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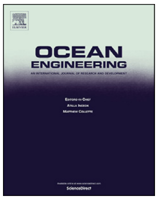

Numerical analysis of tsunami-like wave impact on horizontal cylinders

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ABSTRACT

During the past few decades, several tsunami events have caused tremendous devastation to onshore and offshore infrastructures. Although the tsunami waves have been studied with solitary waves since 1970s, the wave profile differences between solitary and tsunami waves directly result in the significant differences in their energy carrying capability and potential destructive impacts. In this study, a tsunami-like wave profile has been adopted by using a composition of solitary waves to simulate a real tsunami wave profile. A two-phase flow model was numerically resolved with the finite volume method with the volume of fluid method to track the free surface. The numerical model was first validated against the experimental and theoretical studies with the solitary wave. And then, the impact of tsunami waves at submerged horizontal cylinders was numerically studied. The hydrodynamic differences between the solitary wave and tsunami-like wave passing the submerged cylinders have been discussed, which shows the significant differences on the punching forces and the velocity field evolution around the cylinders. Moreover, the effects of wave height and submersion depth on the hydrodynamic loads were considered, and the influence of the spacing distance on the interactions between cylinders in a tandem arrangement was also investigated.

1. Introduction

A tsunami is a series of water waves generated by the displacement of a substantial volume of water during the subsea earthquakes, volcanic eruptions, landslides and other disturbances above or below water. The velocity of tsunamis varies with parameters such as the bathymetry, height of the originating wave, initial pressure changes in the sea, etc. and it can travel with a velocity of more than 1 000 km/h (Harinarayana and Hirata, 2005). When they approach the shallower water, they undergo shoaling as their wave length and speed decrease while the wave height grows. And it may cause more damages to industrial equipment, buildings and other objects than wind induced waves or storm waves, since the tsunami waves are faster, higher and stronger. For instance, in Indonesia, the 2004 Indian Ocean tsunami destroyed 120,000 homes, 3000 government building and 14 ports (Suppasri et al., 2012). The 2011 Japan tsunami devastated the eastern part of Japan and caused significant damage to buildings and industrial facilities, including the explosion at Fukushima nuclear plant. Yu et al. (2017) made a survey on industrial parks impacted by 2011 Japan tsunami, and showed that around 30% of the responding industrial facilities suffered damages due to the tsunami. As reported by the Japanese Fire and Disaster Management Agency (2011), 1404 of the surveyed 211,887 hazardous materials facilities were damaged by the tsunami, and fires, explosions, and hazardous material releases occurred during that disaster.

The tsunami hazards emphasize the urgent need to understand the fundamental damaging mechanisms to increase the resilience of the coastal infrastructures subjected to tsunami event. Owing to the unpredictable nature of a tsunami event, it is difficult to conduct a field experiment. Thus, most of the studies on that topic were carried out by the physical experiments (Chen et al., 2016; Sassa et al., 2016.) and numerical simulations (Ha et al., 2014; Wei et al., 2015.). Experiments and numerical studies usually model tsunami waves as solitary waves (Cho et al., 2004; Liang et al., 2013; Ha et al., 2014; Maza et al., 2015; Wei et al., 2015.). However, the solitary wave is rarely observed during tsunami propagation (Sriram et al., 2016), and the tsunami wave develops at completely different temporal and spatial scales from that of solitary wave (Madsen et al., 2008; Madasen and Schäffer, 2010). In fact, there are a variety of tsunami waves in terms of both periods and wave

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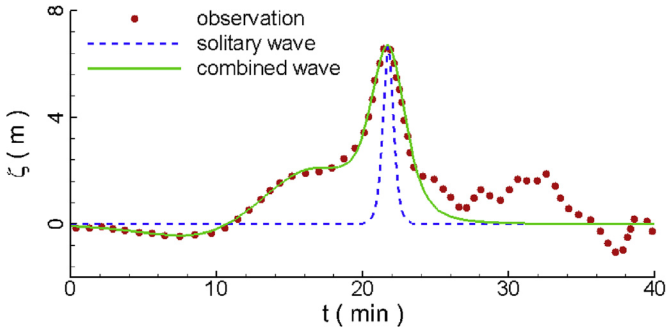


Fig. 1. Wave profile of observation, solitary wave, and tsunami-like wave elevation (ζ).

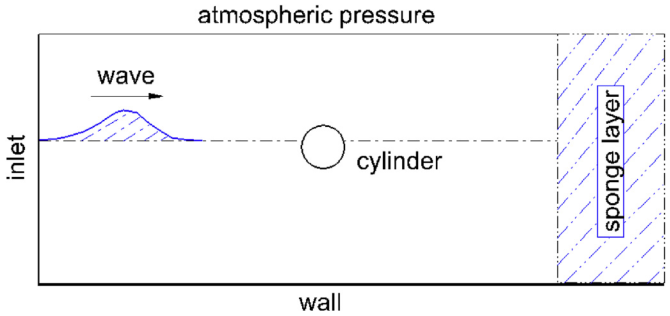


Fig. 2. Schematic representation of the computational domain.

shapes due to the wave propagation in large-distance and the complicated ocean bottom. Hence, use of solitary waves as an initial condition for the tsunami simulation has limited applicability (Synolakis, 1987).

