The Importance of Pressure Sampling Frequency in Models for Determination of Critical Wave Loadings on Monolithic Structures

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The importance of pressure sampling frequency in models for determination of critical wave loadings on monolithic structures

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Introduction

Wave induced pressures on model scale monolithic structures like caissons and concrete superstructures on rubble mound breakwaters show very peaky variations, even in cases without impacts from slamming waves.

The forces used in the analysis on the overall stability against sliding and tilting of the structure are determined by integration of the pressures over the structure surfaces. The size and uncertainty of these wave forces depends not only on the number of pressure gauges and their distribution over the surface, but also on the sampling frequency of the pressures.

The paper presents the results of experimentally based analysis of the influence of pressure sampling frequency and time averaging on the estimated wave forces.

Variability and uncertainties related to wave forces

Considering a stationary wind generated sea state one can observe the following contributions to the variability and uncertainty of force measurements:

a) Natural variability of characteristics of the waves in irregular seas. This imply that two sequences of waves, e.g. lasting 3-5 hours, will not contain the same statistics of the larger waves, although the significant wave height could be almost identical. This variability which causes variations in larger forces is always inherent in realistic model tests; and should not be removed for example by using preset wave trains, but instead dealt with by repeating tests.
b) Apart from oblique waves the directionality (horizontal spread) of the waves causes a horizontal spatial variation of the instant pressures along a monolithic structure of some size. This cannot be represented in a 2-dimensional flume test model.
c) The number of pressure gauges are not always sufficiently densily spaced to capture the instantaneous spatial pressure variation. It is for example a problem if only one row of small gauges is placed in a wall behind armour consisting of large units which in an uneven way shields the wall.
d) The forward momentum of the incident wave is converted into an impulse exerted on the structure. The impulsive pressure will, for a given momentum, be inversely proportional to the duration of the pressure. Both the size and the duration of the impulse will be determining for the response of the structure. The impulse might be too small to move or damage the structure, but in any case it is very important to sample with a frequency high enough to capture the load peaks in order to perform a dynamic analysis of the structure response. Only a dynamic analysis, taking into account the deformation characteristics of the structure and its foundation, can tell which load peaks will be critical for the design.The sizes of the maximum force and impulse are however very dependent on the applied pressure sampling frequency in that identified maximum values decrease with the sampling frequency.

Item d is the subject of the following analyses.

Identification of the most critical combination of simultaneous forces on the surface of the structure

A simplified failure function for horizontal sliding, based on static considerations, is applied to illustrate the problem:

$$g = (G - F_{w,uplift}) f \; - \; s \cdot F_{w,horizontal} = \begin{cases} \geq 0 \text{ no sliding} \\ < 0 \text{ sliding} \end{cases} \qquad (1)$$

in which G = gravitational force
f = friction coefficient between caisson base and foundation , here $f = 0.6$
s = safety factor, here $s = 1.2$
$F_{w,uplift}$ = wave induced uplift force on caisson
$F_{w,\,horizontal}$ = wave induced horizontal force on caisson

The load conditions giving the minimum value of g is the most critical
(minimum values of the failure functions for all failure modes, including slip foundation failures, must be considered in a real design case).

Example of influence of wave load sampling frequency and averaging on the maximum recorded load and the failure function value

The wave loadings on a caisson with dimensions shown in Fig. 1 is analysed.

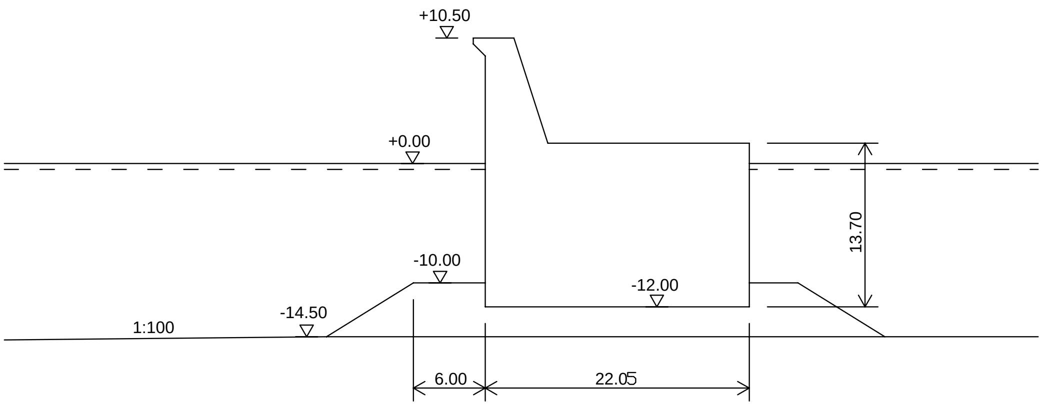

Fig. 1. Caisson dimensions. Measures in metres.

A zero-down crossing time domain analysis of the incident waves in a JONSWAP-spectrum irregular sea state is made in order to identify the relation between the height of the individual waves and their loadings on the caisson.

