

SPH modelling of horizontal and vertical tsunami effects on deck girder bridges

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ABSTRACT

Coastal infrastructure can be damaged by extreme hydrodynamic phenomena such as tsunamis and storm surge. The interaction between the waves and the coastal infrastructure is challenging to characterize due to the infrequent nature and complex physics involved during extreme hydrodynamic events. Physical and numerical simulations play a critical role in generating complementary data to study the highly nonlinear phenomena involved in fluid-structure interaction (FSI) processes. In this presentation, the Smoothed Particle Hydrodynamics (SPH) method implemented in DualSPHysics is adopted to reproduce data from an experimental program conducted at the Hinsdale Wave Research Laboratory (Oregon State University, NHERI experimental facility). Recorded and synthetic data are correlated to assess the efficiency of SPH reproducing tsunami-like flow and its effects on vertical and horizontal components of a deck girder bridge. The bridge model is then adapted to represent a simplified model of bridge without flanges. The quantification of pressure exerted on the vertical direction is relatively similar on both models. On the horizontal direction, the time series of pressure calculated from the simplified model shows a smoother shape form and a peak value 40% smaller than the one estimated from the original model.

PHYSICAL SETUP

The experimental data was instrumentally acquired during an experimental campaign carried out at the large flume of the Hinsdale Wave Research Laboratory [1,2]. The flume is 104m long, 3.66m wide, and 4.57m deep and is equipped with a piston wave-maker.

The instrumentation setup combined wave gauges (WG), ultrasonic wave gauges (USWG) and acoustic Doppler velocimeters (ADV) to record hydrodynamic quantities in by the piston wave maker, near and after the elevated structures. Pressure gauges (PG) and load cells (LC) measured pressure and forces, respectively, exerted on horizontal and vertical directions of the deck. Virtual gauges were set in the numerical domain. Fig.1 shows the experimental setup.

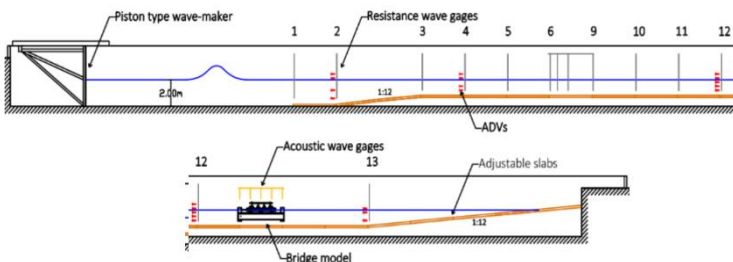


Figure 1: Physical and instrumental setups of the specimen at the HWRL flume.

NUMERICAL SETUP

The fluid-structure interaction model is governed by Navier Stokes governing equations (NS), solved via Smoothed Particle Hydrodynamics (SPH) method implemented in the open-source DualSPHysics code [3], assuming weakly compressible and near irrotational flows. Classic and modified dynamic boundary conditions are adopted to model the piston wave-maker and the deck, respectively. The deck is 3.45m wide, 1.95m long and 0.05m-high. The girders are W8x13, 0.21m height. Fig. 2 shows the bridge configurations.

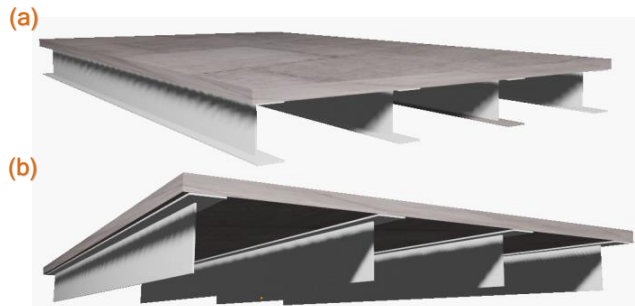


Figure 1 – Three-dimensional rendering of the deck configurations modeled: (a) deck girder bridge with web and flanges, which was the original configuration of the experimental campaign, (b) deck girder bridge with web, without bottom flanges.

