NUMERICAL MODELLING OF SOLITARY AND FOCUSED WAVE FORCES ON COASTAL-BRIDGE DECK

Rameeza Moideen, PhD Scholar, Indian Institute of Technology Bombay, India, rameezasindoora@gmail.com
Manasa Ranjan Behera, Assistant Professor, Indian Institute of Technology Bombay, India, manasa.rb@iitb.ac.in
Arun Kamath, Research Fellow, Norwegian University of Science and Technology, Norway, arun.kamath@ntnu.no
Hans Bihs, Associate Professor, Norwegian University of Science and Technology, Norway, hans.bihs@ntnu.no

INTRODUCTION
In the recent past, coastal bridges have been subjected to critical damage due to extreme wave attacks during natural calamities like storm surge and tsunami. Various numerical and experimental studies have suggested different empirical equations for wave impact on deck. However, they do not account the velocities of the wave type properly, which requires a detailed investigation to study the impact of extreme waves on decks. Solitary wave assumption is more suitable for shallow water waves, while the focused wave has been used widely to represent extreme waves. The present study aims to investigate the focused wave impact on coastal bridge deck using REEF3D (Bihs *et al.,* 2016).

THEORY
The incompressible unsteady Reynolds-Averaged Navier-Stokes (URANS) equations along with continuity equation are used to solve the fluid flow problem with free surface.

$$\frac{\partial u_i}{\partial x_i} = 0 \qquad (1)$$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\nu + \nu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + g_i \qquad (2)$$

where ρ is the fluid density, p is the pressure, u is the velocity averaged over time *t*, ν is the kinematic viscosity, ν_t is the eddy viscosity and g is the acceleration due to gravity.

Turbulence modelling is done using k-ω model. The Hamilton-Jacobi formulation of the WENO scheme is used for convective discretization. Total Variance Diminishing (TVD) third order Runge-Kutta explicit Scheme is used for the discretization of time dependent terms. CFL criterion is used to maintain adequate time step size. The Level Set method is employed in REEF3D to model the free surface.

Focused wave group used for representing extreme wave (Ning *et al.*, 2009) is generated by summing up linear waves so as to get required amplitude at specified location and time. This type of dispersive wave focusing depends on water depth, d and fails for higher a/d ratio, where a is the amplitude of the wave.

VALIDATION
Experimental study by Seiffert et al. (2014) on a flat plate representing coastal bridge structure subjected to solitary wave forces is considered for validation of REEF3D modelling approach. The study with amplitude, a = 0.03432 m in a water depth, d = 0.114 m is considered (Scale-1:35) for validation. The model test specimen is an acrylic plate of length L_p= 0.149 m, width B = 0.305 m and thickness t_p = 1.27 cm. A numerical wave tank is set up of length 15 m, height 0.39 m and one grid size width of 0.025 m (Figure 1).

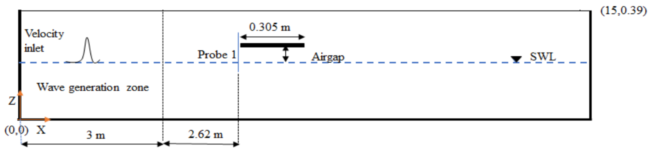
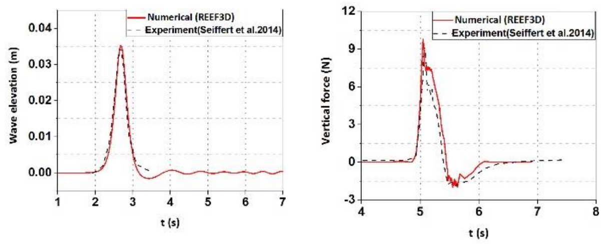


Figure 1: Schematic of the numerical wave tank and deck

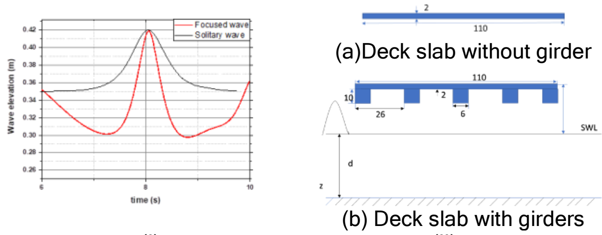
Results
The comparison of wave amplitude and vertical impact force on deck between numerical and experimental results show good agreement (Figure 2). The sudden impulse force of shorter duration and both pulsating negative and positive force is captured well by the numerical model.



(i) (ii)

Figure 2: Comparison of numerical results with experiment. (i) Amplitude (ii) Vertical impact force

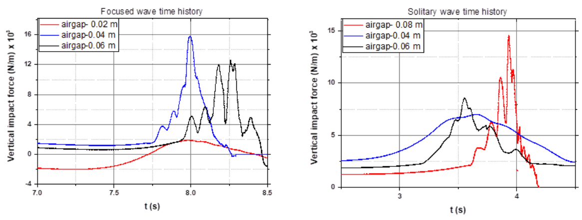
The numerical model is used to study the impact of focused and solitary wave of same amplitude on a deck with and without girders (Figure 3). The test case of solitary wave with amplitude, a = 0.07 m generated in water depth of 0.35 m and focused wave with same amplitude generated at predefined distance x = 5m and time t = 8 sec are compared (Figure 3). The wave is allowed to impact a 2D deck with and without girders for different airgaps (-0.02, 0, 0.02, 0.04, 0.06, 0.08, 0.1 m). Airgap (S) is the distance measured from SWL to the top of the structure and is selected such that the deck is fully submerged, partially submerged and elevated. Airgap is negative when the structure is placed below SWL. The maximum positive vertical force at different airgaps for focused and solitary wave are compared and shown in Figure 4.



