# Coastal Hazard Mitigation via Structural Shape Modification: Investigating the Influence of Curved Structural Cross-sections on Wave Forces using SPH Modeling

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## INTRODUCTION

When hurricanes strike, the forces of hurricane-induced waves acting on coastal structures may cause significant damage and loss to coastal communities. For instance, structures were damaged by the strikes of Hurricane Ivan (2004), Hurricane Katrina (2005) and Typhoon Haiyan (2013), which led to tremendous loss (Chen *et al.*, 2021). Previous studies have shown that structural geometry plays a significant role in determining the associated wave forces and well-designed structural geometries would be able to reduce wave force magnitude and thus facilitate coastal resilience (Hayatdavoodi and Cengiz Ertekin, 2016; Chen *et al.*, 2021).

Box-type structural forms are commonly seen along the coasts: they can be seen in box-girder bridges, breakwaters, and seawalls. The vulnerability of box-shaped coastal structures is usually related to the associated wave forces. To study if geometric modifications would reduce the vulnerability of coastal structures, a numerical study is conducted herein. The influence of curved cross-sections of box-shaped structures on wave loads are investigated, and comparisons between various cross-sections are made based on wave forces. Smoothed particle hydrodynamics (SPH), a numerical algorithm that has gained evolving popularity in recent years to simulate violent wave-structure interaction due to its mesh-free formulation, is employed in this paper. The findings can be applied to the optimal design of coastal structures including box-girder bridges, breakwaters, and coastal building facades.

## SPH FORMULATION

In SPH, continuum domain is discretized into particles and the physical quantity of a particle is calculated using kernel function and the physical quantities of neighboring particles (Domínguez *et al.*, 2022). With these assumptions, the governing equations for fluids, i.e., the Navier Stokes equations, can be numerically solved based on the initial conditions.

To simulate the structures in SPH, modified dynamic boundary condition (mDBC) is employed herein to accurately represent the structural forms in the SPH domain (English *et al.*, 2021).

## PARAMETERS STUDIED

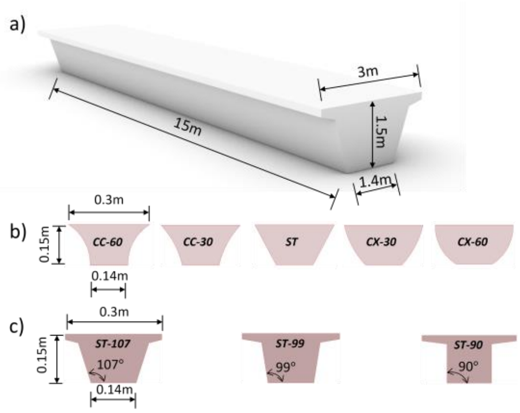

*Figure 1:a) Prototype structure; b) Curved cross-sections with different curvature values in SPH modeling (1:10 scaled); c) Conventional cross-sections with different angle of inclination of the web plate in SPH modeling (1:10 scaled)*

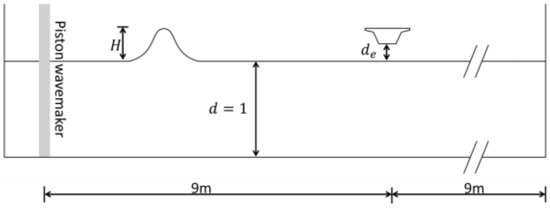

*Figure 2 SPH domain (unit:* m*)*

The prototype structure is shown in Figure 1.a, which can be viewed as a footbridge, a box-type breakwater or a hybrid breakwater-footbridge structure. The prototype is 15m long and 1.5m deep. The deck width is 3m and the bottom width is 1.4m. In SPH, a 2D 1:10 scaled model is implemented (Figure 1.b and c). Various box-type geometries are considered herein, including curved cross-sections with five different curvature values (Figure 1.b) and conventional straight-line cross-sections with three different angle of inclination values of the web plate (Figure 1.c). For curved cross-sections (Figure 1.b), “CC” represents concave geometries, “CX” is for convex forms and “ST” is the transitional form between “CC” and “CX” (i.e., using straight lines). The numeric value after “CC” or “CX” quantifies the curvature of the web using the angle of the arc in degrees.

2D SPH domain is shown in Figure 2 and the water depth $d$ is set as a constant, $d$=1m. The following parameters are considered to create different wave-structure interaction scenarios: relative elevations of the structure ($d_e$) of 0 m, 0.1 m, and 0.15 m, and wave heights ($H$) of 0.1 m, 0.15 m, 0.2 m, and 0.25 m.

## RESULTS AND ANALYSIS

The wave force resultant as well as the pressure distributions on various geometries are analyzed herein. Among curved cross-sections considered (Figure 1.b), convex geometries (positive angle) present higher vertical uplift forces than concave geometries (negative angle) while they have similar horizontal wave forces, as illustrated Figure 3.

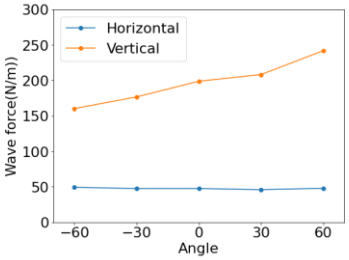

*Figure 3 Comparison of wave forces on curved cross-sections when* $d_e$ *= 0 m and H=0.25 m (negative angle is for concave geometries "CC", positive angle is for convex geometries "CX", and zero angle is for "ST")*

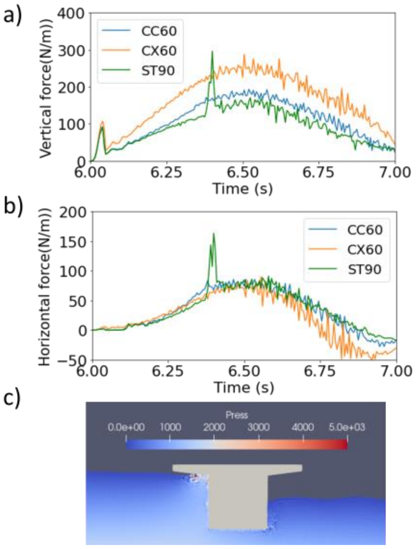

*Figure 4: a) Comparison of the time history of the uplift wave force; b) Comparison of the time history of the horizontal wave force; c) Time instant when the wave impacts ST90*

Furthermore, curved cross-sections are advantageous over conventional geometries (i.e., ST sections in Figure 1.c) when high waves strike, as they can significantly reduce the impact wave forces. For instance, when $d_e =$ 0m and $H =$ 0.25m, we present the time history of uplift wave force (Figure 4.a) and horizontal wave force on CC60, CX60 and ST90. The first peak of the uplift wave force (Figure 4.a) is similar on curved cross-sections (CC60, CX60) and conventional geometry (ST90), as it is when the wave impacts the bottom of the box girder and both geometries have the same bottom flange. However, when the wave continues to propagate, it imposes a second impact force (Figure 4.a and b) acting only on ST90 when it reaches the intersection between the web plate and the overhang, as visualized in Figure 4.c. On the contrary, due to the smooth transition, curved-cross-sections avoid this type of impact force that may significantly damage the structure.

## CONCLUSIONS

The findings show that innovative curved cross-sections would significantly reduce impact wave forces when compared to conventional geometries formed by straight lines and thus reduce the associated vulnerability of box-shaped coastal structures against hurricane-induced wave strikes. Among curved geometries, concave shapes have smaller wave forces compared to convex geometries. Recommendation on innovative geometric design of box-shaped coastal structures is proposed herein to further facilitate the resilience of coastal structures in the context of extreme weather event.

## REFERENCES

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