# STABILITY OF SAND TUBE SEAWALL AS A TSUNAMI PROTECTION

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## ABSTRACT

Tsunami height cannot be predicted accurately. When under predicted, tsunami may overtop a tsunami wall that is aimed at mitigating the disaster. The consequence is huge especially when the wall collapse. A lesson learned from the East Japan tsunami in 2011 should be considered seriously to improve the way of protecting the coastal area from tsunami disaster. Large concrete seawalls along the coast have been partly destroyed by the tsunami. The seawall failures modes were drifted away or overturned due to heavy scours behind the seawall. Concrete seawall is expensive as well as unnatural which sometime does not go with the environment or landscape. Model of sand tubes wall is proposed for tsunami mitigation. The wall is constructed using fabric-tubes filled with sand. In area where the coast is sandy, it should not be difficult to find such material for the construction. Physical model was used to study the performance of the sand tube sea wall against tsunami. The height of the wall was varied. The tubes were placed in layers to create sand tube walls of trapezoidal shape. The sand-tube walls were than tested under tsunami attack in the Hydraulic Laboratory of Department of Civil and Environmental Engineering Universitas Gadjah Mada. The tsunami hydrograph model was set to represent a type of hydrograph recorded during the East Japan Tsunami. The results showed that sand tube seawall with sufficient sizes can be used as a tsunami protection. Sufficient protection is required to avoid scour at the rear toe of the wall.

*Keywords*: sand tube, seawall, tsunami, stability, protection, mitigation

## 1. INTRODUCTION

Indonesia has been hit by a number of tsunamis recently. In 2018, there were two tsunamis small to medium sizes that hit Indonesia in Palu and Sunda Strait. These tsunamis underlined that tsunami hazard may happen any time and at any location prone to tsunami in Indonesia. The inundation and run-up height of both tsunami events were about 2 to 9 m (Mikami et al. 2019, Mira et al. 2019, and Putra et al. 2020). Recently, Indonesia developed a medium size international airport close to the south beach of Java Island. In fact, the distance of the runway that is almost parallel to the shoreline is approximately 100 m. The beach is prone to a giant tsunami attack as it lies approximately 275 km to the north of subduction zone between the Indo-Australian plate and Euroasian plate, the same plates by which the gigantic tsunami of Aceh was generated. When a large tsunami is generated at this subduction zone, the south Java beach including the area of the New Yogyakarta International Airport will undoubtedly be swept by the tsunami resulting in a significant disaster.

Tsunami mitigation to reduce the impact of the tsunami is necessary. This can be done by seawall construction along the beach. The seawall should be high enough to assure that the tsunami cannot overtop the wall. Overtopping tsunami may create two problems. First it may still endanger the protected beach area and second, it may also scour the foundation of the wall. Tsunami overflowed seawall that was dedicated for tsunami protection during East Japan Tsunami in 2011. A large portion of the tsunami wall protection was failed and resulting in a disaster at the area under protection (Kato et al. 2012, Mikami et al. 2012, Suppasri et al. 2013, Kazama and Noda 2012). The wall failure was due to a number of reasons including the scouring behind the seawall followed by seawall failure (Jayaratne et al. 2016, .Kato et al. 2012, Sato and Okuma 2014).

The construction of tsunami wall is very expensive especially when large tsunami is not allowed to overtop. Secondly, the wall is also unnatural which sometime does not go with the environment or landscape. A new seawall type is proposed to reduce the cost of the wall and to make it more natural by using sand bags mounds. The sand bags are installed in layers to create a trapezoidal cross section along the protected area. A model was constructed in a hydraulic laboratory and was tested against tsunami. The model was used to observe the stability of the seawall.

## 2. THEORETICAL BACKGROUNDS

When tsunami arrives at the seawall, it will exert an impact force especially when the seawall is vertical. When the seawall is sloping, the tsunami force on the seawall reduces as tsunami may run-up on the seawall surface. For a sloping seawall therefore, the impact force is not the main concern related to seawall stability. The second force of tsunami on the seawall is the hydrostatic force. As a tsunami fully arrives at the seawall, water level is increasing and may or may not overtop the seawall. The hydrostatic force on the seawall is quite large and should be withstood by the seawall. A massive seawall constructed using sand bag should be able to resist such force due to its gravitational force and resistance on each layer and foundation. Therefore it is important to make sure that each layer of the sand bags has the strength to withstand such force. The hydrostatic force of the tsunami is discussed below.

