Fluid Structure Interaction Analysis of Abnormal Wave Slamming Events

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Introduction

A slamming impact is a highly nonlinear fluid-structure interaction problem characterised by high pressure peaks localised in time and space. Slamming loads can lead to severe structural damage, and may be a problem for the local structural integrity as well as the global behaviour of offshore structures and ships. The breaking waves in a slamming impact are challenging to recreate in model tests and in numerical simulations. The coupled interaction between the structural response and the fluid flow also adds complexity to the problem. Simplified methods and numerical simulations can be useful tools for estimation of the structural response, although several aspects of the slamming phenomenon have to be simplified. So far, slamming experiments have only been conducted for elastic structural response. For abnormal wave slamming actions, the response will be elasto-plastic with large deformations. There is a need for experimental data for nonlinear plastic deformations to verify the numerical and analytical calculations of slamming impacts.

Objective and Scope of Work

The focus in this thesis has been to investigate established engineering practice for estimation the dynamic response of a stiffened panel. The analytical estimations have been compared with nonlinear structural analysis in LS-DYNA where the slamming impact was recreated as a drop test. Another part of the thesis has been to perform an experimental drop test of a water-structure impact causing nonlinear plastic deformations. The goal of the drop tests is to use the experimental data to validate the numerical simulations in LS-DYNA and to obtain a better understanding of the physical effects of the slamming phenomenon.

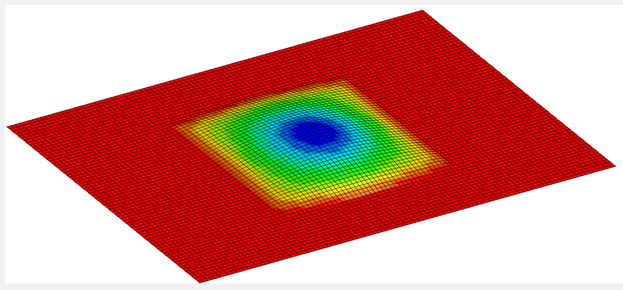
References

[1] J. Amdahl, Z. Yu, and Y. Sha. Large inelastic deformation resistance of stiffened panels subjected to lateral loading. *Marine Structures*, 2017.

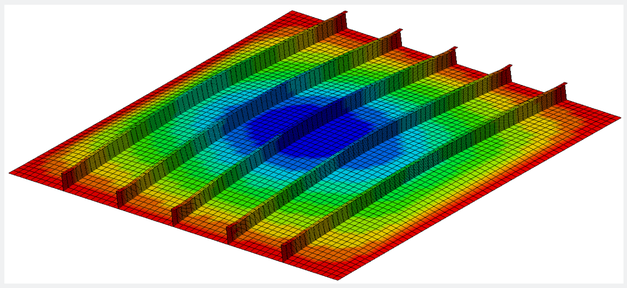
[2] DNVGL. Dnv-rp-c204 design against accidental loads, 2016.

Numerical Simulations in LS-DYNA

The finite element model of the drop test impact was modelled in LS-DYNA. The drop tests have been conducted with an unstiffened aluminium plate embedded in a rigid plate and a top side steel plate in full scale. The plate falls through air with an initial velocity towards a calm water surface. The impact is simulated using an ALE-formulation where the water and air are modelled as Eularian elements and the structure as Lagrangian elements. The fluid-structure interaction is defined though a coupling algorithm that estimates the penetration force of the slave plate though the master fluid elements. The duration of the load impulse relative to the highest natural period of the plate, categorises the impacts in the dynamic impact domain. Contour plots of the maximal lateral deformation of the plates during the drop test impact are shown below.