Tsunami waves are normally observed as leading-depression waves. As a good description of the profile for the leading tsunami wave could be sufficient to provide a reasonable estimation of the maximum run-up height (Chan and Liu, 2012), Tadepalli and Synolakis (1994) introduced a concept of N-shaped solitary wave, which could be designed to be either leading depression or elevation N-wave to fit the profile of tsunami wave. Madasen and Schäffer (2010) also proposed a form of N-wave composed of superposition of positive and negative single waves. As Madsen et al. (2008) suggest to break with the solitary wave paradigm and to use field measurements for studying tsunami waves, Chan and Liu (2012) proposed a combination of three sech2 profiles to approximate the temporal evolution of the tsunami wave recorded at Iwate South station during the 2011 Japan Tohoku tsunami. The tsunami-like wave generated by that method has been adopted as an initial condition by Qu et al. (2017) to study tsunami wave run-up in the coastal area and by Williams and Fuhrman (2016) to study the tsunami-scale wave boundary layer.

As the tsunami-like wave was found to have different hydrodynamic characteristics against solitary wave (Qu et al., 2017), the phenomena that tsunami-like waves impinging the ocean and coastal structures would differ with that of solitary waves. Therefore, in this work, impacts of tsunami-like wave on submerged industrial equipment shaped as horizontal circular cylinders was investigated with an incompressible two-phase flow model. The horizontal circular cylinders are often found in offshore and marine structures as marine pipelines, wave energy converters and fish cages, and the essential hydrodynamic quantities needed for engineering design could be obtained with the Computational Fluid Dynamics. For instance, Stokes waves passing the partially/fully-submerged circular cylinders have been investigated by Zhu et al. (2001), Kang et al. (2015), and Ong et al. (2017). And the flow regime from solitary wave acting on circular cylinders has been numerically studied by Xiao et al. (2013), Lin and Liao (2015). To investigate the hydrodynamic characteristics of circular cylinder under tsunami-like waves, the wave profile measured in the 2011 Japan Tohoku tsunami was applied as the input condition to simulate the tsunami-like wave in this work.

To numerically solve the two-phase incompressible flow, based on a self-developing code, the continuity and Navier-Stokes equations were discretized over an unstructured grid system with the Finite Volume Method (FVM), and the Volume of Fluid (VOF) method was used to track the free surface. The numerical model was first validated against the theoretical solutions and experimental data using the solitary wave. Then, numerical studies on the tsunami-like wave impinging submerged circular cylinders were carried out. The hydrodynamic characteristics of the tsunami-like wave versus a solitary wave were discussed, which shows a great disagreement on wave impinging forces and velocity field evolution. Furthermore, the Effects of wave height and submersion depth on the hydrodynamic loads and the influence of cylinder spacing in a tandem arrangement were also investigated.

2. Model description

The three-dimensional Naiver-Stokes solver has been applied to simulate the unsteady incompressible viscous flows with a free surface.

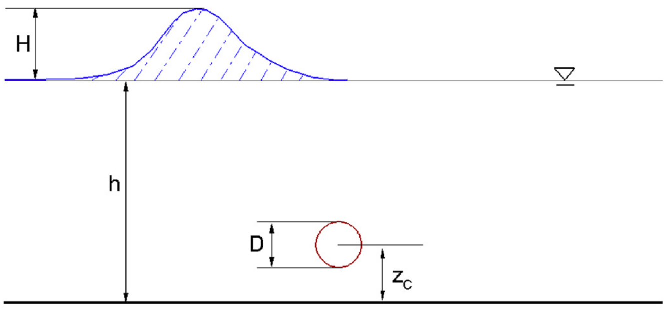
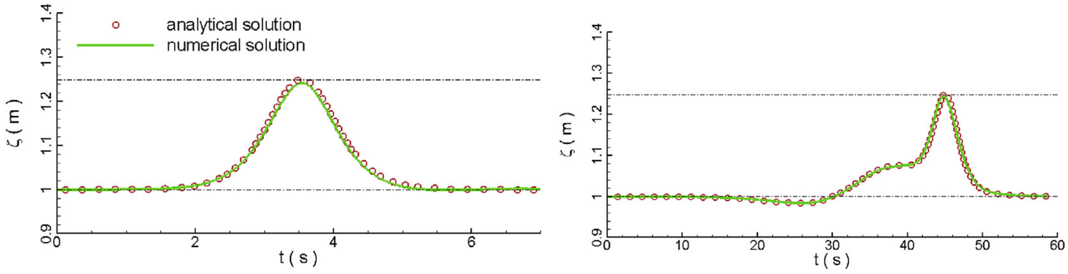


Fig. 4. Computational layout, Z_c is the clearance of the circular cylinder, measured between its centroid and bottom.



(a) (b)

Fig. 3. Wave profile comparisons between numerical and analytical solutions; (a) solitary wave; (b)tsunami-like wave.