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Experimental and numerical investigation of wave forces on partially submerged bodies in close proximity to a fixed structure

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ABSTRACT

Impact loads on an offshore structure due to wave driven icebergs and bergy bits are an important design concern. The hydrodynamic interaction between an iceberg or a bergy bit and an offshore structure, when the two are in close proximity, is an important factor that governs the impact speed and consequently the input energy. Recently, a set of experiments was conducted at the Ocean Engineering Research Center (OERC) of Memorial University of Newfoundland to measure wave loads on different sized spherical masses at different proximities to a fixed structure. A six component dynamometer was used to measure the loads in six regular waves. The objective was to investigate changes in wave load on the sphere at different separation distances from the structure. The experimental results show that the distance to wavelength ratio dictates the corresponding wave loads in horizontal and vertical directions. The mean drift force in the horizontal direction becomes negative (against the direction of wave propagation) for most cases, when the body is close to the structure. Also, as the body is positioned closer to the structure, the non-dimensional RMS forces in the horizontal direction decrease, and the non-dimensional RMS forces in the vertical direction increase. This implies that the approaching body will be slowed down in surge but at the same time will experience increased heave motion. Numerical studies for some of the experimental cases, using the commercial CFD software Flow3D, show good agreement with the experimental data.

1. Introduction

The impact of small (1000 t–20,000 t) pieces of glacial ice with offshore installations is a potential hazard for operations off the east coast of Canada and in other regions where icebergs are common. Pieces of ice this size are small enough to be affected by wave action and Standards such as ISO 19906 (2010) stipulate that ice movement due to waves should be considered when designing such structures. Although many studies have indicated that small ice masses tend to drift around large fixed structures (Isaacson and McTaggart, 1990b, 1990c; Salvalaggio and Rojansky, 1986) without actually hitting the structure, the conservatively adopted approach has more often been to add the mean drift velocity to the peak wave induced velocity to derive a worst case ice impact velocity (Lever et al., 1988b; Fuglem et al., 1999). Several studies have noted that impact velocity can be substantially reduced and several phenomena such as negative wave drift force, fluid cushioning, shadowing, change in added mass, hydrodynamic damping, eccentric impact etc. have been reported because of reflected and standing waves (Bolen, 1987; Colbourne et al., 1998; Colbourne, 2000; Gagnon, 2004). A number of studies specifically related to wave induced motions with emphasis on smaller ice fragments have been conducted since 1980. A series of experiments conducted by Attwood (1987), Lever et al. (1988a, 1988b) revealed that small icebergs showed fluid particle type behavior for wave length/ iceberg size ratios greater than 13. Salvalaggio and Rojansky (1986) observed that no impact occurred if the iceberg diameter was less than approximately half the structure diameter. Upon finding considerable effects of iceberg model shape on wave induced motions, Lever et al. (1990a) extended their impact velocity probability statistics to include randomly varying iceberg shape. Lever et al. (1990b) conducted model tests of wave driven bergy bits impacting with a semi-submersible in irregular waves. Mak et al. (1990) conducted a similar study in regular and irregular waves with a floating oil production platform with larger physical dimensions than the transparent semi-submersible tested by Lever et al. (1990b). Wave diffraction effects were observed with fewer impacts in beam seas than head seas, and a substantial reduction in impact rate for the smaller berg. Isaacson and McTaggart (1990a) presented summary results of experiments carried out to investigate

