EFFECT OF MEASUREMENT SYSTEMS ON IMPACT LOADS ON RIGID STRUCTURES

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Abstract

Laboratory experiments were carried out in small scale wave flume to evaluate the performance of the measuring system on the estimation of impact loads on rigid structures. Three different measuring system were used: two classical (array of pressure transducers on a vertical line and load cells) and one innovative system (Pressure Mapping System). Two different regular wave attacks were repeated 120 times each in order to consider the natural variability of the phenomena in the analysis. Good agreement were found in the comparison of the mean total force measured with the load cells and calculated with the vertical distribution derived by the pressure transducers measurements. A bigger scatter on the data is present on the results obtained from the pressure transducers. Also good agreement in terms of envelope of vertical pressure distribution is found between pressure transducers and the Pressure Mapping System. Some differences are appreciable between the two systems in the impact zone slightly above the SWL. The tactile system (PMS) return higher values in this zone most probably due to the higher spatial resolution.

Keywords: Impact loads, Wave loads, Pressures measurements, Force measurements, Vertical structures

1. Introduction

The correct measurement of impact loads on rigid structures is one of the most intriguing challenges for a maritime physical modeller. Traditionally the measurement of impact loads is indirectly conducted through the use of one or more array(s) of pressure transducers. The vertical pressure distribution is accordingly recorded and the impact load is estimated as the integral of the measured pressures. The use of such arrays is to present the preferred method for measuring wave induced pressures and it was previously used in break through works that led to the development by Goda of his vastly used formula for the calculation of both pulsating and impulsive pressures and loads (Goda 1985, Takahashi et al., 1994). Nonetheless, in 1996, Allsop (Allsop et al., 1996) used load cells to directly measure the total force induced under by waves on a vertical structure instead of indirectly estimating it by pressure measurements.

Although, since their introduction, both aforementioned measuring methods/systems have been exhaustively used, a comprehensive comparison between them has not been previously performed. However, past experience on the measurement of impact loads on rigid structures with different techniques, indicates that substantial differences (Bullock et al., 2007) on the results can occur.

In this paper three different measuring systems are designed and compared. The first two are based on the “standard” methods for load measurements mentioned above, whilst the third one involves the use of tactile pressure sensors, a newly technique introduced in this field of pressure measuring system (Stagonas et al. 2012). Two benchmark wave cases are chosen in order to compare the performance of all systems under two critical impact loads (impulsive wave). In order to overcome problems related to the stochastic nature of the phenomenon (Marzeddu et al. 2014), the performance of all systems is statistically assessed repeating each of the two wave cases 120 times.
2. Methods

2.1 The experimental layout

The experiments have been carried out in the CIEMito wave flume of the Laboratori d'Enginyeria Maritima (LIM) of the Universitat Politecnica de Catalunya BarcelonaTech (UPC). The flume is 18m long, 0.38 m wide and 0.56 m high. It is equipped with a piston type wave maker driven by software developed at LIM/UPC that allows generation of regular and random waves characterized by a target spectrum as well as a target wave time series. A scaled model of a vertical breakwater has been built and tested against regular wave attacks. The flume has a flat bottom and an approaching 1/15 sloping beach that ends at the toe of a simplified vertical breakwater. During the tests 0.285m water depth was used. The vertical wall is segmented in 3 parts, with the central part being physically separated and dynamically isolated from the two side parts (Figure 1). The central part of the breakwater is also equipped with eight pressure sensors (Figure 1) and is mounted on two, rigidly fixed, load cells (Figure 1). This, allows for simultaneous pressure and the total force measurements. Initially, the tactile pressure sensor is fixed on the left side part (Figure 1) but experiments are also conducted with the tactile pressure sensor located on the central part and the pressure transducers and the load cells mounted on the left side.

![Figure 1: Left: Experimental layout - Center: (Front view) Pressure transducers and tactile sensors position – Right: (Lateral view) Load cells position](image)

2.2 Instrumentation

The instrumentation used during the experiments is composed of:

- Eight pressure sensors P8AP by HBM ©
- Two load cells Z6 by HBM ©
- One tactile pressure sensors, model number 9550 by Tekscan ©
- Eight wave gages

The P8AP is an absolute pressure transducer based on a strain gauge sensor with a measuring span of 10 bars and an accuracy class 0.3. The fundamental resonance frequency is 12 KHz.

The Z6 by HBM is a bending beam load cell with a nominal load of 50 Kg and an accuracy of 0.009 % of the maximum capacity.

The 9550 operates in a similar manner to a variable resistor of an electrical circuit. When no load is applied the resistor experiences a very high resistance, which gradually reduces as the applied load increases. The 9550 is a sensor that includes 196 sensing points over an area of 7.11×7.11cm.

After a series of previous tests, in order to assess the impact point of the wave on the vertical wall, the tactile sensor was mounted slightly above the SWL and 7.5 mm under the pressure transducer PS3 (Figure 2).

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All the experiments were performed with a sample frequency of 4.8 KHz for the load cells and pressure transducers, at 4 KHz for the tactile pressure sensor and at 40 Hz for the wave gauges.

2.3 Description of the experiments

Before running the experiments three different calibrations were done in order to understand the behavior of the tactile transducer under different conditions. A first static calibration was performed loading the sensor with a column of water, a second quasi static calibration with a dynamometric hammer and a third fully dynamic calibration with a drop test. The three calibration methods give extremely different results. The last method seems to be the one much closer to the reality of a wave impact (mixture of air and water impacting on a reduced area) and for this reason this one has been used for the comparison of the tactile pad results with the pressure transducers.

