VIOLENT IN-CHAMBER LOADS IN AN OSCILLATING WATER COLUMN CAISSON

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SUMMARY

In 2009, four of 16 chambers in the Mutriku breakwater-integrated Oscillating Water Column (OWC) were badly damaged by storms, probably due to breaking wave loads, and slam within the chamber. To minimize exposure of future plant to such risks, it is necessary to characterise wave conditions under which such an installation could experience impact loads. This characterisation can be crucial to controling the power-take off resistance to increase the survability of the device during extreme weather. Large scale physical model tests in the Grosse Wellenkanal (GWK) included a video camera installed inside the chamber facing the rear chamber wall. Pressure sensors in the ceiling of the chamber were utilised to quantify the water loads. In-chamber impact pressures of up to 8 ρgH were recorded on the chamber ceiling, associated with the 'sloshing' observed. The "sloshing" phenomenon is not uncommon and should be considered in design processes.

INTRODUCTION

The idea of integrating a wave energy converter into a coastal defence or breakwater is not new. This will allow cost sharing between energy generation and harbour / coastal defence functions. Unfortunately, the Mutriku case (see *e.g.* Medina-Lopez, *et al.*, 2015) demonstrated that design uncertainty and unpredictable weather may contribute to potential damage. There is extensive literature - based upon physical and numerical modelling - exploring loadings on the structure and within the chamber. Computational approaches however often assume the water column inside the chamber to behave simply - an assumption not supported by experimental visualisations of the water movement inside the chamber, *e.g.* Müller & Whittaker (1995). Those experiment showed that the water inside the chamber may behave violently under certain waves. Violent, impulsive pressures are however not easily quantified. The new experiements reported here quantify these internal impulsive loads for the first time at large scale.

METHODOLOGY

The experiments were done in the very large wave channel GWK in Hannover, Germany. The model OWC caisson was located 95 m from the wave maker. Power take off (PTO) was modelled using three different orifice diameters (0.1, 0.2 & 0.3 m). In addition, a closed orifice case was also tested. Two arrays of four wave gauges gave offshore and inshore wave conditions. Five further gauges measured in-chamber water levels, at the four corners and at the centre. Twelve pressure gauges were arranged on the front wall, rear wall, and in the chamber ceiling. Two cameras were deployed to get the qualitative image of the water movement: one inside the chamber facing the rear wall, and one outside the structure facing the front wall. A full description can be found in Viviano *et al.* (2016).

RESULTS AND ANALYSIS

A violent sloshing phenomenon is shown in the video sequence (Figure 1), for T_p = 5 s, H_{m0} = 0.81m.

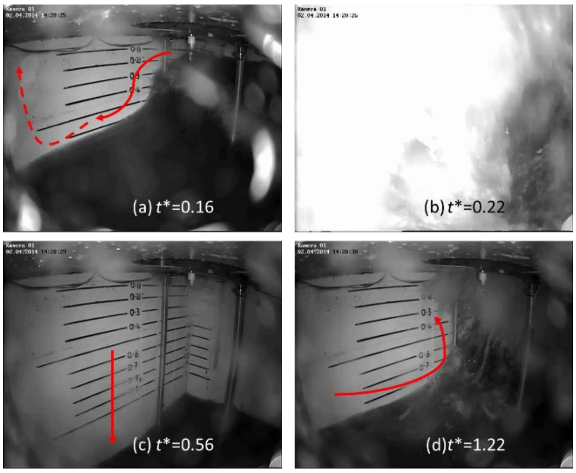


Figure 1. In-chamber camera images with t* representing location of the image relative to a single wave cycle.

Water near the rear wall rises up and moves towards the front of the chamber quickly, as indicated by the dashed-line in Fig. 1 (a) before impacting the ceiling (b). Next comes a wave trough (c) and a further sudden rise of the water near the rear (d). The corresponding pressures are shown in Figure 2 with events of Figure 1 identified by arrows. This sequence of event results in a maximum pressure on the front wall of the ceiling followed by a maximum pressure on the rear wall of the ceiling.