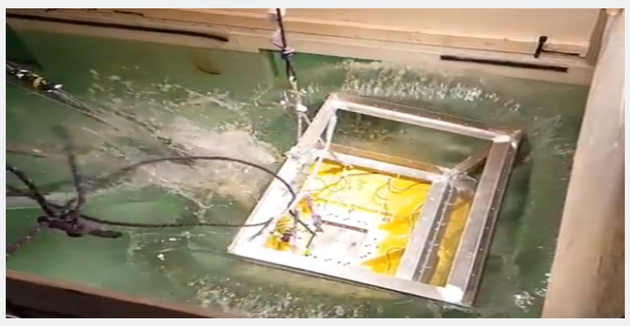
(a) Unstiffened aluminium plate

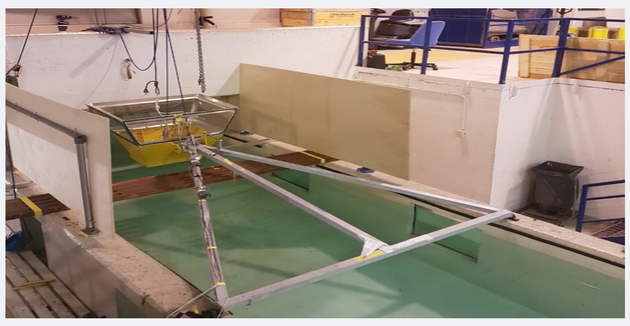


(b) Top side stiffened steel panel

Experimental Set-up

The drop tests with the aluminium plate have been performed in a basin at Marintek. The plate is made of pure aluminium A1050 H111 and has plate thickness of 0.6 mm. The aluminium plate represents a full scale 3x3 m^2 marine panel. The aim of the drop test is to estimate the plastic response of the plate, so the scaling factor λ=13.92 is chosen with respect to correct scaling of the plastic membrane capacity. Snap shots from the drop tests are shown below. The deformable plate is clamped to a rigid steel box that is connected to the bottom of an impactor. The impactor is connected to an arm, which is lowered with ropes to control the initial drop heights. Digital image correlation cameras, DIC, are applied to monitor the plastic deformation during the impact. Four accelerometers and pressure sensors are connected to the bottom of the impactor.



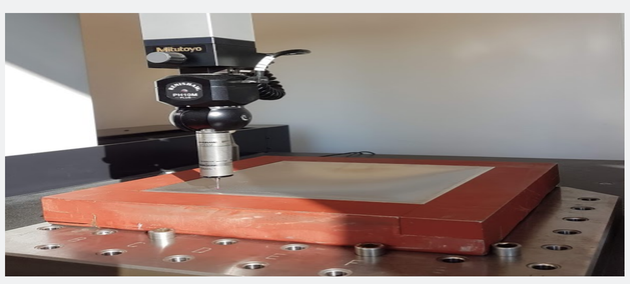


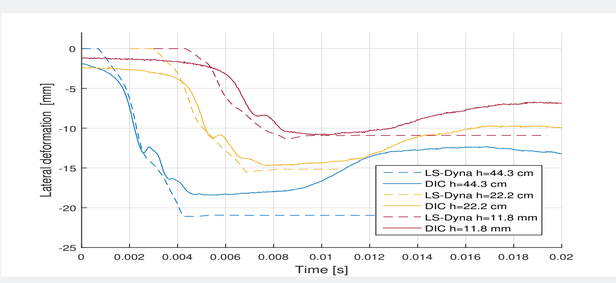
Simplified Methods for Response Estimation

The simplified approach in [1] was applied to find the deformation resistance of the stiffened panel to uniformly distributed lateral loads. The analytical resistance curves were compared to static pressure-deformation curves from LS-DYNA. The single degree of freedom analogy, SDOF, for calculation of response to explosion loads in [2] was applied to predict the maximal dynamic response for the slamming loads.

Results and Discussion

The manually measured permanent deformations agreed well with the permanent deformations from DIC. The FE simulations do not include the decelerate mechanism from the ropes in the drop test, so the maximum deformations are almost permanent. It was also observed entrapped air under the aluminium plate during the impact. Effects of entrapped air has not been modelled in detail in LS-DYNA. For drop test with 0 degree impact angle, the FE simulation estimates larger maximum deformations than the DIC measurements. However, there are good agreement between response predictions in LS-DYNA and DIC for smaller drop heights. When the impact angle is 4 degrees, the maximum deformation is underestimated. The numerical analysis manages to capture the main deformation shape of the plate, but a more detailed analysis is necessary in order to capture the physical effects in detail. The simplified methods provided conservative estimates of the deformation resistance of the stiffened plate, especially for bi-axial membrane stress states and high strain hardening effects. The SDOF analogy for dynamic response estimation gave a maximum deformation with very good agreement to the maximum deformation of the stiffened plate in LS-DYNA.





Conclusion

The numerical simulations in LS-DYNA provide a reasonable estimation for the maximum deformation, especially for smaller drop heights. However, the FE analysis could be improved by modelling the impact conditions of the experimental drop tests with more details. The simplified method for response prediction of explosion loads provided accurate estimations of the maximum slamming loads.

Video from Drop Test

Scan the QR-code to see a video from the drop test experiments.