EXPERIMENTAL AND NUMERICAL STUDY ON OBLIQUE WAVE-IN-DECK LOADS

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INTRODUCTION
Most studies on wave-in-deck loads focus on head-on wave impingement whereas wave-in-deck loads due to waves incident from oblique directions are rarely reported. Numerical simulations for oblique wave-in-deck loads were presented in Iwanowski et al. (2002), Brodtkorb (2008) and Chen et al. (2018). However, in these studies, only numerical validations were performed against either two-dimensional experiments or empirical formulations due to a lack of experimental results. In light of this, we present the experimental results for wave impacts on a solid deck model due to a transient focused wave group incident from oblique direction in this study. The oblique experimental data is compared with the head-on counterpart by Santo et al, (2020) to investigate the incident wave angle effect on wave-in-deck loads. Numerical simulations are carried out to reproduce both the head-on and oblique wave-in-deck experiments using a three-dimensional (3D) numerical wave tank (NWT), and flow field information is interrogated to derive physical insights into complex wave-deck interactions. The solid deck model is a representative of a typical 2nd generation North Sea topside structures commonly exposed to severe winter weather. The configuration is also applicable to coastal structures such as bridges, piers, jetties or docks.

EXPERIMENTAL
Model tests of wave impacts on a solid deck were conducted in the towing tank of the Kelvin Hydrodynamics Laboratory at the University of Strathclyde, Glasgow. A transient focused wave group was used to impinge on the deck model in the experiments. Two relative headings were considered, i.e. head-on when the wave propagation direction was aligned with the long-side of the deck model and oblique when the deck model was rotated clockwise (viewing from above the deck model) by 45 deg from the head-on position. Figure 1 shows the experimental set-up for the oblique wave-in-deck test.

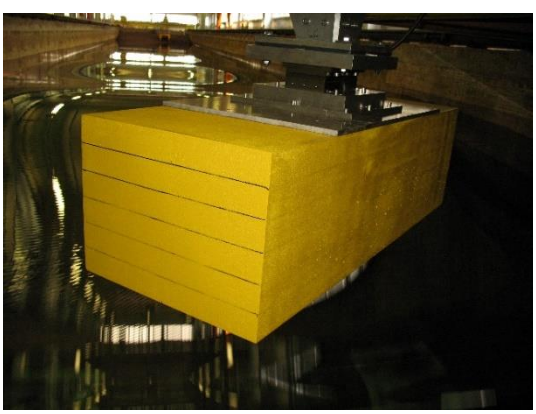

Figure 1 - Illustration of oblique wave-in-deck experimental set-up.

The incident transient wave group was based on a JONSWAP spectrum with peak frequency of 0.52 Hz, and was set to focus at the leading edge of the deck model from the head-on position with a nominal crest amplitude of A = 25.6 cm. The solid deck model was suspended above the still water level with clearance of s = 23.5 cm, so the inundation level was 2.1 cm. The dimensions of the box were (L, B, H)=(1.05, 0.4, 0.3) m, where L, B and H are the length, width and height of the deck model, respectively. The longitudinal, transverse and vertical wave loads on the deck structures were measured in the experiments using a six degree-of-freedom piezoelectric load cell with a sampling frequency of 3571 Hz, which provided a stiff single point support for the deck model as shown in Figure 1. A resistance-based wave probe, sampled at the same rate as the load cell, was mounted from the towing carriage midway between the head-on leading edge of the deck model and the side of the tank to provide incident wave information.

NUMERICAL
A 3D NWT is established to accommodate the structure using OpenFOAM. The open source toolbox 'waves2Foam' (Jacobsen et al. 2012) is used for wave generation and wave absorption. The governing incompressible Navier-Stokes equations in Eulerian coordinates are solved using a finite volume method without use of any turbulence models. The interface between air and water, the free-surface, is tracked using a modified volume of fluid approach. Following the mesh independence study of Wang et al. (2022), the mesh sizes for proper wave generation and propagation are chosen to yield ~550 cells per peak wavelength streamwise and ~ 200 cells per nominal wave height vertically. The transverse mesh size is chosen to have ~730 cells per peak wavelength. To save computational cost, the length of the NWT is reduced and the focus point is shifted closer to the inlet boundary. To account for the difference caused by the change of focus location in the NWT, an iterative method (Vyzikas et al. 2015; Wang et al. 2018) is employed to re-create the experimental incident wave signal recorded at the focus point. Figure 2 shows the time series of the re-created incident wave crest in the NWT compared with the experimental data, where good agreement is achieved.