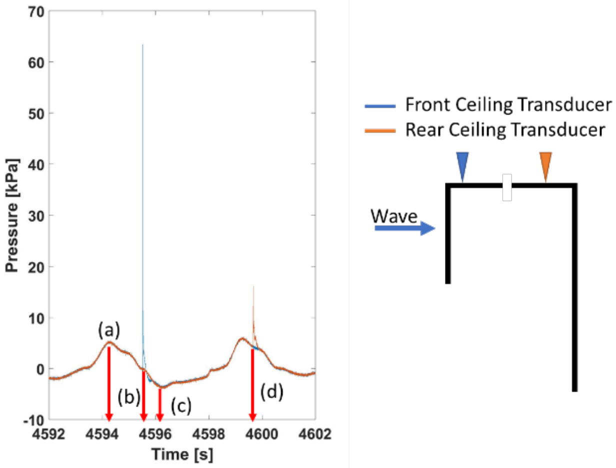


Figure 2. Time series pressure measurement on the celing of T_p = 5s and H_{m0} = 0.81m

In other tests, the water outside the OWC sometimes fell below the front curtain wall. When such "venting" occurred, the pressure inside the caisson equalised with the atmosphere through the gap resulting in loss of the negative pressure needed for the PTO.

In order to characterise the condition under which a “sloshing” event could occur, the in-chamber video record was returned to. The sloshing characterisation depends on the wave height (H), characteristic chamber width over wave length (B_c/L), and opening:chamber area ratio (A_o/A_c). Colour code is utilised to indicate the level of sloshing intensity observed with no sloshing observed (green), low sloshing observed (blue), medium sloshing observed (yellow), and high sloshing observed (red). No sloshing means the water column surface looks calm while oscillating. Low sloshing means the water column surface is not calm, but the oscillation is still visible. Medium sloshing shows a very visible water height difference between the front and rear of the chamber pivoted at the centre as shown by Figure 1 with average water level still oscillating. High sloshing indicate similar characteristics with the medium sloshing, but almost zero mean water oscillation. In addition to the colour code, several symbols are used to explain no test available (/), water level touch the ceiling (^), and major ceiling impact recorded (!).

The results of the characterisation is plotted in Figure 3. It can be observed for the figure that the sloshing mainly occurs during high wave conditions. It can also be inferred that a low sloshing occurance during a closed / near closed chamber may lead to major sloshing in a fully open chamber. For the same B_c/L, higher wave height also almost always lead to high(er) sloshing. The wave height lower than 0.4 m seems to be less dangerous across different B_c/L (0.0697 - 0.1394) except for the fully open chamber and B_c/L 0.1045.

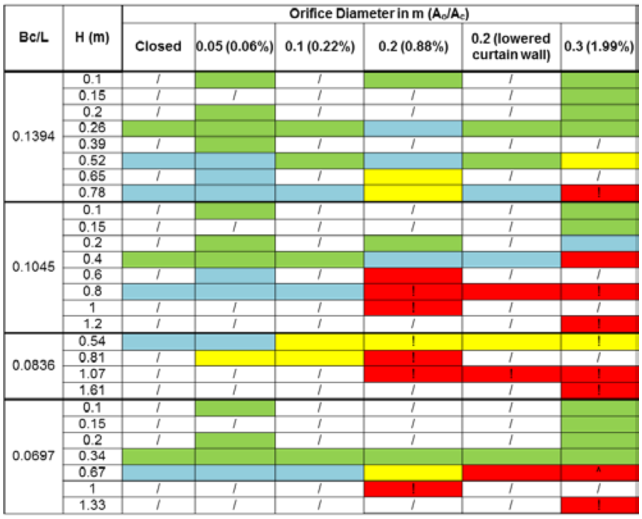
Figure 4 shows the same characterisation regime for irregular waves. The colour code and the symbols used in this figure have the same meaning as Figure 3. The irregular wave were generated with JONSWAP spectra with the wave length calculated based on the significant wave period. The sloshing characterisation here is basing on the significant wave height (H_{m0}). It seems that sloshing increases for every case in the irregular sea condition compared to regular wave conditions. The B_c/L = 0.1394, $H(H_{m0})$ = 0.26, and A_o/A_c = 0.88% case for example is blue for regular waves and yellow for irregular waves. Similar pattern can be observed for the rest of the case. This may happens because in the irregular wave condition maximum wave heights are about 1.8 times the significant wave height so the sloshing may be more likely during maximum waves.

Low and medium sloshing conditions for a closed / near closed chamber may always lead to major sloshing in a bigger orifice opening for both regular and irregular wave condition. It can be concluded as well that the fully open chamber is more prone to sloshing compared to the closed / near closed chamber condition. A limitation of the physical model in these experiments was that the chamber width was fixed. In design point of view, the structure’s peak resonance should be tuned to the frequency of the incoming waves for maximum energy absorption. The chamber width for this experiment is designed according to literature, *e.g.* Takahashi, S., 1989.

