C209

Experimental study on tsunami bore forces and overtopping in seawall structures

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This study investigates how four 5-cm-high seawall designs (slope, curve, step, and box) respond to tsunami-bore forces (F) and overtopping (h) in a 14.5 m wave testing facility. Bores were generated using a dam-break method under wet-bed conditions. Results show that the step-type reduced bore force ($\overline{F}$) most effectively, the curve-type redirected flow but created localized pressure concentrations, the slope-type has the highest overtopping ($\overline{h}$), and the box-type has the highest recorded bore force ($\overline{F}$). The experiment shows how the geometry of a seawall influences the interaction between bores and coastal defenses.

1. Introduction

Tsunamis pose hazards to coastal regions, calling for adequate coastal protection, such as seawalls. The geometry of seawalls that protect the community influences tsunami bore forces (F) and overtopping (h) behavior. While Wüthrich et al. (2018) emphasize the impact of wet-bed conditions on tsunami loading, recent research by Rajaie et al. (2022) and Asadollahi et al. (2019) emphasizes the importance of energy-dissipating designs.

Four seawalls with different profiles were evaluated under F and h in a controlled laboratory setting under wet-bed conditions. The tests measure the peak bore force ($\overline{F}_{max}$) and the overtopping height ($\overline{h}$) acting on seawalls. The results of this study provide insights for a more effective coastal defense design.

2. Methodology

2.1. Experimental setup

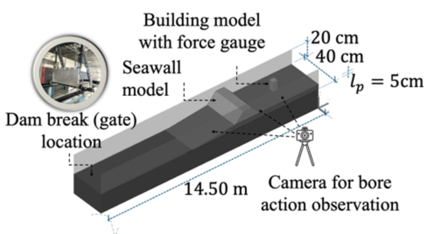

Fig. 1 Experimental setup for tsunami bore.

Four 3D-printed seawall designs were tested in a 14.5 m wave testing facility at Kyoto University's Ujigawa Open Laboratory to evaluate their effectiveness in mitigating F and h. A dam-break setup generated bores toward each seawall, and a 5 cm platform simulated wet-bed conditions (Fig. 1). A building model with a force gauge measured F, while h and bore action were recorded by camera. F, h, and initial reservoir water depth (H = 13, 15, and 17 cm) were measured to assess the performance of the four seawall designs (Table 1).

3. Results and discussion

3.1. Effect of seawall design on overtopping height

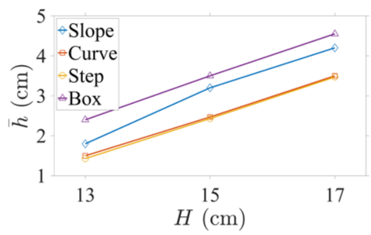

Fig. 2 Overtopping height of seawall designs.

As shown in Fig. 2 and Table 1, the box-type seawall produced the highest $\overline{h}$ with a mean overtopping of $\overline{h}_o$=3.48 cm due to minimal energy dissipation at its vertical face. The step-type recorded the lowest $\overline{h}$ at $\overline{h}_o$ =2.44 cm, followed closely by the curve-type ($\overline{h}_o$=2.49 cm), while the slope-type showed moderately higher values ($\overline{h}_o$ =3.07 cm). These trends reflect geometric influence: steps enhanced turbulence, the

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

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

curved face redirected flow, and the slope delayed impact, but still permitted substantial overtopping.

3.2. Effect of seawall design on force impact

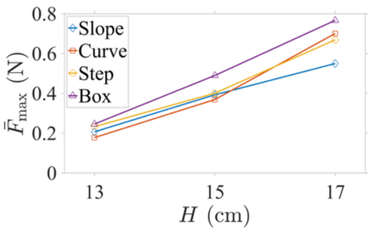

Fig. 3 Hydrodynamic forces on seawall designs.

As shown in Fig. 3 and Table 1, $\bar{F}_{max}$ increased with H for all seawall types. The box-type produced the highest forces ($\bar{F}$=0.501 N) due to limited energy dissipation, while the slope-type generated the lowest ($\bar{F}$=0.383 N). The step type ($\bar{F}$=0.434 N) dissipated energy effectively and balanced F reduction with h control, whereas the curve-type ($\bar{F}$ =0.416 N) redirected flow but created localized pressure peaks.

3.3. Energy dissipation in seawall designs

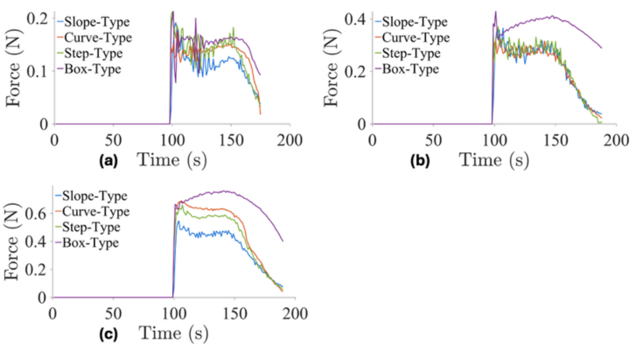

Fig. 4 Time history of bore-induced force (F) on seawall types for initial reservoir depths (H) of (a) 13 cm, (b) 15 cm, and (c) 17 cm.

Fig. 4 shows the time history of F for each seawall type and H, illustrating how geometry affects bore-energy dissipation. The slope-type produces a gradual rise in force and sustained loading, consistent with limited turbulence and higher h. The curve-type redirects some flow seaward but still exhibits F spikes at the crest and toe. The step-type distributes energy most effectively, with turbulence reducing peak forces and h. The box-type, on the other hand, gets the most sudden, high-magnitude impacts.

4. Conclusion

This study assessed four seawall designs subjected to F and h under wet-bed conditions at H = 13, 15, and 17 cm. The box-type had the most h and F, whereas the slope-type had the least F but the most h. The curve-type showed moderate performance, and the step-type achieved the lowest h with balanced F. Under wet-bed conditions, stepped and curved designs were the most effective at preventing energy loss.

References

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