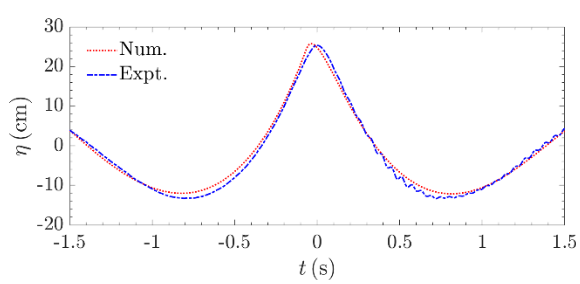

Figure 2 - Comparison of re-created incident wave with experimental data.

RESULTS

Figure 3 and Figure 4 show the comparison of force time series between the experimental and numerical results for the head-on and oblique wave impact cases, respectively. The longitudinal force is along the wave propagation direction and the transverse force is horizontally perpendicular to the longitudinal force. In the experiments, it was discovered that the single point support system was a lot stiffer in the vertical direction than the horizontal direction. Therefore, both longitudinal and transverse force records exhibited oscillations after the wave impact due to structural resonance of the overall system, while the vertical force records were not affected. Similarly, the box model is modelled with rigid support in the NWT and hence the numerical simulations are not affected by the resonance.

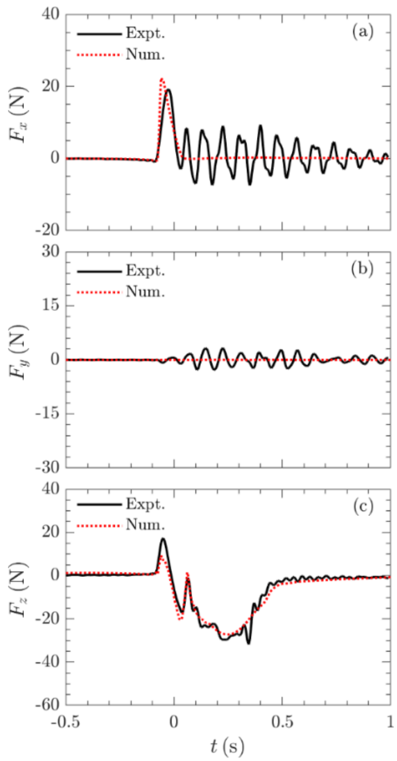

Figure 3 - Comparison of experimental and numerical force time series for the head-on wave impact case. (a), (b), (c) are longitudinal, transverse and vertical forces, respectively.

From the comparison of experimental results with different incident wave angles, it is found that the maxima of the longitudinal force and upward vertical force associated with wave impingement near the front-corner of the deck become smaller when the deck is rotated from the head-on to oblique configuration, while the durations of forces become longer. The oblique test has a larger transverse force as expected and larger downward vertical force than the head-on case.

Generally, the numerical results are in good agreement with the experimental data for both the head-on and oblique cases, despite the fact that the upward vertical forces in both cases being consistently under-predicted by the numerical simulations. The oscillations in the experimental force time series and the slight phase difference observed from the comparison of longitudinal peak force for the head-on case can be removed by low-pass filtering.

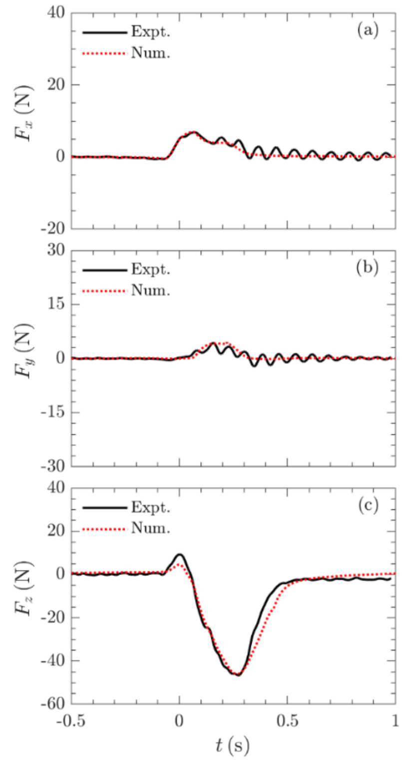

Figure 4 - Comparison of experimental and numerical force time series for the oblique wave impact case. (a), (b), (c) are longitudinal, transverse and vertical forces, respectively.

