UPLIFT FORCES ON A VERTICAL STRUCTURE WITH AN OVERHANGING HORIZONTAL CANTILEVER SLAB

D. Kisacik[1], P. Troch[1]

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1. Introduction

The Pier of Blankenberge which is located along the Belgian coast is a coastal structure consisting of a vertical core attached to an overhanging horizontal cantilever slab. Throughout high tides and storms, the structure is exposed to violent wave impacts, including waves running up against the vertical core and slamming on the horizontal deck. The structure prevents most of the overtopping due to its particular geometry involving closed angles, which does not allow incident waves to dissipate. This introduces an important uplifting force. The lift forces consist of impact loads of high magnitude and short duration. It is reasonably impossible to substitute these impact effects by a static equivalent.

In opposition to a single vertical or horizontal surface type structures, structures consisting of both vertical parapets and horizontal cantilever slabs have scarcely been considered. Recently, Kisacik et al. (2012a) described the loading conditions due to violent wave impacts on a vertical structure with an overhanging horizontal cantilever slab, where tested in a scaled test set-up (scale factor is 1:20) under loading conditions of violent wave impacts. Furthermore, Kisacik et al. (2012b) analyzed the pressure distribution on the same cross-section. They proposed an expression for the location of maximum pressures p_{max} on the vertical part as a function of the wave steepness.

However, the magnitudes of vertical (uplift) forces are still missing a prediction formula. In this paper, based on structure geometry and wave conditions, a set of basic parameters (and certain combination of these), governing the prediction of the wave loading on a vertical wall with a cantilever slab, is presented. The parametric investigation is carried out as a series of small-scale model tests in Kisacik et al. (2012a). The results from the regular and irregular waves are compared and discussed. Finally, a semi empirical model is developed to predict vertical (uplift) forces on the horizontal part and the predicted values are compared with the measurements.

2. Uplift Forces

In the following, a formula for the maximum uplift impact forces F_{v_max} beneath the horizontal part is derived based on the impulse theory and solitary wave theory. Wave height at the toe of the foreshore (H_1), water depth at the structure toe (h_s), wave period (T), overtopping discharge (q) and vertical averaged velocity (V_{av}) of the water jet rising on the vertical wall are found to be the main parameters governing the vertical uplift forces. The forward momentum of a fluid mass ($M = qT\rho$) hitting beneath the horizontal part with a vertical average velocity V_{av} will induce a vertical force impulse. A linear relation is obtained between the natural logarithm of F_{v_max} and $2(qT\rho)V_{av}/t_r$ in Equation 1.

$$F_{v\_max} = exp\left(\beta_1 ln\left(\frac{2(qT\rho)V_{av}}{t_r}\right) + \beta_2\right)\text{...[1]}$$

where, β_1 and β_1 depend on $(c/h_s)^2$, $\beta_1 = -0.015(c/h_s)^2 + 0.22$, $\beta_2 = -0.074(c/h_s)^2 - 2.2$, t_r is the related rise time and c is the clearance between SWL and the horizontal part.

Figure 2. shows natural logarithm of maximum vertical forces (F_v) versus natural logarithm of $2MV_{av}/t_r$ for water depth ($h_s = 0.135\,m$). The linear relation between the parameters is represented by Equation 1. The boundary lines show the lines of non exceedance at level 99.6% and 0.04.

[1] Ghent University, Dept. of Civil Engineering Technologiepark 904, Ghent, 9052, Belgium, dogan.kisacik@ugent.be

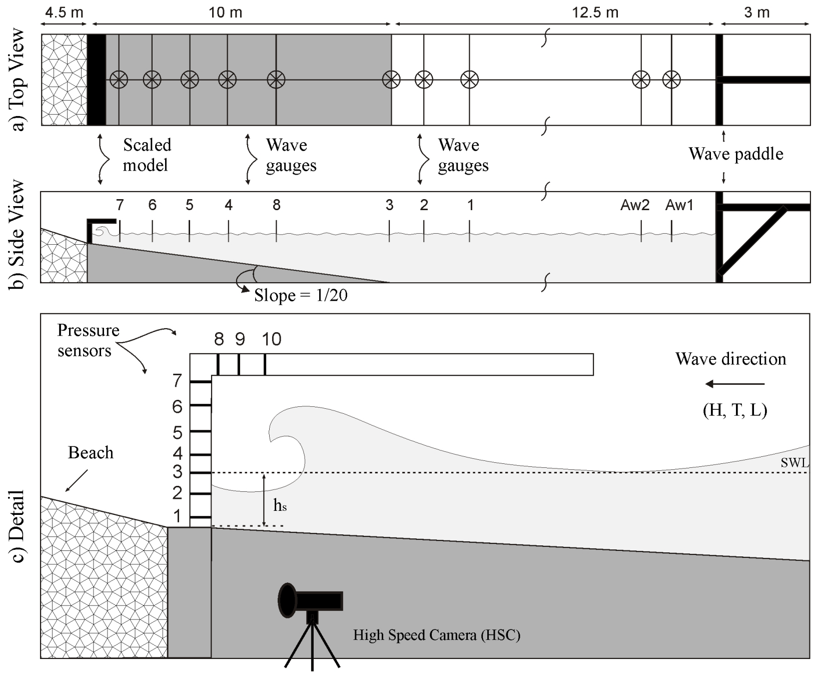

Figure 1. Small-scale model set up. a) is the top view, b) is the side view and c) is detailed view of model

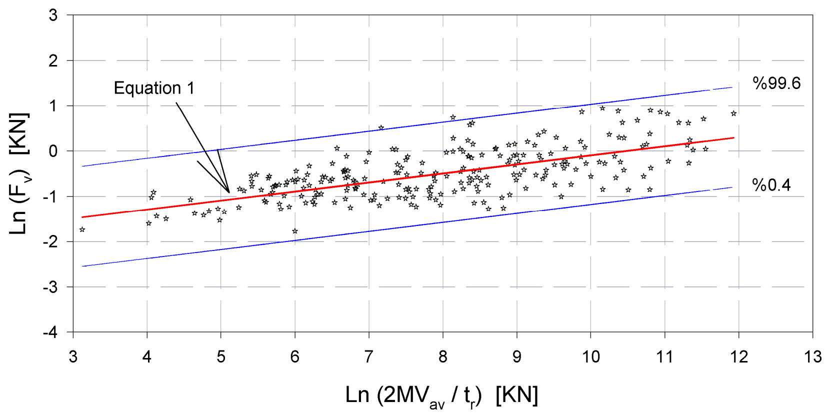

Figure 2. Natural logarithm of maximum vertical forces (F_v) versus natural logarithm of $2MV_{av}/t_r$ and comparison of data with Equation 1, ($h_s = 0.135\ m$)

3. Conclusions

Based on the impulse theory and experimental investigations on breaking wave kinematics and impact loads, prediction formulas for impact forces have been derived for uplift forces below the horizontal part of a vertical wall with overhanging horizontal cantilevering slab. The design concept for breaking wave loads is developed. Hydraulic model tests have been performed to assess the vertical averaged velocities involved in the impact process and to verify the results obtained from theory.

References

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