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Nonlinear Response of Offshore Structures to High Seas

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This paper presents semi-empirical models for the simulation of responses of offshore structures to very high seas. For the lateral forces and motions, these were applied to the simulation of horizontal impacting force on a fixed column and ringing of the Heidrun TLP. For the vertical motion, the model was applied to the simulation of the heaving and pitching motion of a container ship moored in head seas.

INTRODUCTION

The goal of our research is to develop a technique for simulating extreme responses of offshore structures in very high seas. The first task is to identify the properties of different waves, such as weakly and highly nonlinear waves, field waves, laboratory random waves, strongly asymmetric waves, and freak waves. The second task is to procure appropriate response models to these waves.

The Volterra quadratic model (Dalzell, 1976) has been widely applied for responses to weakly nonlinear waves. However, these weakly nonlinear waves do not exist in very high seas.

CFD, which are quite different from the input-output models, have been used to predict the nonlinear vertical response to large amplitude regular waves. In addition, these codes have recently been employed to simulate responses to Gaussian seas (Fonseca and Guedes Soares, 2004).

In contrast to these, we have developed semi-empirical universal nonlinear input-output models, viz. the UNIOM-kinematics, UNIOM-diffraction, and UNIOM-vertical motion models. The first 2 models are for the simulation of horizontal velocities of wave particles below the free surface and horizontal wave-exciting forces on surface-piercing structures. These 2 models have been employed to simulate the horizontal impacting force and ringing of the Heidrun TLP in highly nonlinear random waves, respectively. The 3rd model has been applied to the simulation of vertical motions in very high seas.

The present discussions are given below under WAVES, RESPONSE MODELS TO SEAS, and CONCLUSIONS.

WAVES

In the study of the response of structures to nonlinear waves, it is essential for researchers to know about the field and laboratory waves.

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KEY WORDS: Volterra quadratic model, semi-empirical universal nonlinear input-output model, sea severity, weakly and highly nonlinear waves, very high seas, freak waves, wave impact force and ringing of TLP.

Field Waves

Field waves have been measured in seas of various severities, locations and seasons. Such field wave data have been collected in the form of wave energy density spectra that are defined by the significant wave height and zero-crossing period. In addition, strongly asymmetric waves (Myrhaug and Kjeldsen, 1984) and Draupner freak waves (1995) have recently been observed in the field.

Description of Sea Severity

Sea severity is defined in terms of the range of significant wave height, as shown in Table 1. For instance, very high seas are found in the significant wave height range from 9.00 m to 14.00 m, and the highest frequency of occurrence appears to be in the northern North Atlantic.

The Table 1 data do not include the recent major hurricane-induced sea severity. For instance, API stated that for the return periods of 25, 50, 100 and 1000 in the western Gulf of Mexico, the significant wave heights are H_s (m) = 9.8, 11.3, 13.1 and 16.4. Comparing these sea states with the sea codes given in the above table, we find them belonging to the very high and phenomenal sea sets.

Laboratory Random Wave and Reflection Coefficient

Field waves are usually modeled in a wave tank employing the target spectra.

			Frequency of occurrence		
Code	Description of sea	H_s (m)	World-wide	North Atlantic	Northern North Atlantic
0	Calm (glassy)	0.0	11.2486	8.3103	6.0616
1	Calm (rippled)	0.00~0.10			
2	Smooth (wavelets)	0.10~0.50			
3	Slight	0.50~1.25	31.6851	28.1996	21.5683
4	Moderate	1.25~2.50	40.1944	42.0273	40.9915
5	Rough	2.50~4.00	12.8005	15.4435	21.2383
6	Very rough	4.00~6.00	3.0253	4.2938	7.0101
7	High	6.00~9.00	0.9263	1.4968	2.6931
8	Very high	9.00~14.00	0.1190	0.2263	0.4346
9	Phenomenal	over 14.00	0.0009	0.0016	0.0035

Table 1 Description of sea severity (Price and Bishop, 1974)