THE EFFECT OF LARGE DEBRIS DAMMING ON SCOUR BEHIND A SEAWALL DUE TO TSUNAMI

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ABSTRACT

Debris damming can happen when the debris stuck on buildings or trees. The damming causes many problems such as an increase of the tsunami force on the buildings or the trees and an increase of the scour around the buildings or the trees. When large debris such as ship is stuck on a seawall that is aimed at tsunami protection, part of the water flow sideways of the debris. Such condition may affect the intensity of the flow on both sides of the debris while on the other hand change the scour capacity of the water behind the seawall. It is expected that the scour depth at exactly behind the debris reduces but, the scour behind both sides of the debris increase. Such conditions are important to be considered when designing a seawall for tsunami protection. A model of a seawall was constructed in a hydraulic laboratory. Tsunami attack on the seawall was simulated both with and without debris. The bed material was made of medium to coarse gravel. The scour behind the seawall was measured after each simulation. The tsunami flow was simulated based on the tsunami hydrograph recorded during the East Japan Tsunami in 2011. A variation of flows, debris sizes, seawall heights and the bed material were employed to study the effect of the debris damming on the scour more fully. The experiment showed that the scour behind the seawall due to tsunami without debris was significantly different to those with debris. As expected, more significant difference of scour depth was observed for larger debris size. The scour are deeper and longer at both sides of the debris. The increase of scour depths are 54%, 43% and 10% for debris length to seawall height ratio (l_d/h_b) equals 1.0, 0.66 and 0,33, while the maximum scour length increase are 17%, 14%, and 8%. The flow discharge over the wall, the wall height and the material are also found to be important variables to be considered in the design of seawall as tsunami protection.

Keywords: debris, tsunami, scour

1. INTRODUCTION

Over the past several decades after the Indian Ocean tsunami 2004 and several tsunamis events such as Chili 2010, Japan 2011, Palu 2018 and the last Sunda Strait 2019, many researches have been conducted to investigate the behavior of tsunami and the effect to the coastal area and structures (Mikami et al. 2019, Tanaka and Sato 2015, Tanaka et al. 2012, Putra et al. 2020, Robertson et al. 2013, Omira et al. 2019, Ye et al. 2020).

During the tsunami event, debris may be dragged by tsunami both propagating from the ocean and tsunami drawdown from the land. Naito et al. (2014) state that based on four quantitative characteristics: mass, stiffness, size, and buoyancy, debris in coastal regions were categorized into small, moderate, and large debris. An example of large debris is a huge tanker that was dragged towards the land and grounded at Kamaishi Port (Sozdinler et al. 2015). Tsunami-driven debris can be stuck on structures and lead to decreased capacity of the structures in resistance of sliding and overturning (Yeh et al. 2014). The magnitude of impact force on the structure is a linearly corelated with the impact velocity (Ko et al. 2015, Riggs et al. 2014). Yeh et al. (2014) state that the debris damming will increase the cross-section area and linearly increase the hydrodynamic force.

A ship and shipping container is the most possible large debris dragged by the tsunami from the ocean and stuck at a seawall protection, especially in a harbor area. When the tsunami height is over the seawall protection, the overflow may cause scour behind the seawall. Scour behind of a seawall was the main cause of seawall collapse due to tsunami overflow in Japan 2011 (Kato et al. 2012). Scour profile behind the seawall is changing during the tsunami overflow because of overflow discharge variation (Warniyati et al. 2019, Tsujimoto et al. 2014). The scour growth may be affected by the large debris which stuck at the seawall. At that condition, the aspect of debris impact may be considered on the design of tsunami protection. The objective of the experiment is to explain the influence of large debris damming on the scour behind the seawall due to tsunami overflow.

2. EXPERIMENTAL METHODS

The experiment was conducted in a flume of 9.2 m length, 0.8 m width and 2 m height. The tsunami wave was generated based on control discharge from a reservoir into the flume. A seawall model was placed in the middle of the flume, gravels were placed behind the seawall model as a movable bed. The seawall model height at the upstream (h_s) was 0.16 m, the movable bed was 0.30 m below the seawall crest. In this case, the seawall height (h_b) is 0.30 m. Various width (l_d) of large debris model was placed (fixed) in the center of seawall length. Two cameras were placed at the side and the top of the model to observe the scouring process. The schematic of the experimental setup is illustrated in Figure 1 and the schematic of the symbol is illustrated in Figure 2.

