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# Dynamic response of a horizontal plate dropping onto nonlinear freak waves using a fluid–structure interaction method

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## HIGHLIGHTS

- This paper present a numerical study of the wave-entry problem caused by freak waves, which is new in the field.
- The freak waves are generated based on the Peregrine breather solution, which is one of the most advanced nonlinear freak wave model.
- During the freak wave-entry impact, the local fluid–structure interaction is considered through a fully coupled method.
- The differences of impact caused by a nonlinear freak wave and a regular wave are revealed.
- The effects of carrier wave amplitude, initial impact location and dropping distance are discussed, which have application value.

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ABSTRACT

Freak waves are giant surface waves with huge wave heights which can lead to severe slamming to ships and offshore structures. However, few researches have been conducted to investigate the wave impact of a dropping plate against nonlinear freak waves. In order to study this phenomenon and predict the structural response of the dropping plate, a 2-D numerical wave tank is built in which nonlinear freak waves based on the Peregrine breather solution are generated. By combining the fluid domain governed by the Navier–Stokes (N–S) equations and the structure domain discretized by the finite element method (FEM) in a fully-coupled way, the fluid–structure interaction (FSI) is considered. Wave impact of a horizontal plate dropping onto a nonlinear freak wave is simulated and the structural responses of the plate including wetted frequency, maximum deflection, vertical velocity and vibration mode are obtained and analyzed. The unique features of the impact caused by the nonlinear freak wave are revealed through the comparison with a regular-wave-induced impact case. Moreover, the effects of carrier wave amplitude, initial impact location and dropping distance are further investigated and discussed in detail respectively.


## 1. Introduction

Freak waves are type of waves that occur unexpectedly in the ocean with huge wave height, which are also called rogue waves, giant waves or episodic waves (Draper, 1965). In the past century, many events of ship and marine structure destructions caused by freak waves have been recorded (Kjeldsen, 1984; Lavrenov, 1998; Dysthe et al., 2008). However,

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existing researches on the fluid–structure interaction between freak waves and ships or offshore structures are still inadequate, especially those with strong impact phenomena.

For decades, the physical mechanisms of freak waves have been widely studied. On the linear focusing theory of the freak wave generation, most studies were conducted with the superposition model. Kriebel and Alsina (2000) gave an approach to generate freak waves by combining the background random sea and an extreme transient wave. Fochesato et al. (2007) introduced a typical simulation of an overturning rogue wave, and analyzed the sensitivity of its geometry and kinematics to water depth and maximum angle of directional energy focusing. Zhao et al. (2010) simulated extreme waves by using the Volume of Fluid (VOF) method. Hu et al. (2014) proposed a probability-based superposition model which reduced the energy proportion of the focusing wave train and improved the simulation efficiency of freak waves based on the superposition model in a numerical wave tank. On the nonlinear formation of freak waves, a widely-studied breather solution of nonlinear Schrödinger equation is called the Peregrine breather (Peregrine, 1983), which governs the modulation of the leading order of the wave surface expansion. Akhmediev et al. (2009) proposed a method for finding the hierarchy of rational solutions of the self-focusing NLS equation. Chabchoub et al. (2012a, b) generated freak waves in an experimental tank using the deep-water-based Peregrine breather solution of NLS equation. Onorato et al. (2013) generated freak waves in his laboratory under finite depth of water with the Peregrine breather solution of NLS equation. Perić et al. (2015) numerically simulated Peregrine breather solution with a two-phase-flow Navier–Stokes model and studied the initial stage of freak waves' breaking. Hu et al. (2015a) successfully simulated Peregrine breather solution based freak waves in a numerical wave tank under finite water depth.

When ships and offshore structures meet with freak waves, severe slamming phenomena usually happen (Graham, 2000; Qin et al., 2017). Therefore, researches on the local impact caused by nonlinear freak waves are necessary. Among all the related works on local hydroelasticity, water-entry impact is one of the most important problems. When freak wave happens, the motions of platforms and ships are unavoidable violent. It is possible that platforms such as semi-submersibles and large ships might be slammed by the crests of freak waves during heave motions. Existing researches mainly focused on water-entry of V-shaped wedges and flat plates against calm water or regular waves. For example, Lu et al. (2000) studied the interaction between a V-shaped body and water, in which the fluid domain and structure domain are approximated by boundary element method (BEM) and finite element method (FEM) respectively. Khabakhpasheva and Korobkin (2013) studied the problem of elastic wedge impact on free surface by combining the Wagner theory with Euler beams. Piro and Maki (2013) analyzed the hydroelasticity of water-entry and water-exit issues using a CFD method. Maki et al. (2011) conducted research simulating fluid and structure domain with CFD and FEM methods, and studied hydroelastic impact of a wedge-shaped body. Similar jobs can be found in Korobkin et al. (2006) and Luo et al. (2012) as well. Faltinsen et al. (1997) studied the wave impact on a horizontal elastic plate experimentally and theoretically which is called the asymptotic method, in which the hydroelastic response of the plate is analyzed in detail. Kvålsvold and Faltinsen (1995) researched on the water slamming against the wet deck of a multihull vessel in head sea waves analytically and numerically by a 2-D asymptotic method. Korobkin and Khabakhpasheva (2006) developed a computational analysis method of an elastic plate dropped against regular waves within the linear potential-flow theory in a 2-D manner. Different impact conditions including central impact and edge impact were considered. Korobkin and Cooker (2013) studied a 2-D problem of an elastic plate impact onto an undisturbed water surface under infinite water depth, in which the plate was forced to move with a constant horizontal velocity. Wang et al. (2015) analyzed the effect of longitudinal compression force on hydroelastic response of a horizontal plate impacting with water surface, in which the plate was represented as an Euler beam and the hydrodynamic pressure was found by solving a boundary value problem. Wang et al. (2016) investigated the hydroelastic response of a horizontal plate impacting onto water at both forward and downward velocities theoretically and numerically. The theoretical model was validated by a fully-coupled algorithm in LS-DYNA and the available experimental data.

All the researches mentioned above mostly treated the fluid domain as calm water or regular waves. However, a different condition might happen because of the unique features of the nonlinear freak waves. Unfortunately, due to the difficulties in generation of nonlinear freak waves, the freak-wave-induced water-entry phenomena have not been studied particularly.

In this paper, nonlinear freak waves are generated using the Peregrine breather solution of NLS equation in a laboratory scale in a 2-D numerical wave tank, which solves the incompressible Navier–Stokes equations and reconstructs free surface by a VOF-Youngs method (Youngs, 1982). The problem of a horizontal elastic plate dropping onto nonlinear freak waves are simulated using a fully-coupled fluid–structure interaction model, which has not been found in existing study. Grid-independence tests on the freak wave generation and the structural response are conducted, in which a validation of the present numerical method is carried out. Then the wave impact of the flat dropping plate against a nonlinear freak wave is simulated and compared with the one against a regular wave based on the 2nd-order Stokes wave theory to reveal the characteristics of the impact caused by nonlinear freak waves. Lastly, the effects of carrier wave amplitude of freak waves, initial impact location and dropping distance are investigated through 3 groups of parametric studies. The structural response in different simulation conditions are reported and discussed, from which meaningful conclusions are drawn. It should be mentioned that the effects of cavitation is not included in the present study, which would need a substantial change to the numerical model to include fluid compressibility or proper cavitation models, as pointed by Ma et al. (2016).

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