Singularization of Sloshing Impacts

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Highlights

- In the context of long duration sloshing model tests, it was investigated whether sloshing impacts selected from long model tests can be exactly generated with only a short test which was proven to be the case. In other words in order to regenerate a selected impact with any comfity, 15-60 s of relevant tank motions would be sufficient and there is no need to run the complete test until the impact time,
- Regenerating the most relevant impacts with such short test durations enables to quickly perform many repetitions and possibly gain more relevant statistics from samples of pressure peaks,
- Singularization enables a categorization of the impacts with their distinctive physical and statistical properties.

1 Introduction

As outlined by Gervaise et al. (2009) and Kuo et al. (2009), any sloshing assessment of LNG carrier membrane tanks is based on long duration sloshing model tests, usually at scale 1:40, performed with accurate 6 degree of freedom motion platforms. Clusters of pressure transducers are put on the most impacted areas of the tank walls, recording at a high sampling frequency. Samples of pressure peaks are gathered from tests corresponding to all the conditions that the ship will encounter during her life. Every model test is repeated several times in order to enrich the corresponding statistical sample of pressure peaks. Despite many repetitions of every model test the tails of the samples are often poor and statistical distributions (mostly Weibull) are fitted to data in order to extrapolate and predict the extreme loads. In every gathered sample of pressure peaks found from several repetitions of the same model test, peaks corresponding to different impact types (slosh, flip through, and gas pocket) are mixed together. Also every model test at scale 1 : 40 corresponding to a 5 hour sea state would take about 50 minutes to complete and having many repetitions would take a long time.

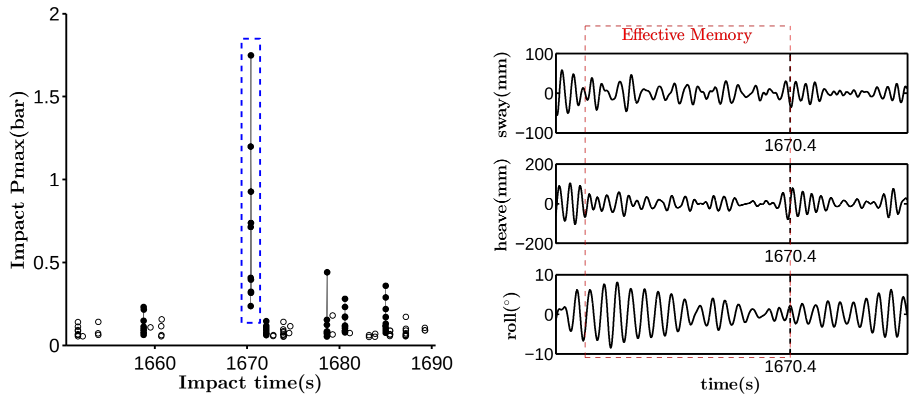
An alternative would be to be able to focus on single impacts and necessarily the most relevant ones with a less time consuming method. One way to achieve this would be to first track down impacts of long sloshing model tests from the knowledge of *impact coincidence* as explained by Karimi and Brosset (2014). It would be then favorable not to spend a long time (in the order of a complete model test) to regenerate every selected single impact. The objective of the study is to show that only short tank motions right before the desired impact time are necessary to recreate the same exact impact conditions with the right statistical properties as obtained in long model tests. It will be demonstrated that there is only a short *effective memory* (m_e) in terms of tank motions, before the selected impact time that should be respected. A study based on 2D sloshing model tests is presented in order to verify the feasibility of this impact singularization.

2 Test Setup

The internal geometry of the utilized tank (made of PMMA) corresponded to a transverse slice of a LNG carrier membrane tank at scale 1 : 40. The tank was placed on an accurate six degree-of-freedom motion platform (hexapod) and filled at 20% of the tank height with water. The Ullage gas was air at atmospheric pressure and ambient temperature. 60 PCB pressure sensors were arranged in a 15×4 regular array with a 10 mm distance between the center of the sensors both horizontally and vertically. The array was placed on the vertical side of the tank, covering the area impacted by the breaking waves during the tests. The sampling frequency of the acquisition system was set at 40 kHz. Only sloshing events (impacts) for which one pressure signal exceeded a threshold were recorded. A Phantom V7.2 high speed video camera was fixed to the tank looking at the sensor array and recording at 4000 fps in order to capture the wave impacts. It was triggered by pressure sensors when exceeding another threshold and was synchronized with the data acquisition. A semi high speed video camera set at 96 fps was fixed to the platform in the plane of symmetry of the tank at the free surface level, far enough from the transverse tank wall in order to capture continuously the entire free surface.