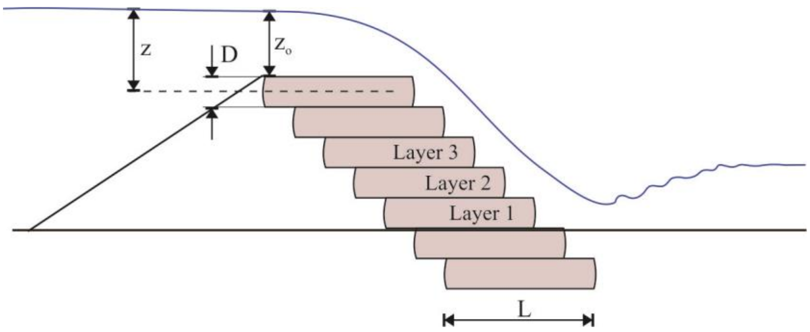


Figure 1. Cross section of a sand tube seawall model

For the stability computation, the effect of upstream sand or rubble is neglected assuming that the material in front of the sand tubes is already fully saturated and that the reduction of the hydrostatic pressure along the upstream sand is small. For safety reason, the hydrostatic pressure of the downstream water may also be neglected. The stability of the top layer tubes can be expressed by Equation 1.

$$S = \frac{f(\rho_s - \rho)gD^2L}{\rho g z D^2} \tag{1}$$

Simplifying Equation 1, yields Equation 2.

$$S = \frac{f(\rho_s - \rho)L}{\rho z} = \frac{f\Delta L}{z} \tag{2}$$

Where $S$ is the safety factor, $f$ is the frictional coefficient, $\rho_s$ is the density of the sand, $\rho$ is the density of the water, $D$ is the diameter of the tube, $L$ is the length of the tube, $z$ is the vertical distance from the center of the tube to the water surface and $\Delta = \frac{\rho_s - \rho}{\rho}$. Since $f$ and $\Delta$ are almost constant, the stability of the tube is determined largely by the ratio between $L$ and $z$. In order to increase the safety factor, each layer is placed partly on top of each other. The safety factor $S$ for a layer underneath other layers can be written as in Equation 3 which can be simplified further to yield Equation 4.

$$S = \frac{f(\rho_s - \rho)(1 + (1 - x) + (1 - 2x) + (1 - 3x) + \cdots + (1 - nx))L}{\rho z} \tag{3}$$

$$S = \frac{f\frac{(n+1)}{2}(\rho_s - \rho)(2 - nx)L}{\rho z} \tag{4}$$

Where $x$ is less than 1. The value of (1-$x$) represents part of the tube that is placed on top of the other and, $n$ is the number of layers on top of the layer in consideration. When $0.5 \leq x < 1$, it means that a half or less of the tube is placed on top of the other tube. In this case the maximum number of the tube layers that can be considered providing additional weight is 1 layer. The number of layers on top of Layer 1 and Layer 2 (directly on top of Layer 1) shown in Figure 1, are $n$ = 4 and $n$ = 3 respectively, while for Layer 3, $n$ =2.

In order to stop the water from flowing in between the sand tubes, it is necessary to block the entire front face of the sand tubes with an impermeable material such as clay. This material transfers the hydrostatic force onto the tubes. Hence, in such a case, the hydrostatic force acts on the entire sand tubes and that the sand tubes work together to resist the hydrostatic force by the frictional force at the bottom of the tubes. For such condition Equation 4 is modified to yield Equation 5.

$$S = \frac{f\frac{(n+1)}{2}(\rho_s - \rho)(2 - nx)AL}{\rho z D^2} \tag{5}$$

For simplicity, the area of the sand tubes cross section ($A$) is assumed equal to an area of a circle with diameter $D$. Hence Equation 5 can be rewritten as Equation 6.

$$S = \frac{\pi}{4}\frac{f\frac{(n+1)}{2}(\rho_s - \rho)(2 - nx)L}{\rho z} \tag{6}$$

A drag test was conducted for the tube to find out the friction coefficient. It was found that $f$ depends largely on surface bottom. In this study the bottom surface was made of rough coconut fiber mat which yield a high friction factor. In reality the friction coefficient depends on the bottom surface of the foundation.

