# TSUNAMI FORCE ON BRIDGE MODELS AND FORCE REDUCTIONS BY MANGROVE MODELS

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**ABSTRACT :**

The fourth largest earthquake in the world since 1900 has happened on December 26, 2004, at 00:58:53 UTC (or 07:58:53 local time), off the west coast of Northern Sumatra, Indonesia. In a quick response to the disaster, a Japanese group of researchers led by the second author departed to Banda Aceh and surrounding areas in an attempt to study the lessons. One of the bridges surveyed was Ulee Lheue Bridge in Banda Aceh, Indonesia. The bridge is still functioning although some damages were clearly spotted. The bridge is located close to the coast where the tsunami height was estimated as 12 meter. The bridge was survived but displaced 35 cm to the upstream direction. Other bridges surveyed in nearby areas showed similar damages or being washed away. In order to understand the tsunami force on bridges, experimental tests were carried out to measure the hydrodynamic force. The effect of mangrove models to the force reduction was also studied. The parameters were mangrove's flexibility, height, thickness, and density. One results show that mangroves are effective in reducing tsunami force when the height is more than the tsunami flow height.

**KEYWORDS:** Tsunami, hydrodynamic force, mangroves, bridge

## 1. INTRODUCTION

The fourth-largest earthquake in the world since 1900 happened on December 26, 2004, at 00:58:53 UTC (or 07:58:53 local time), off the west coast of Northern Sumatra, Indonesia. The magnitude was 9.0, the focal depth was 30 km, and the epicenter is 255 km from Banda Aceh, the nearest provincial capital in Sumatra. The earthquake itself caused some damages and casualties in Banda Aceh and Meulaboh. The subsequent tsunami killed more than 125,468 people, and left 94,550 people missing in Northern Sumatra region.

A Japanese group of researchers, where the first author was a member, departed to Banda Aceh and surrounding areas in attempt to study the lessons from the huge earthquake and tsunami. One of the bridges surveyed is Ulee Lheue Bridge in Banda Aceh1), near the north coast, where the tsunami flow depth is estimated as 12 meter. The bridge is still functioning although the girders were displaced 35 cm laterally near the abutment and displaced more near the mid span.

## 2. EXPERIMENTS ON TSUNAMI FORCE

### *2.1 Experimental Set Up*

The purpose of the experiments is to study the effect of mangroves on tsunami force, velocity, and flow height around the bridge models. The experiments were carried out at Ujigawa Open Laboratory, Kyoto University. Experimental Set Up is shown in Figure 1.

The mangrove is located at 1 meter from the shore (scale factor of 1:77). The bridge model is located at 4 meter from shore (scale factor of 1:77). The tsunami force was measured at the base of the bridge model. The velocity and flow depth were measured at 2 cm above the solid surface and 10 cm in front of the mangrove and bridge models. The mangrove models used herein (10 cm tall) has flexibility that represents real mangroves. Stiff mangrove models were also used for comparison of results (Figure 2).

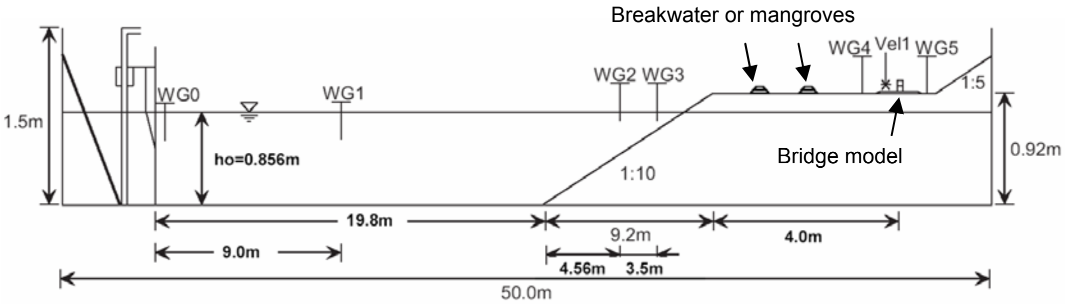


Figure 1 Experimental Set Up of the Tsunami, Mangrove, Breakwater, and Bridge Models

