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Wave-induced uprush jet velocity on a vertical structure

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ABSTRACT

A vertical wall with an overhanging horizontal cantilever slab was tested in a small-scale test setup (with a scale of 1:20) under wave impact (impulsive) loads. A single breaking wave creates two distinct sequential impacts on the vertical and horizontal parts of the cantilever. The breaking wave jet hits on the vertical wall then rises with an uprush jet velocity and creates the second impact on the horizontal cantilever. This upward water momentum depends on the uprush jet velocity. In this study, data from pressure sensors was used to analyze the average uprush jet velocity (u_{v_av}) under regular breaking waves. A formula to predict the average uprush jet velocity on a vertical structure is proposed. Wave height at the toe of the foreshore (H_1), water depth at the structure toe (h_s), and wave period (T) were found to be the main parameters governing the average uprush jet velocity. In addition, the influence of geometric properties such as clearance between still water level and horizontal part of the cantilever (c') were analyzed. The proposed formula is applicable within the range $0.45 \le H_1/h_s \le 1.2$, $2.0\ \mathrm{s} \le T \le 2.8\ \mathrm{s}$ and $0.75\ \mathrm{m} \le h_s \le 1.65\ \mathrm{m}$.

1. Introduction

Vertical walls are used as coastal protection structures to control the overtopping of the waves during storms and high water levels (Gunbak et al., 2013). Engineers design these structures with a return crown wall or with a horizontal cantilever slab to reduce the wave overtopping. However, this superstructure exposes the structure to additional horizontal and uplift forces. These forces are impact loads which should not be substituted by a static equivalent in the design.

In literature, a handful of formulas is given in design codes to calculate the horizontal loads on vertical walls (Minikin ,1963; Goda ,1974; Blackmore and Hewson ,1984; Allsop and Vicinanza ,1996; Oumeraci et al., 2001; Cuomo et al., 2010). Also, much research has been conducted to evaluate wave loads on horizontal platforms due to the slamming of approaching wave crests. Kaplan and Silbert (1976); Kaplan (1992); Kaplan et al. (1995); Shih and Anastasiou (1992); Toumazis et al. (1989); Bea et al. (2001); Tirindelli et al. (2002); McConnell et al. (2003, 2004); Cuomo et al. (2003) and Cuomo (2005) are the well-known examples in this field.

However, complex structures of vertical walls and horizontal cantilevering slabs have scarcely been considered in the literature. Recently, Kisacik et al. (2012a) described the loading conditions due to violent wave impacts on such a complex structure. They showed that a single breaking wave creates two distinct sequential impacts on the vertical wall and the horizontal cantilever slab (see Fig. 1). The breaking wave jet hits the vertical wall with a horizontal velocity u_h then rises vertically with an uprush jet velocity u_v and creates the second impact on the horizontal cantilever slab.

Incident waves are classified into four breaker types according to the breaker shapes on the vertical wall (Fig. 1). These are (a) slightly breaking waves (SBW), (b) breaking waves with small air trap (BWSAT), (c) breaking waves with large air trap (BWLAT) and (d) broken waves (BW) (Kisacik et al., 2012a).

In SBW, the waves tend to break in front of the structure, but the water level at the wall accelerates vertically before the wave crest reaches the wall (see Fig. 1a). Then, the accelerated vertical component collides with beneath the horizontal cantilever slab as an uprush water jet (Kisacik et al., 2012a).

In BWSAT, the wave hits the vertical wall with a more or less parallel face, and only a little amount of terminate air is enclosed (see Fig. 1b). Enclosed air compresses due to impact effects and the wave crest quickly disintegrate into droplets creating an upward water spray. The spray and the following aerated uprush jet hit beneath the horizontal cantilever slab (Kisacik et al., 2012a).

