Abstract

Coastal highway bridges are vital components of transportation system which were severely damaged during recent hurricanes. Hurricane Katrina and Ivan's damage to these structures well exceeded 1 billion dollar to repair. A numerical model based on a three-dimensional two-phase compressible Navier Stokes equations is used to investigate hydrodynamic forces applied to these structures with an emphasis on the effect of air entrapment and entrainment on hydrodynamic forces applied to these structures. Numerical simulation results are validated by comparison to experimental data available from the O.H. Hinsdale Wave Research Laboratory at Oregon State University. Numerical model was capable of calculating horizontal and vertical wave forces applied to bridge superstructure with a reasonable accuracy. In this study Computational Fluid Dynamic (CFD) is used as a tool to calculate hydrodynamic forces applied to bridge superstructures. It has been shown that with proper choice of mesh and time step size, it is possible to calculate total horizontal and vertical forces applied to bridge superstructure with a reasonable accuracy. In addition, since the trapped air under the bridge superstructure between bridge girders and diaphragms were a major contributing factor to many bridge failures, the efficacy of air vents cored in bridge decks and diaphragms are evaluated and it has been shown that they can be used as an effective retrofitting option for mitigating damage to existing and new bridge superstructures.

Comparison of Simulation Results to Experimental Data

Governing Equation

Navier Stokes Equations:
\[
\begin{align*}
\frac{d}{dt} \int \rho V dV + \int p(V - V_g) da &= 0 \\
\frac{d}{dt} \int \rho V dV + \int \rho \nabla \cdot (V - V_g) da &= \int (T - pI) da + \int \rho bdV
\end{align*}
\]

Transport Equation for Evolution of Volume of Fluid (VOF) in Each Cell:
\[
\frac{d}{dt} \int \alpha_s V dV + \int (\alpha_s (V - V_g)) da = 0
\]

\(\rho\) is fluid density; \(V\) is fluid velocity vector; \(V_g\) is grid velocity; \(V\) is cell volume; \(p\) is pressure; \(T\) is viscous stress tensor; \(I\) is identity matrix; \(\alpha_s\) is face area vector; \(S\) is cell surface; \(\alpha_i\) is volume fraction of the ith phase.

Concluding Remarks

In this study Computational Fluid Dynamic (CFD) is used as a tool to calculate hydrodynamic forces applied to bridge superstructures. It has been shown that with proper choice of mesh and time step size, it is possible to calculate total horizontal and vertical forces applied to bridge superstructure with a reasonable accuracy. In addition, since the trapped air under the bridge superstructure between bridge girders and diaphragms were a major contributing factor to many bridge failures, the efficacy of air vents cored in bridge decks and diaphragms are evaluated and it has been shown that they can be used as an effective retrofitting option for mitigating damage to existing and new bridge superstructures.

Retrofitting Coastal Bridges with Air Vents

After looking into the mode of failure shared by most of highway bridges, it became evident that the failure of the bent cap connections was the specific cause of the overall failure. Investigations of the failure mechanism for theses bridges theorize that the uplift force due to buoyancy combined with the horizontal and vertical hydrodynamic forces due to impacting waves imposed a large enough force to overcome the weight of a bridge superstructure element and the capacity of any bent cap connections. Once the bent cap connections failed, subsequent waves were able to push the element off of the supporting bent caps. In this study efficacy of air vents cored in bridge deck and diaphragm are evaluated and compared with each other. For wave height of \(H=0.34\)m, \(5\) cm air vents cored in bridge deck were able to reduce total vertical force applied to bridge superstructure by 62 percent.