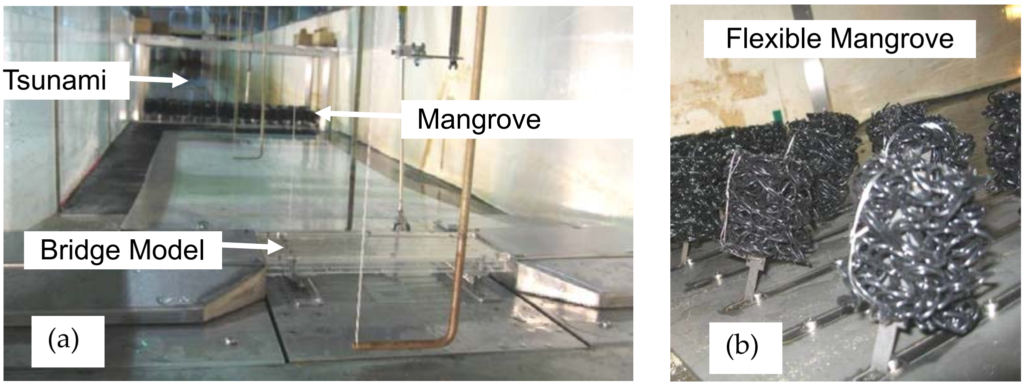


Figure 2 Photograph of mangrove models (a) position (b) flexible trunks

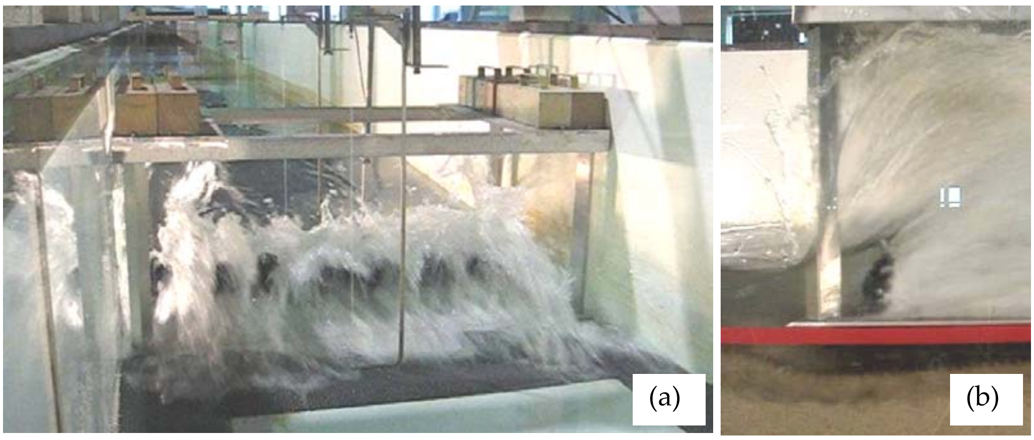


Figure 3 Photograph of tsunami hitting mangrove models (a) back view (b) side view

### *2.2 Experimental Results*

When the tsunami hits the mangrove models, the models bend towards the back (Figure 3). The effect of these models to the tsunami force, tsunami flow velocity, and tsunami flow depth in front of the bridge models are shown in Figure 4.

From Figure 4, the stiff and flexible mangrove models are capable of reducing tsunami force effectively. However, flexible mangrove models which are not densely populated ("LD" in Figure 4b) is not as effective in reducing tsunami force. Densely populated flexible mangrove models are still significant in reducing forces since the models works together as stiff models. This has practical implication that densely populated mangroves are better than those of rarely populated since they are stiffer (consequently are also stronger).

Nevertheless, when the tsunami flow depth is higher than the height of the mangrove models (as in the case of Banda Aceh city), the effectiveness is reduced (Figure 4).