In BWLAT, the wave starts to break early, and the tongue of the plunging wave hits the vertical part (see Fig. 1c). In this case, a significant amount of air is enclosed, and it disintegrates into bigger bubbles. Splashes due to the first impact and the following aerated

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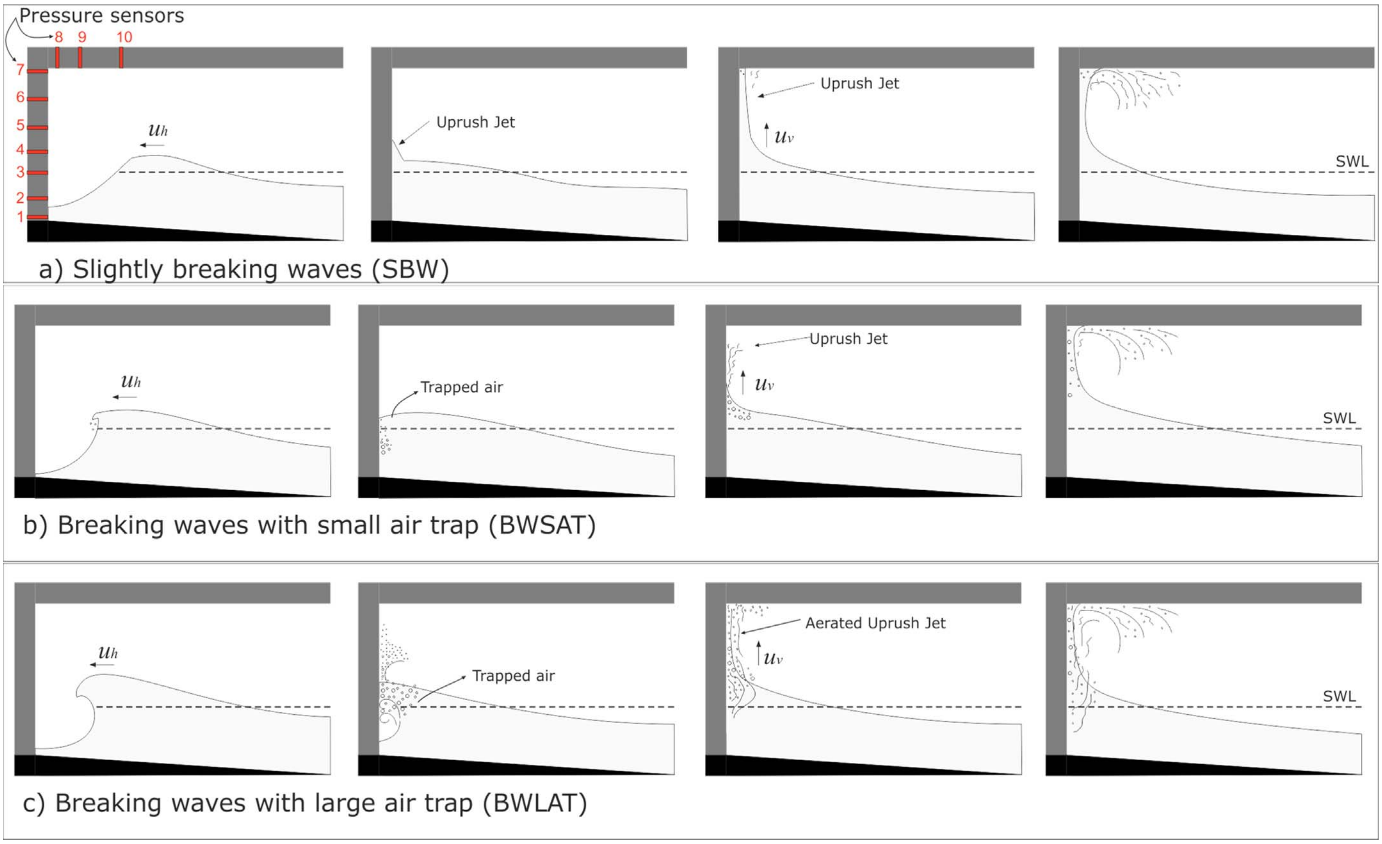

Fig. 1. Definition of breaker types which create uprush jets on the vertical wall with a horizontal cantilever slab. a) slightly breaking waves (SBW), (b) breaking waves with small air trap (BWSAT) and (c) breaking waves with large air trap (BWLAT).

uprush water jet rise on the vertical wall and collide with the corner of horizontal cantilever slab (Kisacik et al., 2012a).