3 Approach

Irregular motions were imposed on the tank by the hexapod. The motions were downscaled to scale 1:40 according to Froude similarity from BEM calculations of ship motions for a 5 hour sea state with a zero crossing period of $T_z = 8\,s$ and a significant wave height of $H_s = 6\,m$. Only the three degrees of freedom in the plane of the tank (sway, heave and roll) were used. The duration of one test was $2966\,s$ long including ramps at both ends.



(a) (b)

Fig. 1: (a) The maximum pressure for the chosen impact as captured in 10 repetitions of long model tests (b) It is assumed that only a short duration of tank motions immediately before the impact governs the fluid flow at the impact time as if there is a short effective memory involved

10 repetitions of the same tank motions were performed. Based on the knowledge of impact coincidence as introduced by Karimi and Brosset (2014), an impact was selected occurring at exactly $t = 1670.4\,s$ in all the repetitions as shown in *Fig.* 1(a). Maximum impact pressures recorded at sensor level for the 10 impacts covered a rather large range which specially included high pressures.

The wave shapes corresponding to 9 out of 10 of these repetitions were recorded as depicted in *Fig.* 2. There were slight variations of the wave shape. The unique form of the crest made it distinctive. This impact made a target for the verification.

3DOF motions right before the expected time of the chosen impact were applied on the tank with a range of durations from 1 second to 120 seconds to be able to find the right *effective memory*. Fig. 3 shows the shortened heave signals (for sway and roll similar procedure was used) to respect effective memories of 15, 30, and 90 seconds. The motions continued for 1 second after the expected impact time. The extracted signals were completed by $5\,s$ and $1\,s$ long cubic-splines respectively at the beginning and the end for smooth transition to zero motion (continuous accelerations). In order to facilitate the comparison between the tests, a common initial time convention $t = 0$ was taken at the nominal impact time.

4 Results

For very short motions, global flow did not have time to match the global flow obtained from long duration tests. For durations of 15 seconds and more this matching was more obvious as depicted by *Fig.* 4 and continued until

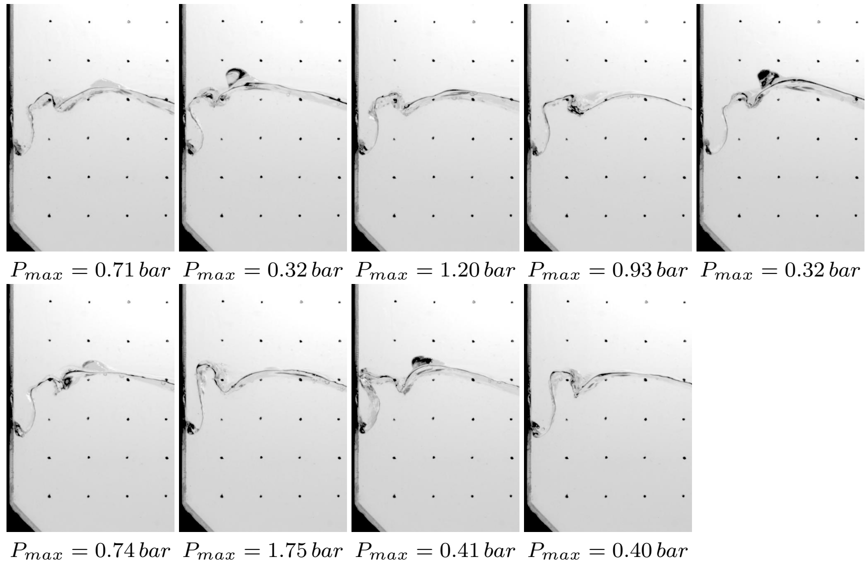


Fig. 2: The high-speed video recordings of the chosen impact captured in 9 out of 10 repetitions of long duration model tests and the maximum induced pressures at sensor level

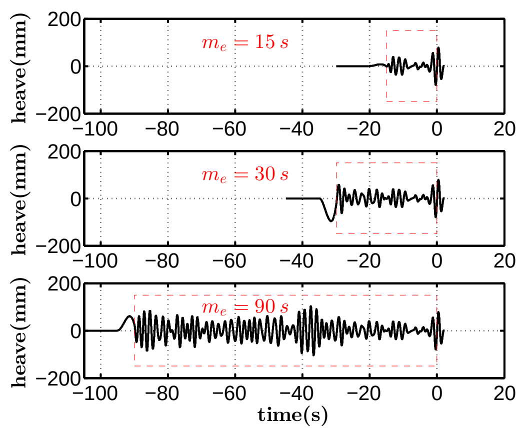


Fig. 3: The heave signals cut assuming 15, 30, and 90 seconds of effective memory. The same procedure was used to cut sway and roll signals.

the moment of the impact[1].