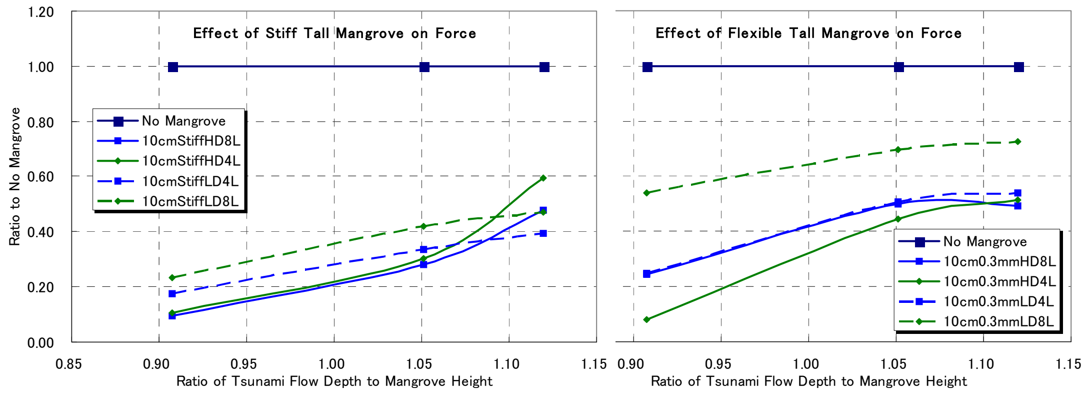


Figure 4 Effect on force (a) stiff and (b) flexible mangrove models

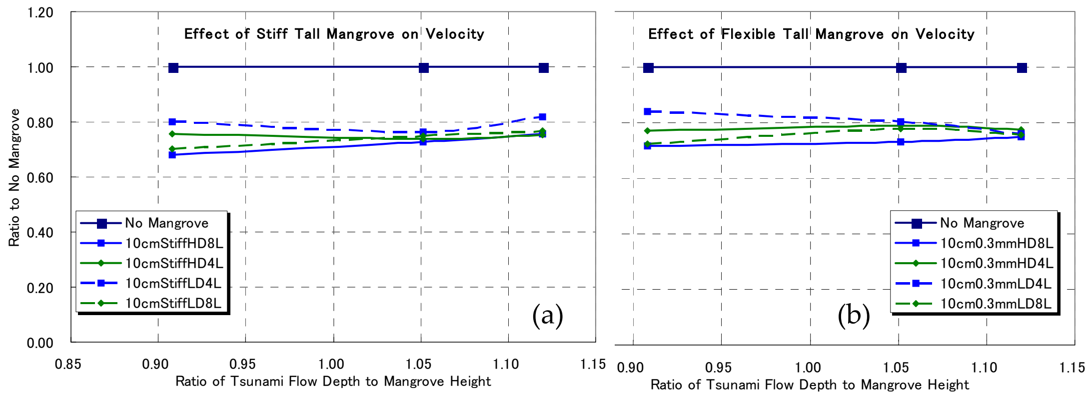


Figure 5 Effect on flow velocity (a) stiff and (b) flexible mangrove models

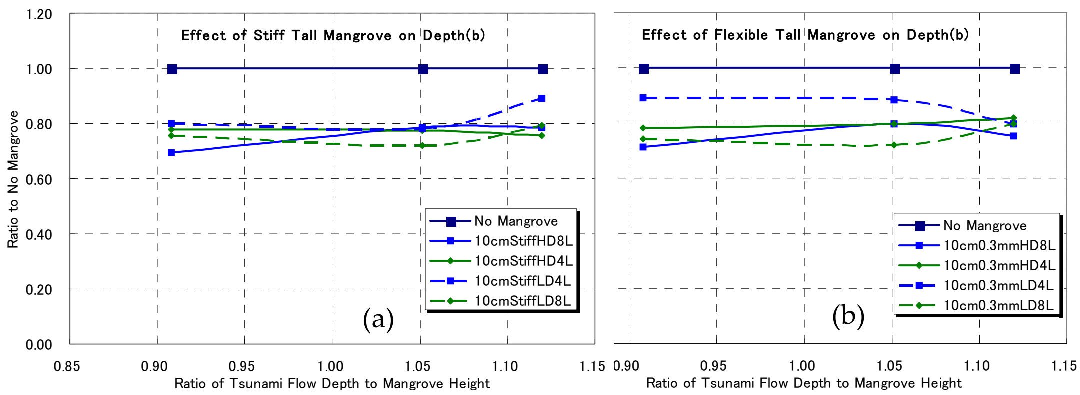


Figure 6 Effect on flow depth in front of bridge (a) stiff and (b) flexible mangrove models

The effects on flow velocity and depth are not so significant (Figures 5 and 6). Looking at the fact that the force reduction is more significant than the flow reduction, it seems the mangrove models reduce the density of the water mass rather than the velocity of the flow. The water may contain more bubbles and consequently produce lower force.