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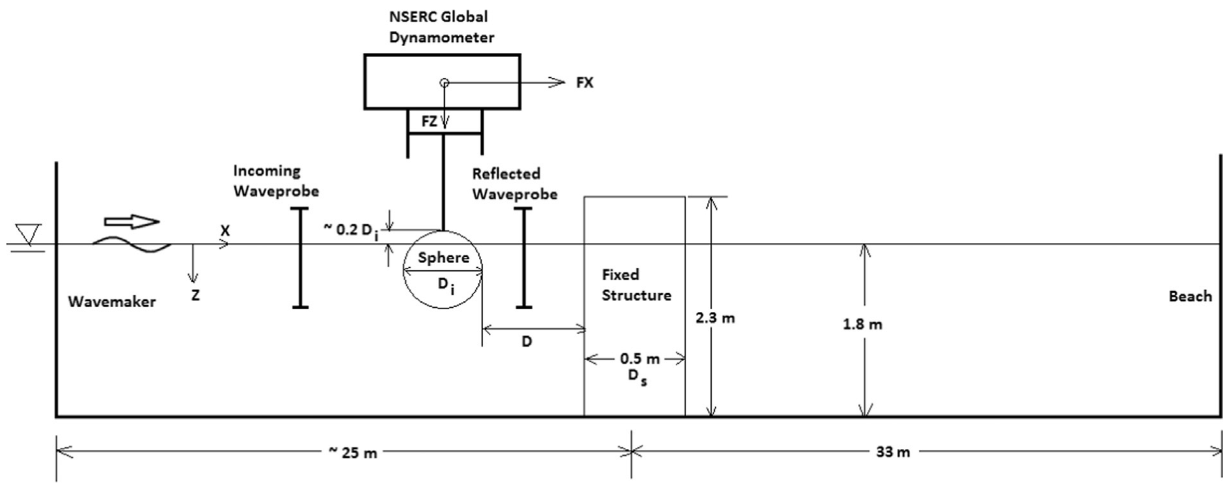

Fig. 1. Schematic layout of the experimental set up in towing tank.

Fig. 2. Experimental set up – dynamometer, fixed structure and sphere D_i/D_s=0.6.

Table 1
Wave particulars.

	Wave height, H (m)	Wave period, T (s)	Wavelength/ structure diameter (λ/D_s)	Wave frequency, f (Hz)	Wave steepness (H/λ)	Wave period (s), full scale
Wave -1	0.05	0.98	3	1.02	1/30	6.93
Wave -2	0.067	1.13	4	0.88	1/30	7.99
Wave -3	0.083	1.26	5	0.79	1/30	8.91
Wave -4	0.1	1.39	6	0.72	1/30	9.83
Wave -5	0.0875	1.06	3.5	0.94	1/20	7.49
Wave -6	0.1125	1.2	4.5	0.83	1/20	8.49

iceberg drift in proximity with offshore structures. For the cases when waves were the only driving force, no impact occurred when the ratio of iceberg diameter and structure diameter is less or equal to 0.2 whereas Salvalaggio and Rojansky (1986) in their experiments found the ratio to be 0.5. Kazi et al. (1998) conducted experiments to investigate hydrodynamic interaction between a fixed cylinder and free floating cylinders of various shapes and sizes. A repulsive interaction force was observed between the fixed and floating cylinder. Model experiments for the Terra Nova FPSO (Colbourne et al., 1998) indicated that impact energies may be reduced in higher sea states and it was speculated at the time that this may be due to wave reflection or other near-field hydrodynamic effects. Gagnon (2004) conducted comprehensive model tests to investigate hydrodynamic interaction between floating ice mass with a tanker passing at speed. This study indicated that the radiation/ proximity effect can be significant but this work did not directly consider collisions. An increase in maximum sway motion was also observed due to the presence of the tanker as a temporary wall boundary thus influencing the wave-induced hydrodynamic forces on the ice mass. The author attributed this to negative added mass and drift force because of standing waves between the tanker and the ice mass. Tsarau et al. (2014) tested a fixed submerged sphere (ice mass) and a cylinder (structure) was towed past the sphere at different speeds and separation distances in calm water. The hydrodynamic forces were found to vary between positive and negative depending on separation distance. Kim (2014) conducted drop tests of laboratory grown ice blocks onto stiffened steel panels in air and impact tests in water with a moored structure and ice blocks towed at 1 and 2 m/s at NTNU and Alto University. The objective was to investigate simultaneous inelastic deformations of ice and steel structure and the drop tests in air helped to separate associated hydrodynamic aspects. McGovern and Bai (2014a) conducted an experiment on isolated ice floes and investigated their kinematics in regular waves. The motions observed for ice floes were found to be different than those of icebergs because of flat low draft geometry of ice floes. McGovern and Bai (2014b) investigated the presence of a circular cylinder on the kinematics of ice floes in regular and irregular waves. At separation distance to cylinder diameter ratio less than 10, increase in heave response and significant reduction in surge response was observed.

A considerable volume of work has been directed towards the iceberg-structure interaction problem. It is clear that predictions of ice impact loads depend most strongly on the velocity at impact and that this velocity depends on the hydrodynamic forces at play just before impact. It is evident from the literature that the complex hydrodynamic