## 3. MATERIAL, METHODS AND EXPERIMENT

The size of the sand tubes to be used is 4 cm in diameter and 20 cm long. The sand tubes were filled with sand with average weight of 400 gram each. The porosity of the sand is approximately 45% with bulk density underwater $\rho$ = 2.17 kg/cm$^3$.

### 3.1 Friction test

The friction coefficient of the model was tested using a simple method. The sand tube model was placed on a horizontal surface of sand. One end of the tube was connected to a nylon string which can be pulled by a weight through a smooth stainless steel smeared with lubricant to assure insignificant resistance as shown in Figure 2. The weight was increased starting from very small and stopped when the tube was moved. The weight when the sand tube start moving was the horizontal force that was used to calculate the friction coefficient of the sand tube. A number of pull tests were conducted to find an average of frictional coefficient for the sand tubes. It was found that the friction coefficient on a wet mat was 1.08.

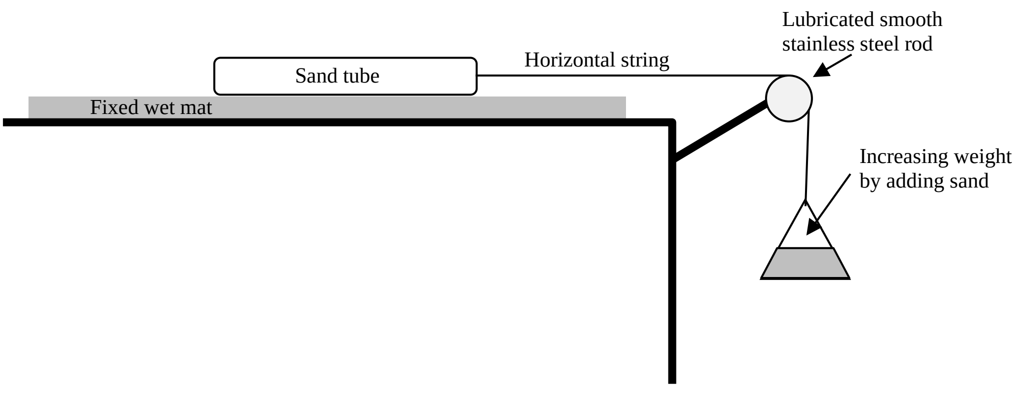


Figure 2. Scheme of sand tube model friction coefficient test

### 3.2 Sand tubes seawall stability test

The sand tubes were placed in the flume to form a seawall. The layout of the sand tubes is given in Figure 3. In front (upstream) of the tubes is mound of gravel of 2-3 cm diameter. However, in reality, the gravel may be placed only at the outer part of the seawall that protect the sand dunes from erosion. In this model the gravel represents the extreme condition when the upstream material has been fully saturated where the pressure at the sand tubes can be assumed equal to the upstream hydrostatic pressure. The upstream and downstream slopes of the gravel were 1:1.

In order to minimized the water from upstream through the gravel and the sand tubes, the upstream part of the sand tubes was sealed. The seal represent clay component just upstream of the sand tubes.

During the test, the water levels upstream and downstream of the seawall were observed. The downstream water level was kept small to make the condition of the stability test severe. The tsunami height was started small and was increased until the seawall failed. The number of the layers was also varied. After each test and when the model was stable, the next test was carried out. When the seawall model failed, the model was reconstructed for the next test.