In Kisacik et al. (2014), a new prediction model for uplift impact forces, as a function of the rise time t_r was suggested. The uplift force is the result of the accelerated uprush water jets which climb on the vertical wall (Stagonas et al., 2014). Beneath the horizontal cantilever slab, these accelerations create shock pressure even for non-breaking waves. (Kisacik et al., 2014). Therefore, accurate prediction of uprush jet velocity is crucial for correct prediction of the uplift force on the superstructure.

Based on small-scale tests, Bruce et al. (2004) suggested uprush jet velocities of 4–7 times the shallow water velocity ($\sqrt{gh}$) under strongly breaking conditions (h_*<0.15). However, they measured larger velocities ($11\sqrt{gh}$) at large-scale tests. Wolters et al. (2005) reported field and large-scale measurements of water jet velocities up to $13\sqrt{gh}$. In these formulas, h^* is a parameter characterising the intensity of wave breaking at the structure ($h^*=h_s/H_s \times h_s/L_0$), where h_s is the water depth at the structure, H_s is the significant wave height and L_0 is the deep water wave length ($gT^2/2\pi$).

To efficiently design superstructures such as an overhanging horizontal cantilever slab on a vertical wall, more information on the characteristics of the water-jet interaction is required (Shiravani et al., 2014). However, a formula to predict the uprush jet velocity due to breaking waves on such structures is not available to the best of the authors' knowledge. The simultaneous measurements of the uprush jet velocity with the load and pressure distribution are expected to increase the knowledge on the interaction of overhanging horizontal cantilever slab with breaking waves.

In this paper, based on structure geometry and wave conditions, a set of basic parameters governing the prediction of the uprush jet velocity on a vertical wall with an overhanging horizontal cantilever slab is presented. The parametric investigation was carried out as a series of small-scale physical model tests with regular waves as described in Kisacik et al. (2012a). Finally, an empirical model is suggested to predict uprush jet velocity on the slab as a function of the incident wave height (H_1) at the toe of the foreshore slope, the water depth at the model toe (h_s) and the clearance between SWL and cantilever slab (c').

2. Experimental setup and data acquisition

Physical model tests were carried out in the wave flume (30 mx1 mx1.2 m) of Ghent University in Belgium (see Fig. 2). A scale of 1:20 was selected to model the structure to ensure correct reproduction of all wave processes. A high-speed camera (HSC) recorded all the events with a frequency of 250 frames per second. Ten Quartz pressure sensors using a 20 kHz sampling frequency measured the pressure at several locations. The incident wave height (H), water depth at the structure toe (h_s), wave period (T), impact velocities of the fluid mass in the horizontal and vertical directions (u_h and u_v, respectively) and the geometrical parameters of the structure were used as the main parameters to determine the wave loading on a structure. The incident wave heights were measured at wave gauges from 1 to 8 as H_1 to and H_8, while wave length for any depth, L was calculated according to the linear wave theory. The geometric parameters l_m, h_m and c' (model width and height and clearance between SWL and horizontal part respectively) are defined in Fig. 2 where the foreshore slope is 1/20.

Fig. 3 shows the configuration of the pressure sensor locations on the vertical wall and the horizontal cantilever slab. The accuracy of the pressure profiles depends mainly on their spatial resolution. Due to the stability of the material and installation difficulties, it was hard to drill open holes closer than 3 cm. Therefore, pressure sensor holes were arranged at 3 cm intervals along two rows. The lateral distance between