The simulations were carried out using DualSPHysics 5.2, running on a GPU GeForce RTX 2060 accelerated platform. The time of simulation was set to $t = 100s$, with Courant-Friedrichs-Lewis coefficient $CFL = 0.20$.

A convergence analysis was conducted to define the initial particle inter-distance (Δp). The varied from $\Delta p = 100$ mm to $\Delta p = 2.5$ mm. The convergence study showed that, for unbroken waves resembling the quasi-steady phase of tsunami waves during the inundation stage, it is reasonable to use $\Delta p = 30$ mm, which corresponds to a ratio $\Delta p/h \approx 10$ (h is the wave height). The ratio is in agreement with values described in the literature for unbroken waves [4,5]. Fig. 3 (a) and (b) show the flow velocity fields at $t = 87s$ in the vertical and horizontal directions, respectively.

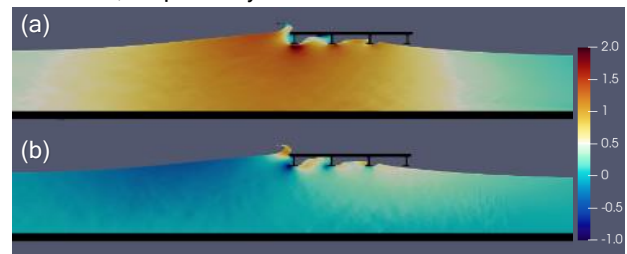


Figure 3 – Flow velocity at $t = 87s$: (a) horizontal direction, and (b) vertical direction. (Units: m/s).

PHYSICAL-NUMERICAL RESULTS CORRELATION

A correlation between physical and numerical data was conducted to assess the efficacy and efficiency of the SPH analyses in reproducing the FSI phenomena in the tsunami-like waves. The comparisons are performed for hydrodynamic quantities (free surface elevation (η), flow velocity (u)) and effects on the bridge, such as pressures exerted on the vertical P_h and horizontal P_v directions. Fig. 4 shows the correlations of the hydrodynamic quantities, η and u , at representative points of interest.

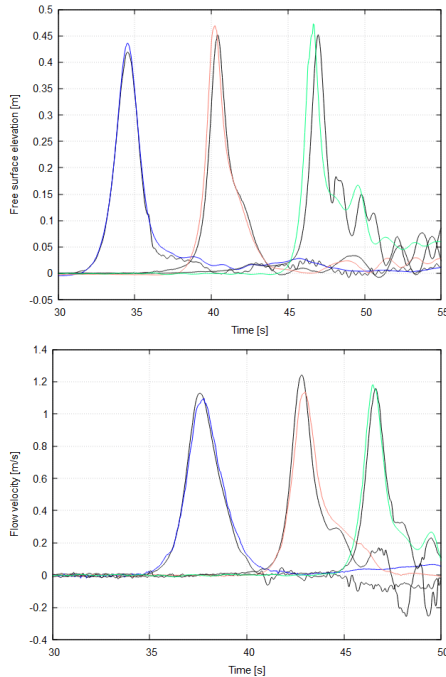


Figure 4 – Correlation between recorded (black) and numerical data. Free-surface elevation (top) and flow velocity (bottom) in the flume (blue), near (red) and after deck (green).

The correlation shows a good fitting of the recorded data and numerical solutions of hydrodynamic quantities, particularly at the flume location before the wave interaction with the bridge. After the impact, the quality of the solutions slightly decreases due to numerical cumulative error and probably due to some tridimensional effects lacking in the 2D simulations. Moreover, the correlation considers data from only one trial, missing the variations associated with the physical processes. After validation of the numerical solutions, the numerical model is then adapted to assess the influence of having a simplified model of the bridge (configuration (b) in Fig. 2). The correlation includes pressures exerted on horizontal and vertical directions, P_3 and P_{11} , respectively (identified in Fig. 5).