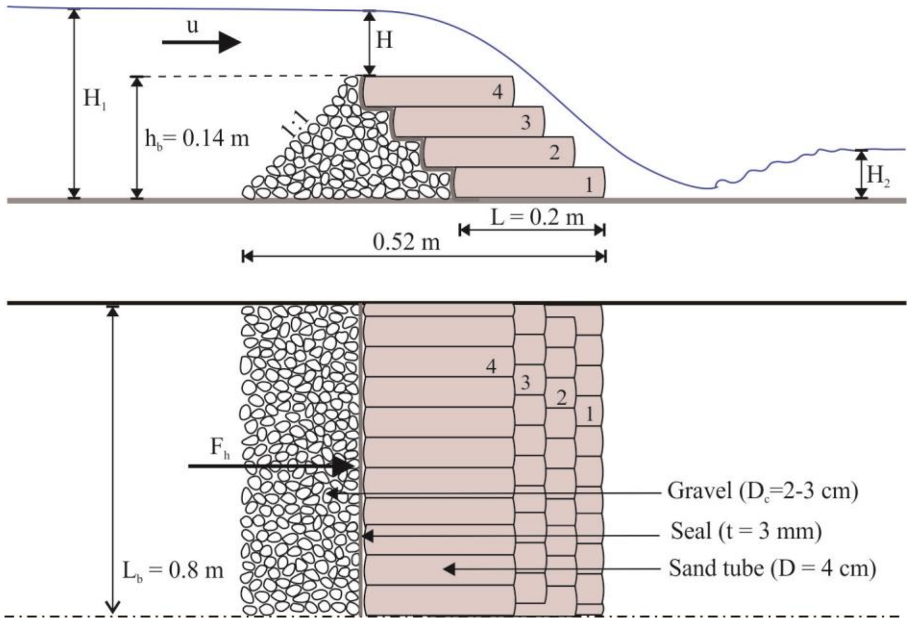


Figure 3. Model set up

## 4. RESULTS AND DISCUSSION

### 4.1 Tsunami hydrograph

The water surface in front of the seawall were measured during the experiment. Figure 3 shows the tsunami hydrograph model in front of the seawall. Variations of tsunami hydrographs can be generated by modifying the opening and closing time of the valve and also varying the initial water level at the overhead tank. Further detail of such method can be found in Warniyati et al. (2019).

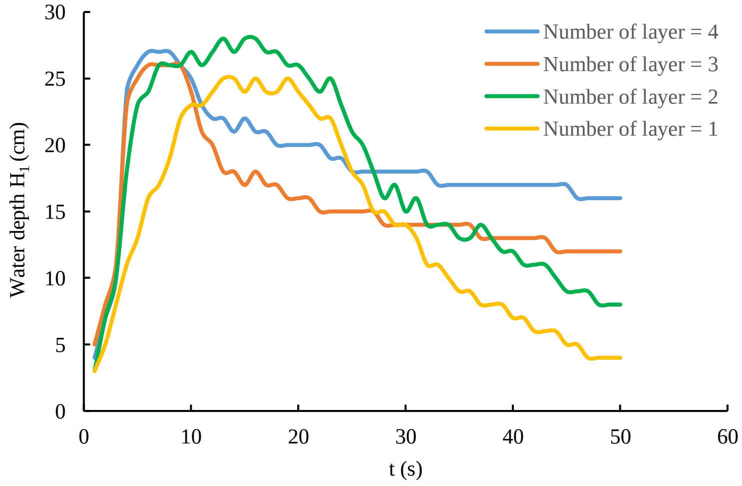


Figure 4. Tsunami hydrograph model in front of the sand tube seawall

The results of the tests are given in Table 1. As can be seen in the table that the sand bags were stable even after the inundation height was higher than the seawall where the tsunami overflows the crest of the seawall. The safety factor (the ratio between the resistance force and the calculated hydrostatic pressure) indicates that the seawall stable when it is higher than unity. As this ratio was close to unity when the seawall collapsed, indicates that the hydrostatic pressure can be used as an indication of whether the sand tube seawall is stable.

### 4.2 Seawall stability

The experiment indicated that the seawall destabilizing force was caused mainly by hydrostatic force. This was indicated by the fact that the seawall destabilization was started by the movement of the sand tubes away from the rubble mound. After that, as the shape of the seawall was not properly aligned, and the seal between the sand tubes has been disintegrated due to the movement, the sand tubes start to be displaced from their positions relative to the other and finally the whole seawall collapse. The initial failure condition of sand tubes seawall during the experiment are shown in Figure 5.