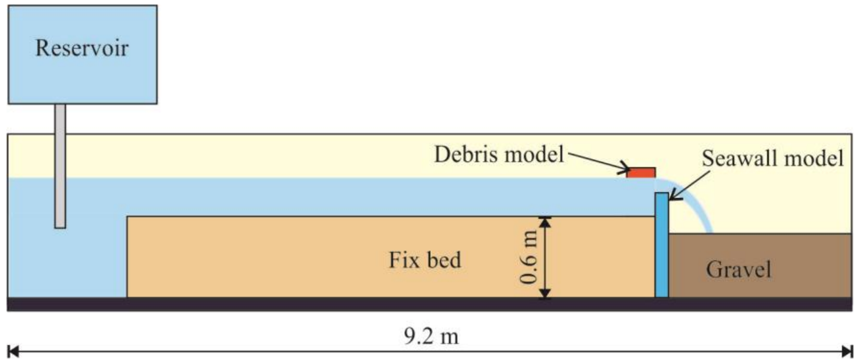

Figure 1. Experiment setup

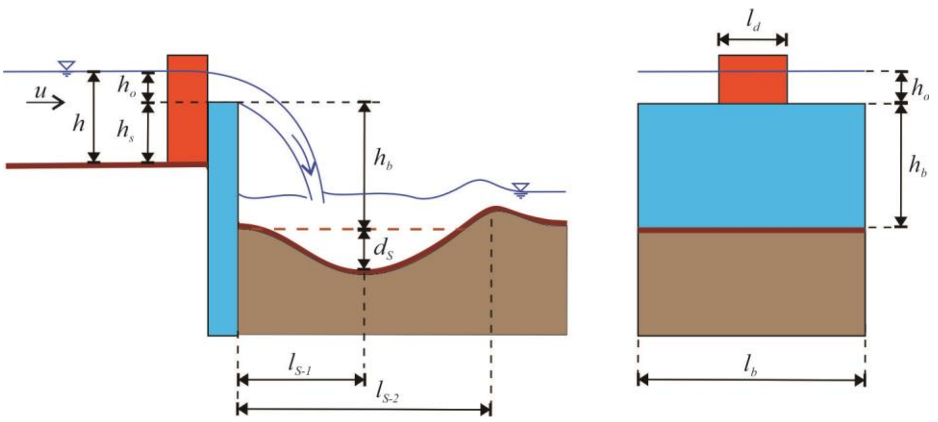

Figure 2. Shematic of symbol definition

By opening the gate valve at the pipe system, volume of water is released from the reservoir to generate tsunami model in the flume. In the beginning, the water was blocked by the debris and seawall model and then the water level rise-up and overflow. The overflow induced scouring behind the seawall model. Gravels of 0.025 m in diameter with density of 2,500 kg/m^3 was placed behind the seawall as a mitigation effort to reduce scour depth. The positions and orientation of the large debris was locked at the center of the seawall width (l_b) to avoid the movement of the model during the experiment. Both the maximum depth (d_s) and the maximum length (l_{s-2}) of the scour were measured at the end of the model tests. The scour depth was measured along the seawall every 2.5 cm at the maximum scour position (l_{s-1}).

3. Results and Discussion

3.1 Tsunami overflow

The tsunami flow was simulated based on the tsunami hydrograph recorded during the East Japan Tsunami in 2011 (Fritz et al. 2012). The tsunami in the experiment was based on control discharge into the flume which is represented using tsunami hydrograph in Figure 3. The tsunami hydrograph was generated by controlling the discharge from the reservoir into the flume to simulate the scour due to the tsunami overflow. The overflow induced vortex at behind the seawall that lifted the material and transported downstream. This hydrodynamic process caused scour behind the seawall.

When large debris such as a ship is stuck on a seawall that is used for tsunami protection, part of the water will flow sideways of the debris. Such condition may affect the intensity of the flow on both sides of the debris and ultimately change the scour capacity of the water behind the seawall. The flow sideway the debris on this experiment is presented in Figure 4. As the flow was diverted by the debris the overflow energy was reduced at that location. This condition may increase the energy at the outer side of the debris area and affected the scour process.