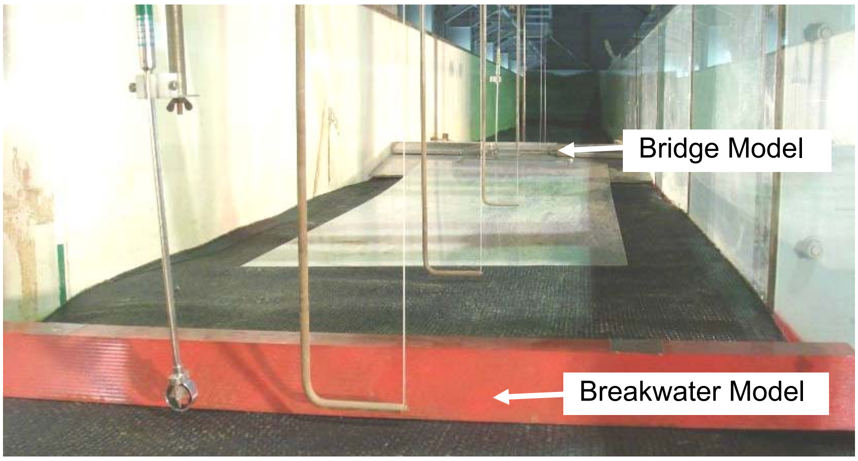


Figure 7 Photograph of breakwater model in front of bridge model

The effect of breakwater in front of bride models was also studied (Figure 7). The breakwater is 5 cm tall. When the tsunami flow depth is about the same as the height of the breakwater height, the breakwater is quite effective in reducing tsunami force. However, when the flow depth is more than two times the height of the breakwater, the effectiveness is quite small. The practical implication is that breakwater is effective for tsunami depth lower than the height of the breakwater.

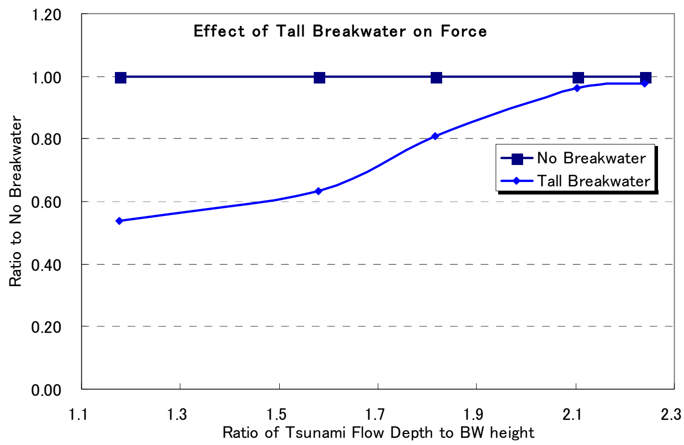


Figure 8 Effect of Breakwater Model on Force

The effect on tsunami flow velocity and depth is not significant. In some cases, the flow depth in front of the bridge models slightly increases. Again, the same explanations may works for the breakwater case as well: the breakwater models reduce the density of the water mass rather than the velocity of the flow. Figure 11 shows the side view photograph of the tsunami hitting a breakwater model. The water mass density after hitting the breakwater seems to be lower than that before hitting.