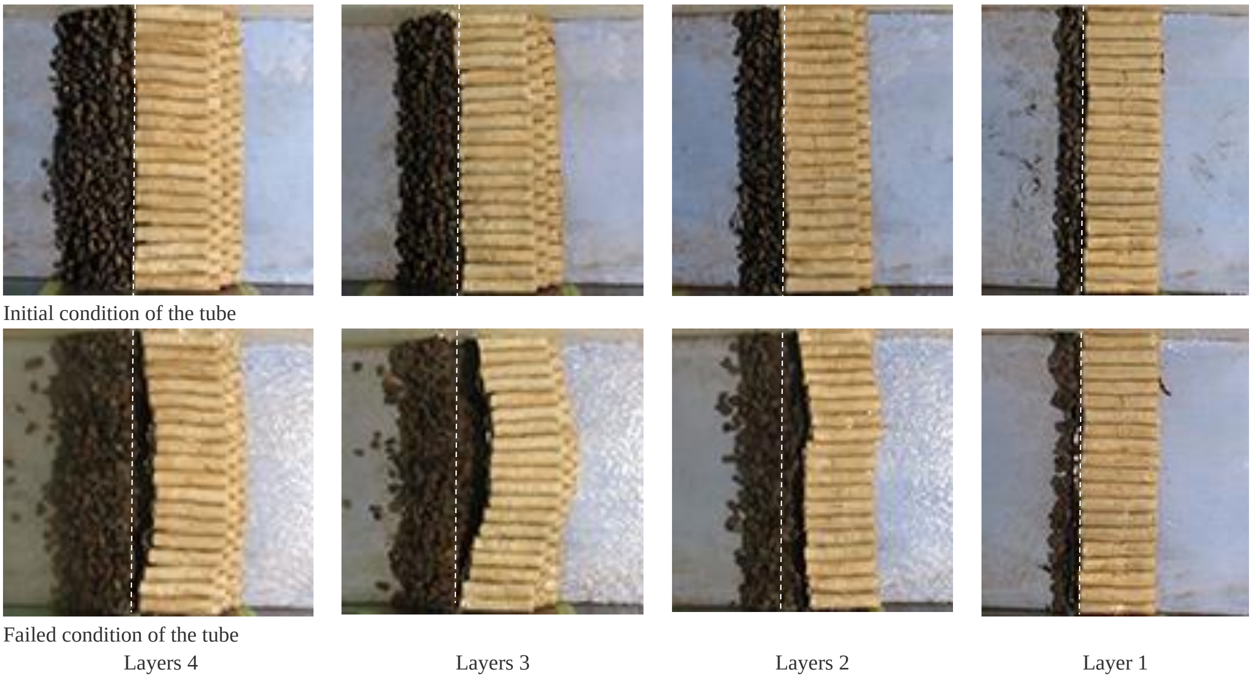


Figure 5. Top view of the initial conditions (top row) and initial failure conditions (bottom row) of the sand tubes (no failure happen to the Layer 1 sand tubes seawall)

Table 1 shows the final conditions of the seawall at different tsunami sizes. In the table, the seawall heights and the water depths were measured while, the hydrostatic force, the stabilizing force and the safety factors were calculated based on the experimental data. The hydrostatic forces were calculated based on the water upstream and downstream of the seawall. The sand tube condition was based on the observation.

As can be seen in the table, the safety factors are close or under 1.0 when the seawall failed. This indicates that as mentioned previously the model stability depend largely on the hydrostatic force and the resistance force due to gravity. Actually, there are other destabilizing forces such as shear force that applies at the top of the seawall but, this seem to be relatively small. It is worth to show the results in a non-dimensional graphic as given in Figure 6.