Fig. 2 shows the horizontal forces measured in a sea state with incident waves corresponding to Hs = 6.2 m and Tp = 13 s, based on sampling frequencies 50 Hz and 1000 Hz. It is seen that the 1000 Hz logging identify significantly larger forces. The values of the simplified failure function (1) are given. In these cases g attains negative values corresponding to smaller safety factors against sliding than s = 1.2

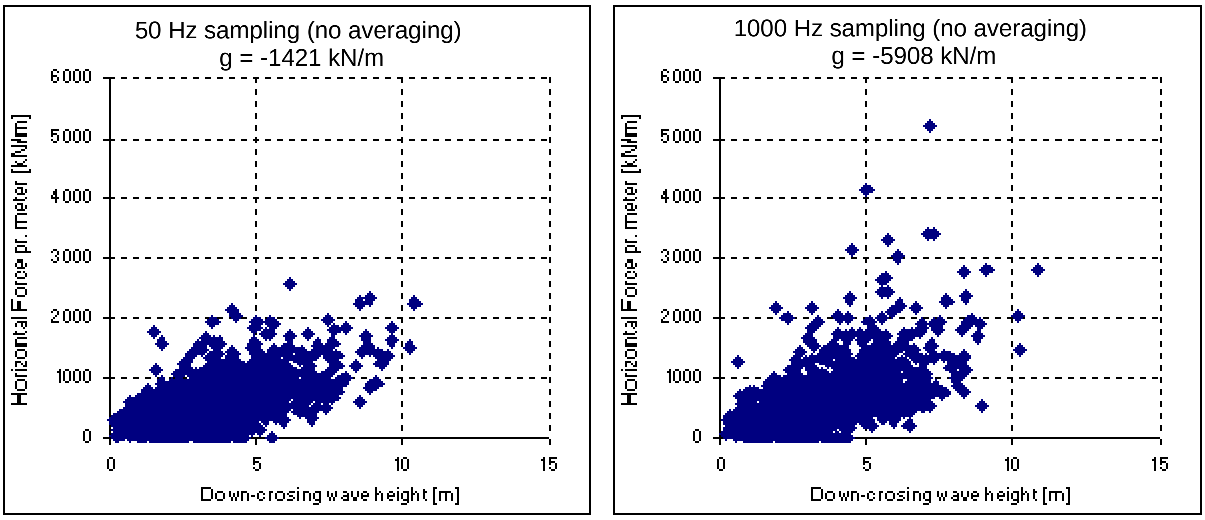

Fig. 2. Comparison of horizontal forces logged at 50 Hz and 1000 Hz in model scale for the prototype incident sea state: Hs = 6.2 m, Tp = 13.0 s, water level at 0.00 m.

The results of averaging the recorded forces over 0.1 s in model scale are shown in Fig. 3.

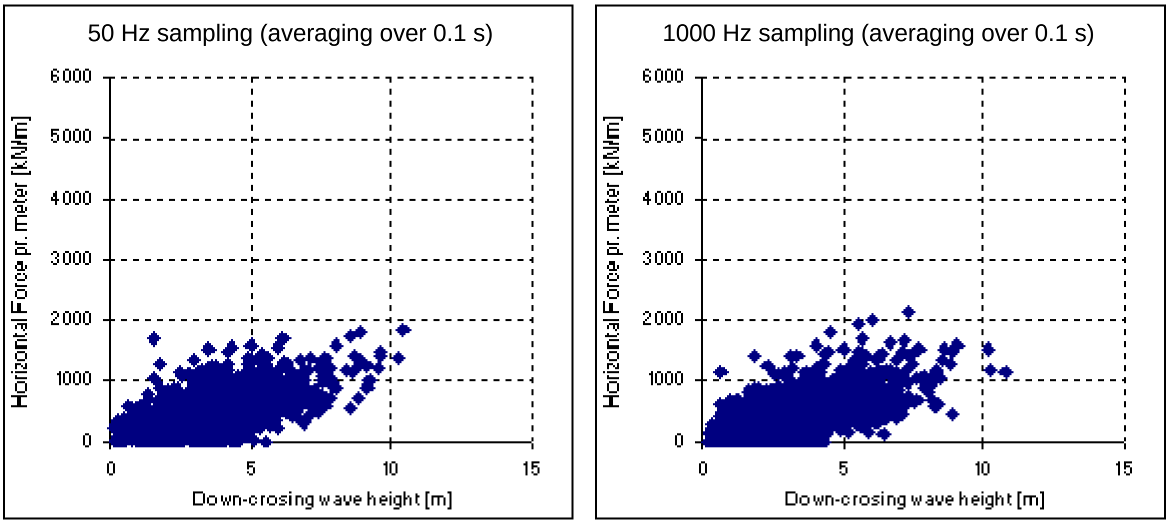

Fig. 3. Comparison of horizontal forces logged at 50 Hz and 1000 Hz but averaged over 0.1 s (model scale values). Prototype scale incident sea state: Hs = 6.2 m, Tp = 13.0 s, water level at 0.00 m.

It is seen that an averaging over 0.1 s reduces quite significantly the larger forces, and in this case also eliminates almost completely the influence of the force sampling frequency.

Conclusion

The size of the identified critical design wave forces depends very much on the pressure sampling frequency and the time averaging, in case of peaky loadings.

Which wave force sampling frequency and time averaging to apply in model testing can only be determined on the basis of a dynamic response analysis of the individual prototype designs as discussed above.

The distribution of the recorded wave induced pressures on the structure is also very much affected by the pressure sampling frequency in case of peaky loadings. This will be illustrated in the paper.