第 II 部門　　EXPERIMENTS OF TSUNAMI BORE FORCES ON SEAWALL STRUCTURES

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1．INTRODUCTION

Tsunamis generated by undersea earthquakes pose a serious threat to coastal communities because of their high energy and destructive inundation potential. The 2004 Indian Ocean and 2011 Tōhoku tsunamis illustrated the vulnerability of coastal protection systems and the need for more effective tsunami mitigation measures[1),2)].

Seawalls are widely used to reduce tsunami impacts, and previous studies have shown that their geometry considerably impacts overtopping, force transmission, and wave-energy dissipation[3)]. Although energy-dissipating features such as slopes, steps, and curved faces can improve hydraulic performance, their effectiveness under wet-bed tsunami-bore conditions is insufficiently understood.

Therefore, this study experimentally analyzes the influence of seawall geometry on tsunami-bore overtopping and force transmission under wet-bed conditions. Four seawall configurations were tested using dam-break-generated tsunami bores, and overtopping height and transmitted force were measured to evaluate the hydraulic performance.

2．METHOD

Experiments were conducted in a 14.5 m × 0.40 m × 0.20 m wave flume at the Ujigawa Open Laboratory, Kyoto University (Fig. 1). Tsunami bores were generated using a dam-break method by rapidly releasing water from an upstream reservoir. Three initial reservoir depths (H=13, 15, and 17 cm) were tested.

To simulate wet-bed conditions, a 5-cm-high platform with a 0.45-m-long gentle slope was installed downstream of the gate to simulate wet-bed conditions. Four seawall geometries (slope-, curve-, step-, and box-type) were tested, and a building (5 cm × 5 cm × 10 cm) was placed 50 cm landward of each seawall to measure the transmitted force (Fig. 2).

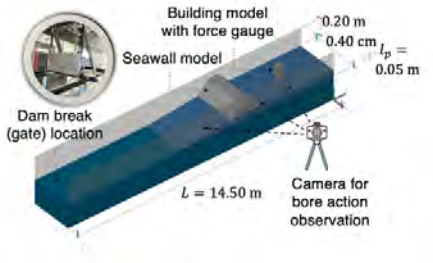


Fig. 1. Experimental setup for tsunami bore generation and impact analysis using a dam-break method.

The impact force (F) acting on the building model was measured using a force gauge connected to a data logger (10 Hz). Overtopping height (h) was determined from video recordings and defined as the maximum water elevation above the seawall crest during bore impact.

Three repeated tests were conducted for each seawall geometry and H. The mean overtopping height ($\overline{h}$) and mean peak force ($\overline{F}_{max}$) were calculated and used to evaluate the influence of seawall geometry on tsunami-bore overtopping and force transmission.

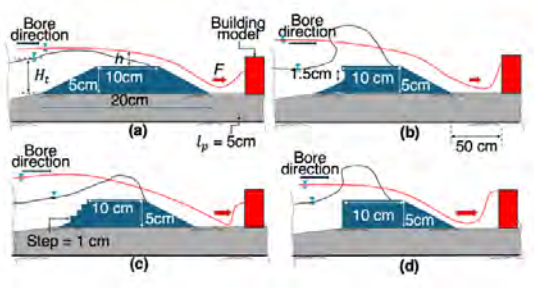


Fig. 2. Seawall designs and schematic illustration of tsunami bore interaction: (a) slope-type, (b) curve-type, (c) step-type, and (d) box-type

3．RESULTS

Table 1 and Figs. 3-5 summarize the overtopping ($\overline{h}$) and peak force ($\overline{F}_{max}$) for the four seawall geometries. Both parameters increased with reservoir depth (H).

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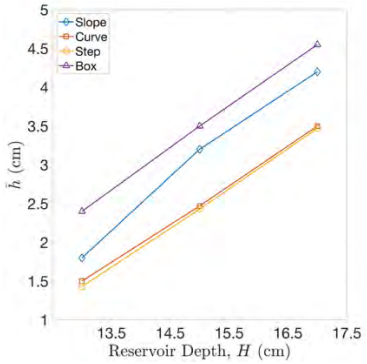


Fig. 3. Variation of mean overtopping height ($\bar{h}$) with initial reservoir depth (H) for the four seawall types (slope, curve, step, and box).