(i) (ii)

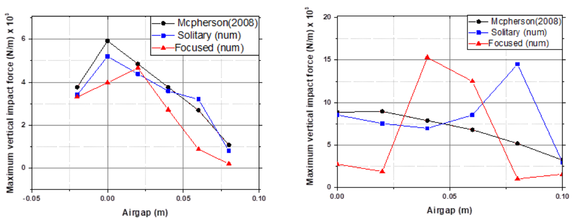
Figure 3: (i) Comparison of solitary and focused wave profiles (ii) Deck configuration with and without girders (Dimensions in cm)

The vertical force time history due to solitary and focused wave impact on deck with girders for different airgaps are shown in figure 4. The maximum positive force is recorded for an airgap of 0.04 m as more free cells are available and the wave elevation is high enough to fill the chambers. This cause large air entrapment between girders and results in higher buoyancy force due to volume displaced by air. Further increase in airgap reduces the impact force as the wave elevation is not high enough to fill up the chambers.



(i) (ii)

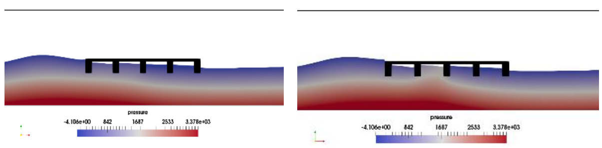
Figure 4: Force time history at different airgaps (i) Focused wave (ii)Solitary wave



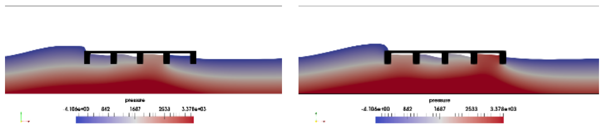
(i) (ii)

Figure 5: Comparison of maximum positive vertical impact force due to focused and solitary wave with different airgaps for deck slab (i) without girder (ii) with girders

Figure 5 shows the maximum positive vertical impact forces for different airgaps. For submerged cases, vertical impact force is same for both focused and solitary waves. In case of deck without girders, maximum force occurs at an airgap of 0 m and 0.02 m for solitary and focused wave respectively. For deck with girders, the maximum vertical force is almost same for focused and solitary wave at airgaps of 0.04 m and 0.08 m, respectively. The trailing smaller wave and main focused wave simultaneously interact with the deck at an airgap of 0.04 m increasing the pressure and elevation inside the chambers. The pressure variation at airgap, S = 0.04 m for focused wave is shown by the snapshots taken at different time steps of wave structure interaction (Figure 6). For higher airgaps, the main wave only interacts with the structure and the pressure is lesser than the solitary wave of same magnitude.



(i) t = 7.85 s (ii) t = 7.9 s



(iii) t = 7.95 s (iv) t = 8 s

Figure 6: Screen shots of pressure variation inside the chambers of focused wave at an airgap, S = 0.04 m at different time steps

The maximum vertical impact force is then calculated by the equation proposed by McPherson (McPherson, 2008). The hydrostatic formulation of McPherson is chosen as it takes into account the overtopping water effects and air entrapment inside the chambers. For different airgaps, the theoretical results and the results obtained by solitary and focused wave for deck with girders are compared and shown in Figure 5.

The theoretical equation proposed by McPherson and the numerical results with solitary wave are in good agreement for submerged. But as the airgap increases, the numerical results give higher impact force. This is because the theoretical equation by McPherson considers buoyancy due to air as 50% and when the airgap increases force due to air entrapment is larger. The focused wave impact at different airgap has no match with the theoretical values as the wave shape and characteristics of focused wave is different.

CONCLUSION

The present study investigates the focused wave impact on coastal bridge deck using numerical model REEF3D. Experimental study on a flat plate representing coastal bridge structure subjected to solitary wave forces is considered for validation of REEF3D modelling approach. Focused and solitary wave of same amplitude is then generated in the numerical wave tank. The impact of these waves on deck slab with and without girders are analyzed for different airgaps and the maximum vertical force at different locations are identified. The maximum positive vertical impact force occurs at different airgaps for deck with girders under the impact of focused and solitary waves. The comparison of maximum forces with theoretical equations shows good match for submerged cases and underestimates when the airgap increases.

REFERENCES

Bihs, Kamath, Alagan, Aggarwal, Arntsen (2016): A New Level Set Numerical Wave Tank with Improved Density Interpolation for Complex Wave Hydrodynamics, Computers & Fluids, Vol. 140, pp. 191-208

McPherson, R.L. (2008). "Hurricane Induced Wave and Surge Forces on Bridge Decks." M.S. thesis, Texas A&M University, College Station, TX.

Ning, Zang, Liu, Taylor, Teng, Taylor (2009): Free surface evolution and wave kinematics for nonlinear uni-directional focused wave groups, Ocean Engineering 36 (2009) 1226-1243.

Seiffert., Hayatdavoodi, Ertekin. (2014): Experiments and computations of solitary-wave forces on a coastal-bridge deck. Part I: Flat Plate, Coastal Engineering 88 (2014) 194-209.