling down variable used in low tide experiment. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Unit                             | Experiment      | Nature          | Ratio           | Description     |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Tidal velocity                  | m/s             | 0.05            | 0.3             | Rule A          |
| Tidal wave height               | cm/1/2          | 0.67            | 25              | Rule A          |
| Horizontal scale                | m               | 1.95            | 513.6           | 13/3424         |
| Tidal period                    | s               | 984             | 43200           | 1/43.9          |
| The ratio of horizontal scale/the ratio of velocity | | | 1/43.9 | Rule B |
| Period of the model             | s               | 984             |                 | Rule C          |

| Table 2. Scaling down variable used in high tide experiment. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Unit                             | Experiment      | Nature          | Ratio           | Description     |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Tidal velocity                  | m/s             | 0.08            | 0.4             | Rule A          |
| Tidal wave height               | cm/1/2          | 1.7             | 60              | Rule A          |
| Horizontal scale                | m               | 1.95            | 513.6           | 13/3424         |
| Tidal period                    | s               | 984             | 43200           | 1/43.9          |
| The ratio of horizontal scale/the ratio of velocity | | | 1/43.9 | Rule B |
| Period of the model             | s               | 984             |                 | Rule C          |
The nature data was collected by using a boat and went to the location (figure 2) to take the tidal velocity and the horizontal scale. To get the tidal velocity data, we used a current meter; while, to measure the velocity and the horizontal scale data, we used GPS to measure the length from the shore to sampling location. The tidal periods and tidal wave height data was gotten from the government website [2].

3. Results and discussion
This is a 3D DEM model from the coastal in the flume tank. From this model, we can see the coastal contour that was generated by the tidal wave from the experiment. On x-axis, the smaller the value means that the contour is higher and on higher value means the contour are lower. From figure 3, we can see the difference in the contour between when the low tide occurs and when the high tide occurs.

At first, the sediment conditions on the coast were not sorted. After being hit by waves from the sea, the sediment begins to be sorted. This morphological change can be seen by the presence of black sediments that were gathered on the beach after running (figure 4). It happens because the black sediment has a finer grain size compared to other grain. This can be known after making further observations using a microscope on sediment used in the experiment (figure 5). Because of that, the black sediments are looked like closer to the beach while the cream or white colored sediments are more towards the sea.

This proves that the waves in the coastal area help to sort the grains where finer grains with lower settling velocity, are transported farthest and sorted near the coastline. Otherwise, larger grain sizes with greater settling velocity, are transported closest to the source of the sedimentation process (wave) and sorted below the smaller grain size.

On the other hand, changes in slope can also be observed from this study. From the results of the two DEMs and photos of this experiment, it can be observed that the occurrence of waves, which was followed by tide, was able to transport sediment grains near the coast. This can be used as a concern for local people living on the coast, not to live in areas that are directly affected by the tide process. The tide process that occurred caused a significant change in the coastline. On the north coast of Jakarta, the tidal process that changes the coastline around 0.5 m is represented by a 2 cm coastal change in the flume tank (figure 4).

After the flume tank has been dried, the sediment structure on the beach can be seen. Sediment structures can be seen with methods like open pit method which are usually done to see the layering.

![Figure 2. Horizontal scale in the real world.](image)
structure in nature. This structure type is cross-lamination. Layering structures on the flume tanks have similarities to the coating structures formed in nature. These two layers have crossed layers (figure 6). Process-based understanding of a sedimentary structure is important for all. Geoscience students who usually observe the product from the sedimentation process from an outcrop can now observe it in a laboratory scale and in real time.

![Figure 3. (a) Low tide and (b) high tide 3D models of DEM.](image)

![Figure 4. The condition on the coast in the flume tank (a) before the experiment and (b) after the experiment.](image)
Reynold scaling down methods can be used to scale down the sedimentation process that comes from waves and tides. This is proven by the similarity of structure, geometry, and sorting produced on the flume tank scale with nature. In the future, the possibility of Reynold scaling down methods can be tried to be applied to scaling down other sedimentation processes.

4. Conclusion

In the coastal area of Flume Tank, there was a significant change. The first thing that was seen was the sediment in the flume tank was sorted, there was black sediment gathered on the coast. The coastline moves to the mainland as far as 2 cm when high tide occurs. The slope in the coastal area also changes when high tide and low tide occurs. At the time of high tide, there is a ripple structure formed because the sand eroded by the waves is deposited in the place. The sedimentary structure is well formed in the flume tank. This structure is very similar to that formed in nature. This experiment is carried out according to Reynolds scaling down so that the results of the experiment can approach the situation in nature.

Tidal waves are one of the main factors forming sedimentary structures on the coast of Jakarta. By learning more details about the process of formation, we become more understanding of the processes that occur in nature. By using a flume tank experiment, we can scale down what was formed in nature into the time of the experiment. So that we can replicate better and get the same results as those in nature.
The coastline moves 2 cm in flume tank it's equal to 5.27 m in nature. If it's happening in nature it can be a dangerous situation for coastal. This sea level rises can trigger the erosion and abrasion on the coastal area. People must aware of this.

Sedimentary structures on the beach can be formed with the help of waves and tides that occur every day. This can be proven in this study. The results of this study show that a cross-lamination structure will be formed on the beach during high tide and low tide. The waves can also sort the sediments carried by them according to the size of the sediment grains.

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