Nonlinear wave loads on decks of coastal bridges *

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1 Introduction

Horizontal and vertical wave forces and overturning moment on decks of coastal bridges are determined by use of a number of theoretical approaches. These include the nonlinear Green-Naghdi shallow-water wave equations (GN), Euler's equations and Laplace's equation.

The problem of interaction of nonlinear waves with the deck of the coastal bridges is divided into two general categories: (a) when the bridge deck is fully submerged due to the storm surge and waves do not break on top of the deck, and (b) when the deck is very close to the still-water level (SWL), or is fully above the surface, which results in wave breaking over the bridge deck. Failure of coastal bridges has been observed under both conditions, see *e.g.*, Robertson et al. (2007). The GN equations, Euler's equations and Laplace's equation are all utilized for condition (a), while only Euler's equations is used in condition (b), mainly due to wave breaking and entrapment of air pockets.

2 Theories

The Level I Green-Naghdi equations are originally derived based on the theory of directed fluid sheets by Green & Naghdi (1974) and are fundamentally different from the classical shallow water wave equations. Within the limits of the numerical solutions, the GN equations satisfy the free-surface, seafloor and body boundary conditions, and the integrated mass and momentum conservation equations, exactly. The GN equations are recently utilized to calculate nonlinear waves loads on decks of coastal bridges by Hayatdavoodi & Ertekin (2015).

An open source Computational Fluid Dynamics (CFD) package, namely *OpenFOAM*, is used to solve Euler's equations and determine the wave forces on a submerged or elevated bridge deck. Wave breaking due to the presence of the bridge deck is captured by use of an interface tracking approach, namely Volume of Fluid method.

Wave forces and the moment on the submerged bridge deck are also estimated by use of two linear approaches. One is a computer program called *HYDRAN*, written to analyze the dynamic of rigid and flexible bodies by use of the Green-Function method. Details of the method used in *HYDRAN* can be found in *e.g.*, Ertekin et al. (1993). The other method is known as the Long-Wave Approximation, and is the solution of the velocity potential given by Siew & Hurley (1977).

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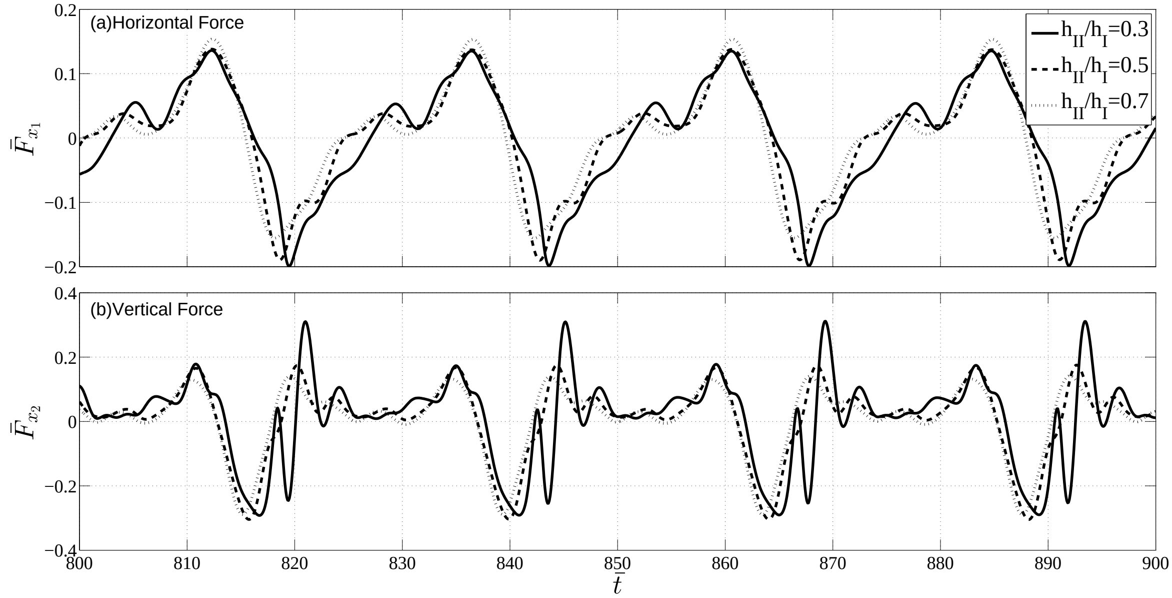

Figure 1: Dimensionless horizontal ($\bar{F}_1 = F_1/\rho g h_I L_p t_p$, where $\rho g, h_I, L_p$ and t_p are water density, acceleration, depth, deck length and thickness, respectively) and vertical ($\bar{F}_3 = F_3/\rho g h_I^2 L_p$) forces due to cnoidal waves ($H/h_I = 0.2$ and $\lambda/h_I = 25$).

3 Results and Discussion

The theoretical approaches are used to determine the time-dependent pressure distribution around bridge decks due to nonlinear waves of cnoidal and solitary type. The horizontal (F_{x_1}) and vertical (F_{x_3}) wave forces and the overturning moment (M_{x_2}) are determined by integrating the pressure around the deck. Variation of the wave forces, and the overturning moment, with wave conditions (wave height, H, and wave length, λ) and deck characteristics (distance from the SWL, and deck width, B) are studied. Figure 1, for example, shows the time history of the horizontal and vertical forces due to the propagation of cnoidal waves on fully submerged bridges deck ($B/h_I = 5$), calculated by solving the GN equations. The submergence depth (h_{II}) is variable here. The vertical uplift force increases as the bridge deck moves closer to the surface. The horizontal force, however, remains constant with the submergence depth.

Results of the computations are compared with the laboratory measurements, and with the existing simplified, design equations.

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