Both the load cells and the pressure transducers were previously calibrated by HBM.

Two different regular waves time series were tested. Each time series is composed by 4 waves divided in 2 ramp-up waves 2 regular waves and 1 ramp-down waves.

The selected target wave conditions are:

- Impulsive wave n1: $H=0.16$ m $T=2.4$ s
- Impulsive wave n2: $H=0.16$ m $T=2.3$ s

120 repetition of the two wave attacks were performed in order to guarantee a good statistic of the phenomena.
3. Results

In order to compare correctly the results of the pressure/force measurements, it is important to assess the good repeatability of the wave attacks. To do that all the time series for all the sensors were synchronized using cross correlation. The mean time series of 120 wave attacks was calculated for each wave gauge and the root mean square error was computed. The repeatability is almost perfect with an RMSE of 1mm that is comparable with the measurement error of a resistive wave gauge. An example with 20 time series compared is shown in Figure 3.

![Figure 3: Example of the repeatability of the generated waves.](image)

Once the repeatability is assessed, it is possible to compare different results from different sensors. A comparison between pressure transducers and tactile pressure sensor and another comparison between vertical pressure distribution and total force measured with load cells will be performed.

3.1 Total force

As evaluated in (Marzeddu et al. 2014) the measurement of the total force using pressure transducers is affected by the interpolation method used in between measures and the extrapolation method used to compute the pressures where the measure was not made directly. From previous experience it was seen that is more safe, to not extrapolate pressure measurements under the lower transducer and over the upper one. This happens because the quasi-static pressures recorded far from the impact zone (lower and upper transducers) are more affected by the electrical noise on the signal when the sample frequency is high. Two interpolation methods will are used in order to compute the total force, the first one using linear interpolation between pressure transducers measurements and the second one using rectangular distribution around the measured pressure (Figure 4).

![Figure 4: vertical pressure distribution computation - red: rectangular interpolation - black: linear interpolation](image)

A brief analysis of the results shows a big variability of the single test but a good agreement on the mean value. Results are summarized in Table 1.
Table 1. Total force comparison between the results from Pressure Transducers and Load Cells

<table>
<thead>
<tr>
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<th>MEAN [N/M]</th>
<th>STD_DEV [N/M]</th>
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<td>LC</td>
<td>787</td>
<td>55</td>
<td>647</td>
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</tr>
</tbody>
</table>

When the mean value of the measured total forces (load cell measurements) is compared against the mean for the calculated forces (the integral of the pressures recorded by the transducers) a relatively good agreement is observed, Table 1. However, a wave by wave analysis reveals that discrepancies of up to 25% are possible with the pressure transducers giving larger estimates for the peak total force.

3.2 Pressures

Impact induced pressure values acquired by the pressure transducers are also compared against those recorded by the tactile pressure sensor. The comparison reported here refers to 80 wave impacts recorded with the tactile pressure sensor placed in the middle of the model seawall (Figure 1). The tactile sensor was accordingly replaced with an array of 8 pressure transducers and another 80 impacts were recorded. On the right hand side of Figure 5, the 15680 (196 sensels × 80 impacts) peak pressure records are plotted (red circles) as a function of the relative location (physical location minus the water depth) of each sensel (pressure sensing unit for the tactile system). The dashed black line corresponds to the highest peak pressures recorded by the pressure transducers for all 80 impacts, in total 640 measurements (8 transducers × 80 impacts); black dots indicate the relative location of the transducers. On the left hand side of Figure 5, only the highest peak pressures reported by the sensels located at and near the physical location of the pressure transducer array are plotted. In total, the pressure profiles for 3 sensel arrays are presented (colored lines) along with that for the array of pressure transducer (dashed black line).

Figure 5: Comparison of the vertical pressure distribution (envelope) between pressure transducers (Black line) and tactile system (Color lines). Left: Comparison considering all the 14 columns of the tactile system – Center: Comparison considering only the columns over the pressure transducers – Right (all measured peaks by the tactile system (red) against vertical pressure distribution envelope from the pressure transducers (black))

Overall, and given the stochastic nature of the phenomenon, the comparison between the two instruments is satisfactory. The general shape of the pressure profile remains fairly similar for both instruments but for the impact zone near SWL, the tactile pressure sensor returns pressures up to two times higher than the maximum peak pressure recorded by the transducers. Although the number (about 20) of these pressures is very small compared to the overall number of tactile pressure measurements (6720 for the area near SWL), a satisfactory explanation for their existence cannot yet been given. However, it should be noted that the majority of these extreme pressures occurred at areas located in-between the (physical) horizontal location of the pressures transducers but the most extreme values were recorded by arrays of sensels located at or adjacent to the physical location of the pressure transducer array, Figure 5.

4. Summary

Although this work is not yet complete our preliminary data suggest that:

- Load cell measurements present less variability, while they do not require any post-
calculation assumptions.
- Pressure transducer/load cell force calculations/measurements compare well with each other only when the mean total force of a number of tests is considered. On a wave-by-wave basis, the pressure transducer measurements resulted in up to 25% higher calculations for the peak of the total force.
- The use of tactile pressure sensors can provide valuable information with regards to the coherence of impact induced pressures; the occurrence of extreme pressures is currently under investigation.
- Ongoing research gives emphasis to the effect of the pressure coherence on the total force calculation. This is expected to shade more light on the discrepancies observed between pressure transducer/load cell indirect/direct measurements.

Acknowledgments
These experiments have been supported by the European Commission 7th Framework Programme project HyRes under the HYDRALAB IV network, contract no. 261520. Special thanks are due to the personal of the CIEMLAB at the LIM-UPC (Barcelona).

References