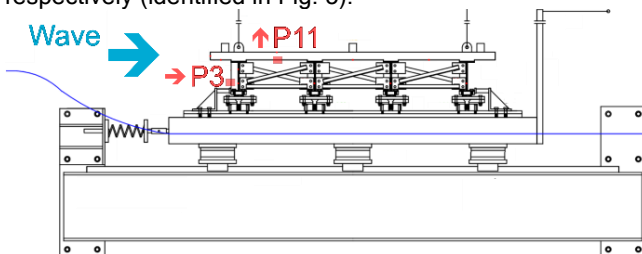


Figure 5 – Points of interest for pressure correlations on the horizontal and vertical directions, P_3 and P_{11} , respectively.

Fig. 6 depicts the correlation between recorded and numerical pressures computed for a full bridge and a simplified model.

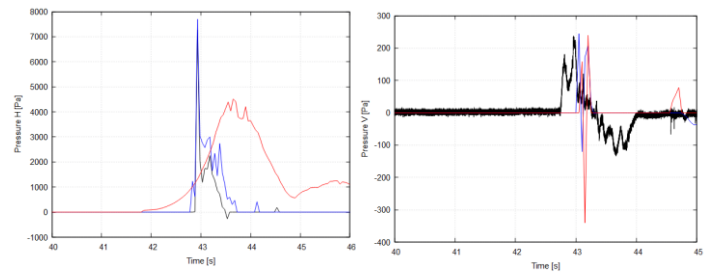


Figure 6 – Correlation between recorded (black) and numerical data. Bridge configurations A and B, see Fig. 2, represented by blue and red lines, respectively. Pressure exerted on horizontal (top) and vertical directions (bottom).

The main observations from removing the bottom flanges are: (a) an underestimation of the pressure exerted on the webs, which may lead to underdesigned structures, and (b) similar uplifting effects on the deck and more pronounced suction effect after the impact of the wave (negative peak).

This is because the bottom flanges act as a barrier. In their absence the energy of the wave is easily dissipated, promoting the wave withdrawal and reducing the pressure exerted on the webs.

CONCLUSIONS

The main conclusions from the experimentally validated numerical solutions are: (a) hydrodynamic quantities are very well characterized using the SPH method (see results in Fig.4); (b) the code shows capacities to predict pressures exerted on a deck girder bridge, particularly in the horizontal direction (see Fig. 6), but there is room for improvement on the vertical pressures. A simulation was carried to assess the importance of modeling detailed features, such of bottom flanges. The estimates of the horizontal pressure on the webs of the deck girder bridge showed an underestimation of the horizontal pressure. The results show agreement on the computation of the pressure exerted on the vertical direction. In the future, models of elevated decks would benefit from including: (a) other geometries, and (b) other wave conditions. Such aspects can provide modeling insights, such as the $\Delta p/h$ ratio to capture more violent flows, and design recommendations, such as the variation of drag coefficients values due to changes in the deck geometry.

REFERENCES: [1] Alam MS, Winter AO, Galant G, Shekhar K, Barbosa AR, Motley MR, Eberhard MO, Cox DT, Arduino P, Lomonaco P. (2020) Tsunami-like wave-induced lateral and uplift pressures and forces on an elevated coastal structure. *JWPortCoastOceanEng* 2020;146(4):1–18.; [2] Istrati D, Buckle IG (2021), Tsunami loads on straight and skewed bridges, Part 1: Experimental investigation and design recommendations. ODOT, EUA. [3] Dominguez JM, Fourtakas G, Altomare C, Tafuni A., ... Gesteira M (2021) DualSPHysics: from fluid dynamics to multi physics problems, *Computational Particle Mechanics*. [4] Reis, C., Clain, Fig. J, Barbosa, A.R., Baptista, M.A., Lopes, M. (2021). Experimentally validated numerical models to assess tsunami hydrodynamic force on an elevated structure. *Eng Str*, 249, 113280. [5] Reis, C., Barbosa, A.R., Fig.J., Clain, S., Lopes, M., & Baptista, M.A. (2022). SPH modeling of elevated structures impacted by tsunami-like waves. *Eng Str*, 270, 114851.