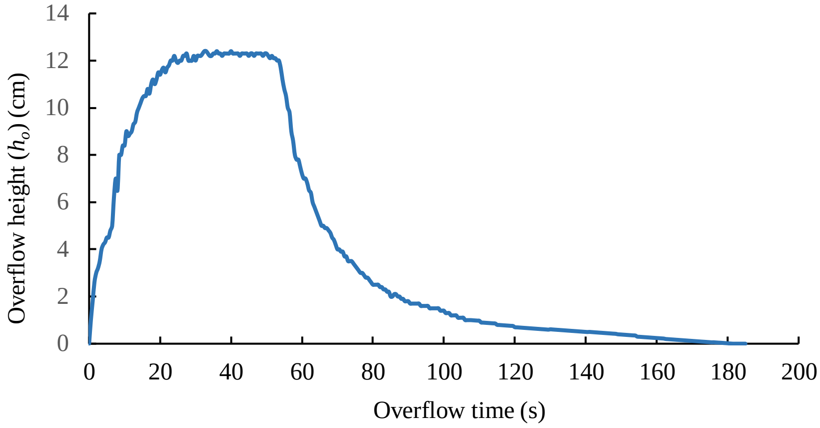

Figure 3. Tsunami hydrograph

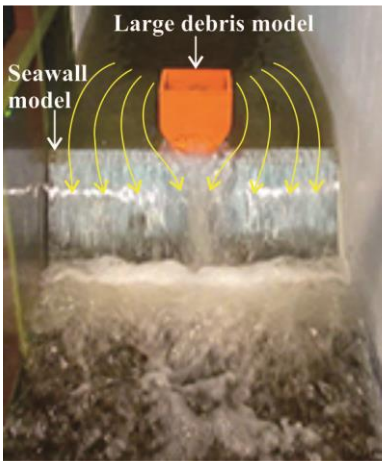

Figure 4. Tsunami Overflow

3.2 Scour patern

Scour behind of a seawall may disturb the stability of the seawall and subsequently cause the seawall to collapse (Jayaratne et al. 2016). The scour behind a seawall becomes complicated when large debris stuck and the tsunami flow is disturbed. When the large debris stuck at the seawall, part of the tsunami flows sideway the debris. The condition affected the scouring process behind the seawall. The experiment result shows that scour behind the seawall where the debris stuck is shallower than the side part. Figure 5(a) is the initial condition of gravel when the energy of tsunami overflow not enough yet to remove the gravel. Figure 5(b) show the scour condition when the overflow is decreased and the scour hole unchanged. Figure 5(c) show the final condition of the scour process. As can be seen in Figure 5, the scour depth at the debris location is lower and shorter than the side part. A puddle seen on the left and right sides of the stuck debris.

(a) Initial condition (b) At process (c) Final scour condition

Figure 5. Scour patern behind the seawall due to large debris damming

In this experiment, various debris length (l_d) are used, these are 10 cm, 20 cm, and 30 cm. At the end of each simulation, the scour depth and scour length were measured. The scour profile is presented in Figure 6, positive x-axis is the relative distance from the center of debris to the right side and negative x-axis is the opposite, the y-axis is the relative scour depth. The scour depth at the debris location and the edge of the seawall (wall of flume) is significantly different. When the debris length is the same as the seawall height (l_d/h_b = 1) and l_d/h_b = 0.66 the differences are about 54% and 43 % respectively. When ld/hb= 0.33 the scour depth is not significantly differenced that is 10%.

By comparing the scour depth at the center of seawall on the condition without debris and with debris, the reduction of scour depth are 47%, 36%, and 5% when the ratio of debris length to seawall height (l_d/h_b) are 1.0, 0.66, and 0.33 respectively. The reduction of scour depth is caused by the reduction of overflow energy as can be seen in Figure 6. The opposite condition is happening in the wall, the scrour increase for about 15%, 12% and 5% when l_d/h_b are 1.0, 0.66, and 0.33 respectively. The higher the ratio of debris length to seawall height, is the higher the difference scour depth. Large size material (gravel) is using for the scour material. When the fine aggregate is applied, the difference in scour depth is higher certainly. The scour depth is depending on material size and seawall height (Jayaratne et al. 2014).