One can imagine, however, the height difference between the front and the rear of the chamber water column might be due to the chamber width being much shorter or much longer than the wave and the wave is reflected by the chamber wall and creates in-chamber impacts on the ceiling.

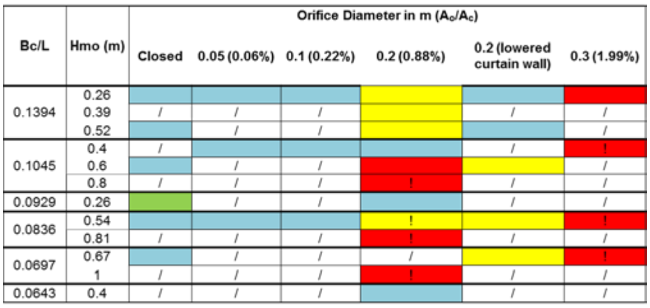
CONCLUSION

In-chamber impacts have been observed with maximum pressures measured up to 8 ρgH. The sloshing regime of both regular and irregular wave condition have been characterised by means of in-chamber video records. Four different levels of sloshing have been characterised based on B_c/L, $H(H_{m0})$, and A_o/A_c settings. A physical model with changeable chamber width will be useful for the future work. Some amount of “sloshing” is not an uncommon situation and should be considered in design and performance assessment of an OWC chamber.



Bc/L	H (m)	Orifice Diameter in m (A_o/A_c)					
		Closed	0.05 (0.06%)	0.1 (0.22%)	0.2 (0.88%)	0.2 (lowered curtain wall)	0.3 (1.99%)
0.1394	0.1	/	🟩	/	🟩	/	🟩
	0.15	/	/	/	/	/	🟩
	0.2	/	🟩	/	/	/	🟩
	0.26	🟩	🟩	🟩	🟦	🟩	🟩
	0.39	/	🟩	/	/	/	/
	0.52	🟦	🟦	🟩	🟦	🟩	🟨
	0.65	/	🟦	/	🟨	/	/
	0.78	🟦	🟦	🟦	🟨	🟦	🟥 !
0.1045	0.1	/	🟩	/	/	/	🟩
	0.15	/	/	/	/	/	🟩
	0.2	/	🟩	/	🟩	/	🟦
	0.4	🟩	🟩	🟩	🟦	🟦	🟥
	0.6	/	🟦	/	🟥	/	/
	0.8	🟦	🟦	🟦	🟥 !	🟥	🟥 !
	1	/	/	/	🟥 !	/	/
	1.2	/	/	/	/	/	🟥 !
0.0836	0.54	🟦	🟦	🟨	🟨 !	🟨	🟨 !
	0.81	/	🟨	🟨	🟥 !	/	/
	1.07	/	/	/	🟥 !	🟥 !	🟥 !
	1.61	/	/	/	/	/	🟥 !
0.0697	0.1	/	🟩	/	/	/	🟩
	0.15	/	/	/	/	/	🟩
	0.2	/	🟩	/	/	/	🟩
	0.34	🟩	🟩	🟩	🟩	🟩	🟩
	0.67	🟦	🟦	🟦	🟨	🟥	🟥 ^
	1	/	/	/	🟥 !	/	/
	1.33	/	/	/	/	/	🟥 !

Figure 3 Water column sloshing regime for the regular wave setting with colour code for no sloshing (green), low sloshing (blue), medium sloshing (yellow), and high sloshing (red) and symbols for sloshing impact (!), no test available (/), and water level reached the ceiling (^).



Bc/L	Hmo (m)	Orifice Diameter in m (A_o/A_c)					
		Closed	0.05 (0.06%)	0.1 (0.22%)	0.2 (0.88%)	0.2 (lowered curtain wall)	0.3 (1.99%)
0.1394	0.26	🟦	🟦	🟦	🟨	🟦	🟥
	0.39	/	/	/	🟨	/	/
	0.52	🟦	/	/	🟨	🟦	/
0.1045	0.4	/	🟦	🟦	🟦	/	🟥 !
	0.6	🟦	/	/	🟥	🟨	/
	0.8	/	/	/	🟥 !	/	/
0.0929	0.26	🟩	/	/	🟦	/	/
0.0836	0.54	🟦	🟦	🟦	🟨 !	🟨	🟥 !
	0.81	/	/	/	🟥 !	/	/
0.0697	0.67	🟦	/	/	/	🟨	🟥 !
	1	/	/	/	🟥 !	/	/
0.0643	0.4	/	/	/	🟦	/	/

Figure 4 Water column sloshing regime for irregular wave setting with similar the colour code and symbols.

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