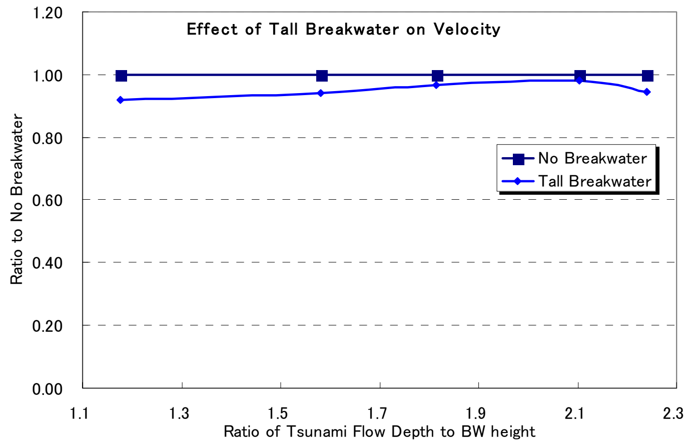


Figure 9 Effect of breakwater model on flow velocity

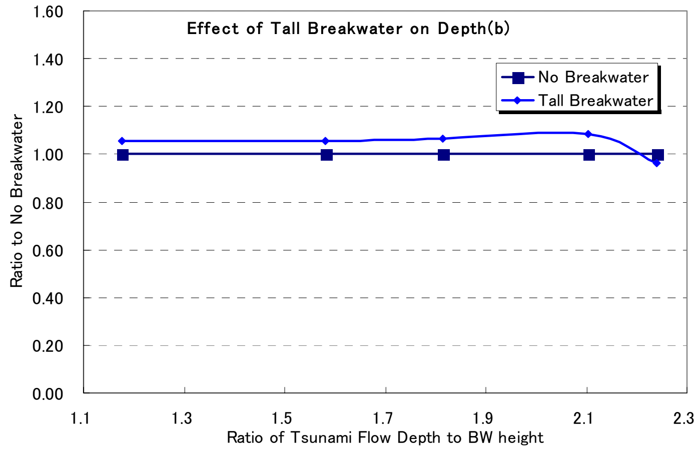


Figure 10 Effect of breakwater model on flow depth in front of bridge model

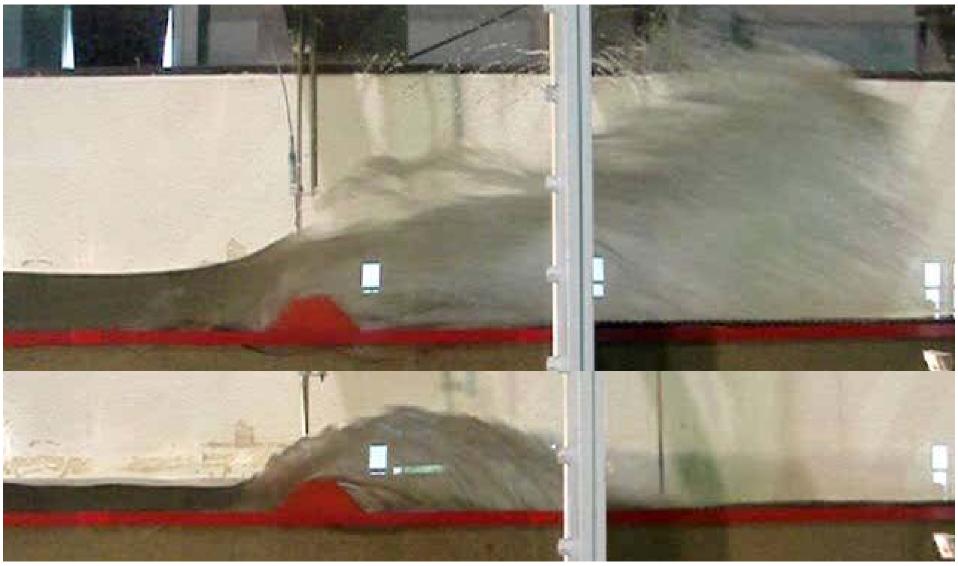

Figure 11 Photograph of tsunami hitting breakwater (a) high level tsunami (b) low level tsunami

## 3. CONCLUDING REMARKS

- Flexible mangrove models which are not densely populated are not effective reducing tsunami force.
- Densely populated flexible mangrove models are significant in reducing forces since the models works together as stiff models.
- Practical implication is that densely populated mangroves are better in performance than that of un-densely populated.
- When the tsunami flow depth is higher than the height of the mangrove models (as in the case of Banda Aceh city), the effectiveness is reduced.
- Breakwater model in front of bride models is quite effective in reducing tsunami force. However, when the tsunami flow depth is more than two times the height of the breakwater, the effectiveness is quite small.
- The practical implication is that breakwater is effective for tsunami depth lower than the height of the breakwater.
- For both mangrove and breakwater cases, the flow velocity and depth is not significantly reduced.

## 4. ACKNOWLEDGEMENT

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## REFERENCES

Cengel, Y. A. and Cimbala, J. M. (2006) *Fluid Mechanics, Fundamentals and Applications*. McGraw Hill.

FEMA55 (2000). Chapter 11 Determining Site Specific Loads. *Coastal Construction Manual*, Vol. 2.

Iemura, H., Pradono, M. H., and Takahashi, Y. (2005). Report on the Tsunami Damage of Bridges in Banda Aceh and Some Possible Countermeasures. *Proceedings of the 28th Earthquake Engineering Symposium*, Japan Society of Civil Engineers, Tokyo Institute of Technology, August 22 – 24.

Iemura, H., Pradono, M. H., Yasuda, T., and Tada, T. (2007). Experiments of Tsunami Force Acting on Bridge Models. *Journal of the 29th Earthquake Engineering Symposium*, Japan Society of Civil Engineers, Fukuoka, August 28 – 30.

Yeh, H. (2006). Maximum Fluid Forces in the Tsunami Runup Zone. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, ASCE, **Vol. 132, No. 6**, November 1.

Matsutomi, H., Sakakiyama, T., Nugroho, S., Matsuyama, M. (2006). Aspects of Inundated Flow Due to the 2004 Indian Ocean Tsunami. *Coastal Engineering Journal*, **Vol. 48, No.2**, pp. 167-195.