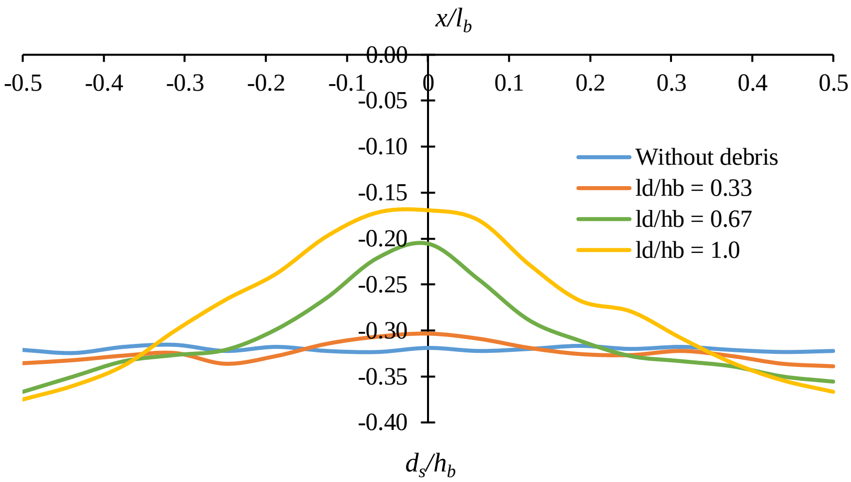

Figure 6. Scour profile cross along the seawall

The relative scour length along the seawall show in Figure 7. As occurred on the scour depth, the scour length is different along the seawall. The debris causes the difference in scour length at the debris location with the far away from the debris. The differences are about 17%, 14% and 8% for the debris length that was tested.

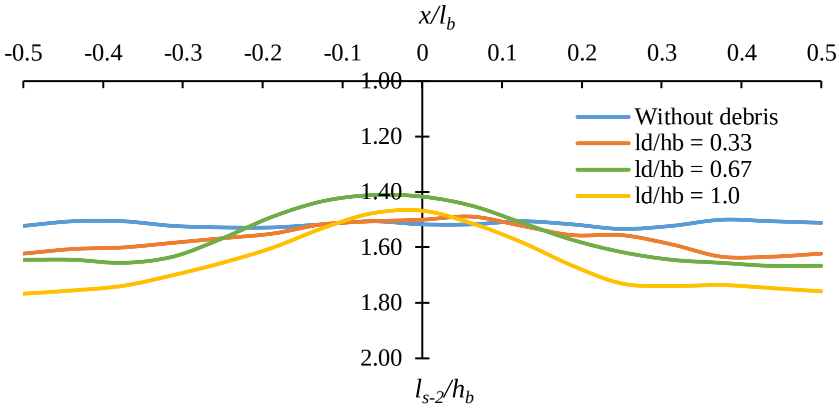

Figure 7. Relative maximum scour length

In this experiment, the boundary condition of the seawall length/flume width is important to be considered. The influence of the debris to the scour depth along the seawall could not be observed well because of the limitation of the flume width. When the flume is wide enough, the maximum area affected by the debris may be clearly observed.

As can be seen in Figure 3, the maximum overflow (h_o) at the above seawall model is about 12 cm, the ratio of debris length to overflow height (l_d/ h_o) are 0.83, 1.67 and 2.5. The height ratio l_d/ h_o induce serious water flow disturbance. The water discharge sideway the debris is higher, hence the scour at the side part debris is deeper certainly. This condition may endanger the stability of seawall around the debris and the whole of the seawall as the tsunami protection. On the design of seawall that is aimed at tsunami protection, it is should be concerned about the possibility the stuck of large debris.

4. Conclusion

Based on the results and discussion, the following conclusions can be drawn:

1. Debris damming and stuck at the seawall cause different the scour profile behind the seawall, the scour is deeper and longer at the far away location of the stuck debris. The differences of scour depth are 54%, 43% and 10% for the ratio of debris length to seawall height (l_d/h_b) 1.0, 0.66 and 0,33, while the maximum scour length differences are 17%, 14%, and 8%.
2. The possibility of debris stuck at the seawall should be considered when designing a seawall as a tsunami protection.
3. This research is a preliminary study of scour behind the seawall due to tsunami overflow with large debris damming. In the future, other scenarios research will be conducted.

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