J. Marine Sci. Appl. (2017) 16: 27-32
DOI: 10.1007/s11804-017-1397-7

Response Spectrum Method for Extreme Wave Loading With Higher Order Components of Drag Force

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Abstract: Response spectra of fixed offshore structures impacted by extreme waves are investigated based on the higher order components of the nonlinear drag force. In this way, steel jacket platforms are simplified as a mass attached to a light cantilever cylinder and their corresponding deformation response spectra are estimated by utilizing a generalized single degree of freedom system. Based on the wave data recorded in the Persian Gulf region, extreme wave loading conditions corresponding to different return periods are exerted on the offshore structures. Accordingly, the effect of the higher order components of the drag force is considered and compared to the linearized state for different sea surface levels. When the fundamental period of the offshore structure is about one third of the main period of wave loading, the results indicate the linearized drag term is not capable of achieving a reliable deformation response spectrum.

Keywords: offshore structure design, response spectrum method, wave analysis, Morison equation, higher order components, drag force, wave loading, extreme wave

Article ID: 1671-9433(2017)01-0027-06

1 Introduction

When designing a structure the engineer can use the concept of a response spectrum that represents a proper assessment of the structural behavior in extreme conditions. To design a structure, a response spectrum is more prevalent for seismic loads than ocean wave loads. Regarding special considerations for ocean wave loads, this method is not easily applicable. There exists a fundamental difference between a response spectrum of a structure affected by an earthquake and ocean wave loads. In seismic loading, besides the seismic loads characteristics, the response spectrum only depends on the natural vibration period of the structure and is independent from other factors such as geometrical specifications. While in wave loading, the response spectrum of a structure depends on the shape of the structural members, water depth, as well as the natural vibration period of the structure.

The second order drag force for the slender members was investigated using the Morison equation (Morison *et al*. 1950).

Borgman (1967) observed the so-called superharmonic phenomenon where significant peaks occured at the odd-order multiples of the peak wave frequency because of the nonlinear effect of a distributed drag force in a power spectrum of the wave force. Naess and Yim (1996) verified the Borgman observation experimentally by measuring force spectra at twice the peak wave frequency.

The concept of applying response spectra when designing a structure against wave loading was studied by a few researchers. Initially, Veletsos *et al* (1983) conducted a feasibility study on the utilization of the response spectrum concept when designing offshore structures against random waves by applying the respective simplifed assumptions.

Motivated by the Veletsos studies, Tung (1986) demonstrated that one can obtain response spectra of the offshore structures from an equal single degree of freedom model by applying deterministic wave theory and linearizing the drag term. In Tung's study, structural damping was not accounted for and only the hydrodynamic damping was considered. Furthermore, the effect of higher order factors in the drag term of the Morison equation were not taken into account. In later years, other researchers such as Hu and Manadato (1991), studied the concept of response spectra and developed a design response spectra against random ocean waves. The proposed spectra in these studies referred to a specific structure in various hydrodynamic conditions, which was not of interest to many designers.

Instead of a Volterra series based method, a method based on Price's theorem and Fourier transforms was proposed by Zheng and Liaw (2004) for evaluating the nonlinear response power spectra of fixed offshore structures modeled as finite-memory systems.

To convert the waves into structural loads, Morrison's equation is applied. This equation consists of two terms of inertia and drag which are explained in linear and non-linear forms, respectively. One can convert the non-linear drag term into a sum of Fourier components with incremental frequencies and decrementing amplitude. Even if the linear

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Received date: 10-Jun-2016
Accepted date: 05-Sep-2016
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Keulegan Carpenter (KC) number that is an augmentation indicator of drag force in the Morrison equation based on Journee (2001). Also with an increase of water depth, the maximum response of the structure is increased due to structural geometry and the nature of ocean wave loading. As an example, the maximum deck displacement for a structure with a 2 second natural vibration period (D/t =100), excitation by waves with a 100 year return period, in water depth of 50 m, is estimated to equal about 0.05 meter.

4 Discussion and Conclusion

In this study a primary template for obtaining response spectrum of fixed offshore structures under wave loading was proposed. Also the effect of second order components of the drag force on the response spectra of a structure was assessed. The equation of motion for an equivalent single degree of freedom structure was obtained and response spectra of structure with and without consideration of the second order component of the drag force were compared. The results of this investigation showed the second order component of drag term had a decisive impact on the response spectra of the fixed offshore structure. Also, with regard to wave conditions of the Persian Gulf region, various water depths, and various diameter to thickness ratios of the equivalent structure, response spectra of structure diagrams were obtained. These diagrams could represent a fair preliminary estimate of the response of the structure in the initial design stage.

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DOI: 10.1115/1.1834623