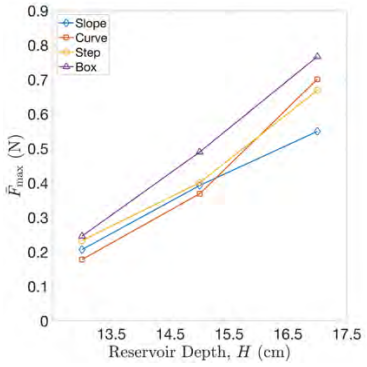


Fig. 4. Variation of mean peak force ($\bar{F}_{max}$) with initial reservoir depth (H) for the four seawall types (slope, curve, step, and box).

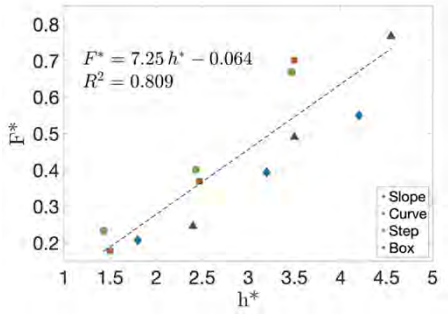


Fig. 5. Relationship between normalized overtopping height ($h^* = \bar{h}/l_p$) and normalized peak force ($F^* = \bar{F}_{max}/(\rho g l_p^3)$) across all seawall types and bore depths.

As shown Figs. 3 and 4, the box-type exhibited the highest overall mean overtopping and force ($\bar{h}_o$=3.48 cm, $\bar{F}$=0.501 N), which indicates limited energy dissipation. In comparison, the step-type seawall showed the lowest mean overtopping ($\bar{h}_o$=2.44 cm) and a relatively low mean force ($\bar{F}$=0.434 N). The slope-type and curve-type seawalls demonstrated intermediate performance.

Fig. 5 shows the relationship between normalized overtopping height ($h^* = \bar{h}/l_p$) and normalized peak force ($F^* = \bar{F}_{max}/(\rho g l_p^3)$). A strong positive correlation,

$$F^* = 7.25h^* - 0.064 \quad (R^2\text{=}0.809), \tag{1}$$

indicates that overtopping height can serve as an indicator of tsunami-bore loading on landward structures. Overall, the step-type seawall provided the most effective balance between overtopping reduction and force mitigation, whereas the box-type seawall exhibited the least favorable performance.

4. CONCLUSIONS

Both overtopping height and peak force increased with reservoir depth for all seawall geometries. The box-type seawall exhibited the highest overtopping and force, whereas the slope-type produced the lowest force and the step-type achieved the lowest overtopping. A strong correlation (R^2 =0.809) was found between normalized overtopping height and peak force. Overall, the step-type seawall demonstrated the best hydraulic performance among the tested configurations.

5. REFERENCES

1. Mori, N., Takahashi, T., Yasuda, T., & Yanagisawa, H. (2011). Survey of 2011 Tohoku earthquake tsunami inundation and run-up. *Geophysical research letters*, *38*(7).
2. Satake, K. (2014). Advances in earthquake and tsunami sciences and disaster risk reduction since the 2004 Indian ocean tsunami. *Geoscience Letters*, *1*(1), 15.
3. Goda, Y. (2010). *Random seas and design of maritime structures* (Vol. 33). World Scientific Publishing Company.

Table 1 Experimental results of tsunami bore interaction with different seawall designs.

Seawall Type	Overtopping Height, $\bar{h}$ (cm)			Overall mean, $\bar{h}_o$	Peak Force, $\bar{F}_{max}$ (N)			Overall mean, $\bar{F}$
	H=13	H=15	H=17		H=13	H=15	H=17	
Slope	1.8	3.2	4.2	3.07	0.207	0.393	0.55	0.383
Curve	1.5	2.47	3.5	2.49	0.178	0.369	0.701	0.416
Step	1.43	2.43	3.47	2.44	0.233	0.401	0.669	0.434
Box	2.4	3.5	4.55	3.48	0.246	0.49	0.767	0.501