Figure 5 and Figure 6 show the free-surface and pressure contour on the front and side faces of the deck model for the head-on and oblique cases, respectively. For the head-on wave case, the incident wave impinges directly on the front-face of the deck, forming a jet shooting vertically upwards. Most of the momentum of the wave crest is destructed during the interaction. As the wave crest propagates away from the front-face, minimal pressures are induced at the side faces. Due to the symmetric geometry of the head-on configuration, the transverse force remains almost negligible.

For the oblique wave case, the incident wave crest impinges on the upstream corner of the deck model before travelling down along the short-side and long-side of the deck, inducing positive pressure regions near the bottom of the front-face and side-face. In contrast to the head-on case, the momentum of the wave crest keeps being destructed as the crest propagates down-wave (see Figure 6(b)), which explains the longer force duration for the oblique wave case as mentioned earlier. The oblique configuration is symmetric till when the wave crest reaches the end of the short-side (or front-face), see the pressure field at t=0.06 s shown in Figure 6(a). As a result, the transverse force is almost zero before t=0.06 s and lags behind the occurrence of the longitudinal force.

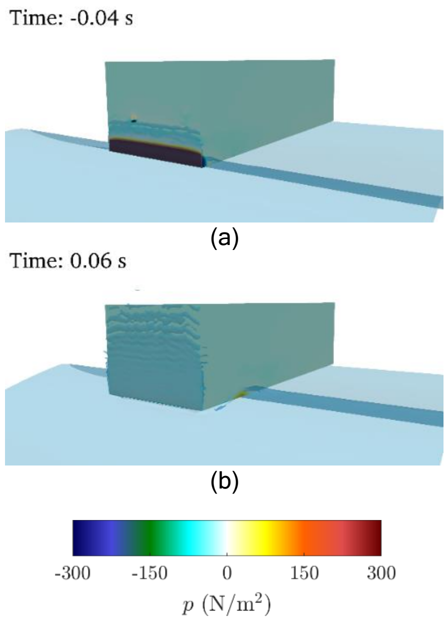

Figure 5 - Snapshots of free-surface and pressure contour for the head-on wave impact case.

The larger downward vertical force of the oblique wave case than the head-on counterpart is due to the larger added mass effect associated with the volume of fluid underneath the fully wetted area accelerating downwards and the wave-back of the crest interacting with the long-side edge of the deck model. The full wave-deck interactions including the free-surface and pressure field on the underside of the deck will be shown in the conference.

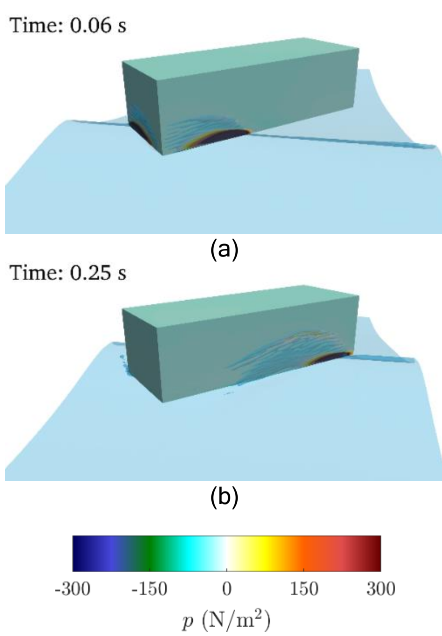

Figure 6 - Snapshots of free-surface and pressure contour for the oblique wave impact case.

CONCLUDING REMARKS

The experimental results for oblique wave-in-deck loads have been presented and compared with the head-on wave-in-deck experimental data. Numerical simulations have been carried out to successfully reproduce the experiments in the three-dimensional numerical wave tank. The differences between the head-on and oblique wave impact loads on the deck are investigated by interrogation of flow field information. More details will be provided and discussed in the conference.

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