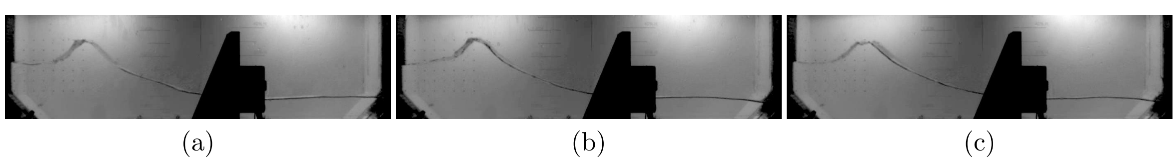
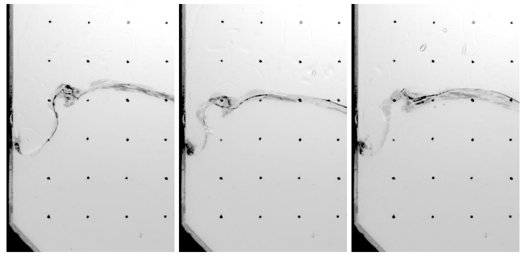


Fig. 4: The global flow in the 2D tank, 2.4 seconds before the impact time with assumed effective memories of (a) 15 seconds (b) 30 seconds (c) 90 seconds

At time $t = 0$ impacts were recorded as shown in *Fig.* 5 which geometrically looked very similar to the ones obtained from long duration tests. The differences between impacts obtained with different durations exist as was the case for impacts obtained from long tests and differences observed at the nominal impact time were comparable with the initial variations observed during the ten repetitions of the complete tests.

Taking benefit of the short excitation duration for recreating a given impact condition, 3000 repetitions of the same impact were created in GTT's laboratory. An excitation with the assumed $m_e = 30\,s$ was used for each test and a break time of one minute was applied in between every two repetitions. More repetitions could have

[1] Click on the *link* to watch the corresponding video or use the address: *http://youtu.be/1ibUgIqTsBs*. From the video, it is clear how the global flows progressively match together especially for the top one which has just started.



$P_{max} = 0.44\,bar$ (a) $P_{max} = 1.72\,bar$ (b) $P_{max} = 0.41\,bar$ (c)

Fig. 5: The impact geometry and maximum impact pressures obtained with assumed effective memories of (a) 15 seconds (b) 30 seconds (c) 90 seconds

been obtained considering a smaller excitation duration and no break between the tested conditions. Maximum pressure obtained from the 3000 repetitions was 3.14 bar to be compared with a maximum of 2.06 bar measured in all the impacts of the ten initial repetitions of the complete irregular test. Different sets of many repetitions for excitations of different durations are intended to be performed soon in GTT in order to complete the study and check whether the samples of pressure peaks are statistically equivalent or not.

5 Conclusions

For short 2D tank motions at scale 1 : 40 the global flow is able to match the global flow obtained from complete long excitations as long as the duration is larger than 15 s. In that case the variations obtained on the wave shape before the nominal impact for short durations are visually as small as the variations observed for repetitions of the long duration test. The study still needs to be continued and in order not to bias any statistics, it should be shown that the variability associated to the flow and finally to the pressure measurements remains similar to the variability that can be obtained from long duration tests.

Singularization of sloshing impacts could lead to new ways to quickly build more relevant pressure statistics for sloshing assessment as

- Instead of mixing measured pressure data from different impact types (a wide range of slosh, gas pocket, and flip-through) during statistical post processing, focus can be made on the same types of impacts and the statistical analysis would be more relevant,
- Instead of performing a limited number of long sloshing tests, thousands of repetitions for dedicated tests on single impacts could be done in a much shorter time with focus on the most relevant impacts which could save time and generate sounder statistical samples.

References

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