Table 1. The condition of the seawall model under tsunami attack

| Number of layers | Seawall height | Water depth (m) | | Hydrostatic Force | Stabilizing Force | Safety factor | Sand tube condition |
|---|---|---|---|---|---|---|---|
| | $h_b$ (m) | $H_1$ | $H_2$ | (N) | (N) | | |
| 4 | 0.137 | 0.25 | 0.03 | 197.53 | 194.50 | 0.98 | Stable |
| | 0.137 | 0.27 | 0.04 | 216.76 | 194.50 | 0.90 | **Failed** |
| 3 | 0.11 | 0.25 | 0.05 | 158.53 | 166.72 | 1.05 | Stable |
| | 0.11 | 0.26 | 0.05 | 167.16 | 166.72 | 1.00 | **Failed** |
| 2 | 0.075 | 0.27 | 0.08 | 111.74 | 125.04 | 1.12 | Stable |
| | 0.075 | 0.28 | 0.08 | 117.62 | 125.04 | 1.06 | **Failed** |
| 1 | 0.04 | 0.25 | 0.12 | 90.25 | 115.57 | 1.28 | Stable |

Figure 6 clearly indicates that the safety factors are close to unity when the seawall is failed. So far, it can be seen that the whole sand tubes stability depends largely on the hydrostatics. This is so because, each of the tube is stable in its positions resisting the hydrostatics and hydrodynamic force. The individual sand tube can be made interlocked with the surrounding sand tubes to assure that they work together for better stability.

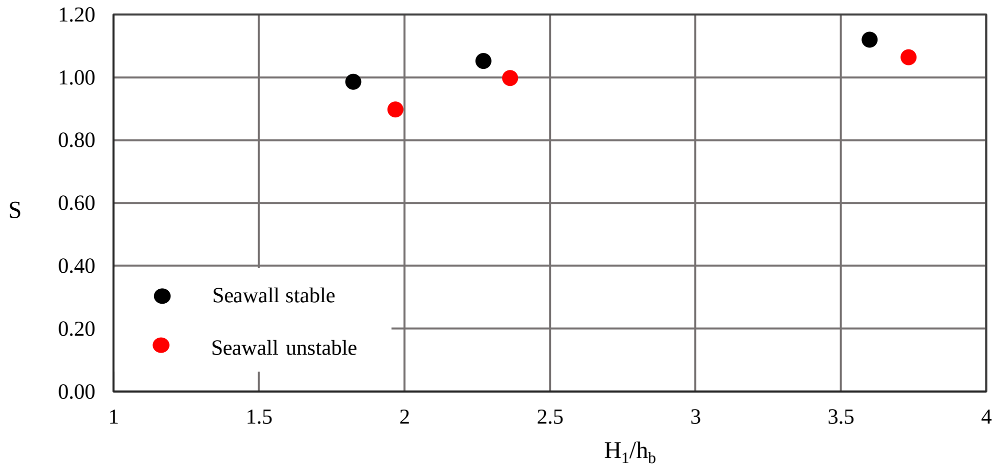


Figure 6. Safety factor of seawall against tsunami attack as calculated based on simulation

It seems that the effect of the downstream water depth become more significant at lower seawall height where $H_1/h_b$ becomes larger. In reality, the downstream depth should be much lower compared to the upstream depth.

### 4.3 Seawall material

In the model, during the experiment, the sand tube was made of loose sand that was filled into a fabric to create a tube of 4 cm in diameter. This technique can also be done in the field by pumping the sand into a similar sand tube. Although sand tube is relatively fast and easy to make, the fabric of the tube may deteriorate in relatively short time. In order to overcome such shortcoming, the sand may be mixed with cement mortar as filler. When the fabric is destroyed by the weather and environment, the concrete can withstand for much longer time.

### 4.4 Scouring underneath the toe of the seawall

Scouring underneath the toe of the seawall may happened during tsunami overflow. The scour depth depends on a number of variables. This phenomenon has not been dealt with in this research. To anticipate such scouring, additional sand tubes can be installed underneath Layer 1 as a foundation as shown in Figure 1. The depth of the additional layers of sand tubes should be slightly more than the expected scour depth.

## 5. CONCLUSION

Sand tubes wall created by placing sand tubes horizontally one over another may be used to withstand tsunami. The stability of the tubes is largely depending on the hydrostatic force when no water is allowed to flow in between the tubes. A minimum safety factor against hydrostatic force of 1.15 is required to assure that the sand tube seawall stable. However, in a real design, much larger safety factor for example 2.0 or 3.0 is recommended. The size of the individual tubes that are placed on the top of the seawall should be able to withstand tsunami. Further study on the suitable filling material should be conducted.

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