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Three-dimensional experiments on landslide generated waves at a sloping coast

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ABSTRACT

This paper describes new three dimensional experiments on water waves generated by landslides. The landslide is reproduced by a rigid elliptical body, sliding along an inclined plane (slope of 1/3, 1 vertical, 3 horizontal). The generated water waves are free to propagate both offshore and alongshore, since the plan dimensions of the used wave tank are of at least one order of magnitude larger than the width of the landslide, which can be considered to be a scale of the wave length. The experimental study has been carried out reproducing both subaerial and partially submerged landslides. The wave generation process is studied by means of video records of the near field flow and measurement of the landslide movement; the properties of the waves propagating along the coast are described on the basis of runup gauges. The waves observed during the experiments always present first a crest and then a trough; as the first wave propagates away from the generation area the crest tends to become smaller than the trough and the maximum runup along the coast is given by the second or by the third wave. An important feature is that the observed runup along the coast firstly grows with the distance from the generation area, it reaches a maximum value at about two times the width of the landslide, and then decreases. An estimate of the celerity at which the waves propagate along the coast is given on the basis of gauge measurements; it results that the crests propagate faster than the troughs, and the wave period increases.

1. Introduction

The interest in landslide generated waves has largely increased in the last decades due the dramatic events occurred in 1958 at Lituya Bay, Alaska (Miller, 1960; Fritz et al., 2001), in 1975 in Kitimat Inlet (Murty, 1979), in 1998 in Papua New Guinea (Tappin et al., 2002), and in 2002 at the Stromboli volcano, Italy (Tinti et al., 2005a,b). Several studies on the wave generation due to landslides have been carried out in the past. The problem has been tackled by means of analytical studies (Noda, 1970; Watts, 1998; Di Risio and Sammarco, 2008), using physical experiments (Watts et al., 2000; Huber and Hager, 1997; Fritz et al., 2003a,b, 2004; Panizzo et al., 2005; Enet et al., 2003; Enet and Grilli, 2005, 2007; Di Risio et al., 2009) and numerical simulations (Heinrich, 1992; Jiang and LeBlond, 1993; Rzadkiewicz et al., 1997; Piatanesi and Tinti, 1998; Grilli and Watts, 2005; Watts et al., 2005; Liu et al., 2005; Tinti et al., 2006).

Most of these studies focused on the waves propagating towards the open sea, with the main goal of defining the properties of these waves as a function of the parameters that may be used to describe the landslide. Few researches take simultaneously into account the complex interaction that exists between the generation and the propagation mechanisms, which appears to be strongly related when the landslides occur at a sloping coast. Under these conditions two systems of waves are generated: the waves radiating toward offshore and the waves that are trapped along the shore due to the refraction (edge waves; Ursell, 1952). The waves trapped, and thus propagating, along the coast are of special practical interest since they are responsible of the inundation of the coastal regions close to the generation area.

In view of this, Liu et al. (2005) and Enet and Grilli (2007) independently performed experiments using tanks whose width is respectively 4 times and 5.4 times larger than that of the landslide; the results of these researches are of high value for studying the near-field but cannot be used for the analysis of the propagation in the far field in the alongshore direction, since the measurements are quickly contaminated by the waves reflected at the side walls of the tank. Briggs et al. (1995) and Liu et al. (1995) have studied the interaction of tsunamis with a conical island, measuring the runup, but the waves were generated elsewhere and not along the coast. Further important three-dimensional experiments are those by Liu et al. (1998), who studied the propagation of edge waves packets similar to those generated by landslides, using a wave tank large enough to focus on the far-field. They used a special wave-maker hinged along a vertical axis to generate the edge waves (Liu and Yeh, 1996). Of high value and importance for practical scopes are also the numerical works by Jiang

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and LeBlond (1993) and the recent one by Lynett and Liu (2005). Lynett and Liu (2005) have presented a careful numerical investigation of the runup of the tsunamis generated by subaerial and submerged landslides at a straight sloping coast. They provide very useful estimates of the maximum runup along the coast, as a function of the properties of the landslide and of the slope of the bottom. However one major limitation of this study is that the maximum slope of the bottom considered is of 1/10 (1 vertical, 10 horizontal), while for some cases of practical interest, the bottom may be steeper.

This paper describes new three dimensional experiments performed at the LIAM laboratory of L'Aquila University, Italy, on water waves generated by landslides. The research intends to study landslide generated waves using a rigid landslide model with elliptical shape, and a wave tank large enough to study the wave propagation in the far-field. The landslide is constrained to slide down the inclined surface by means of rails. The slope of the beach is of 1/3 (1 vertical, 3 horizontal), which is the average slope of the flank (named 'Sciara del Fuoco') of the Stromboli island where landslides fall into the sea (Tinti et al., 2006). The generated water waves are free to propagate both offshore and alongshore, since the plan dimensions of the used wave tank are of at least one order of magnitude larger than the width of the landslide, which can be considered to be a length scale of the edge waves. The experimental study has been carried out reproducing both subaerial and partially submerged landslides. The wave generation process is studied by means of video records of the near field flow and measurement of the landslide movement; the properties of the waves propagating along the coast are derived on the basis of runup and water surface level gauges. The layout and the experimental procedure are very similar to those used by previous researches, such those by Watts et al. (2000) and Enet and Grilli (2007). However the focus here is on the alongshore variation of the generated waves properties, which to our knowledge has never been carefully observed before in laboratory experiments.

The rest of this paper is organized as follows. The next section describes the experimental layout and the test program. The following Section 3 gives details on the analysis of the landslide kinematic. Then analysis of the near-field (Section 4) and of the far-field (Section 5) is presented. Conclusions are finally given.

2. Layout of the experiment

The experiments have been carried out at the Environmental and Maritime Hydraulic Laboratory (LIAM) of the University of L'Aquila (Italy) in a wave tank (see Fig. 1) built in bricks. Dimensions in plan are of 10.80 m (hereinafter referred to as the longshore direction) and 5.50 m (cross-shore) and the maximum water depth is of 0.80 m. Along two of the four tank sides an overspill has been created in order to try to reduce the reflection of the waves (for an estimate of the reflection coefficients see Panizzo et al., 2002) and to fix the maximum water level. A sloping beach has been placed along the long side of the tank. It forms with the horizontal an angle of 18.43°, corresponding to a slope of 1/3 (1 vertical, 3 horizontal). The beach is built in PVC sheets (1.00 m × 2.00 m × 0.01 m), and is sustained by a steel frame. The sheets are aligned with accuracy in order to avoid any disturbance to the fluid motion. The cross-shore section is made of a sloping part and of a constant-depth part 2.15 m long.

The landslide has a regular shape that reproduces half of an ellipsoid of equation $x^2/a^2+y^2/b^2+z^2/c^2=1$ ($a=0.2$ m, $b=0.4$ m, $c=0.05$ m for a total volume $V=2/3\pi abc=0.0084$ m^3). This makes the present layout very similar to that used by Watts et al. (2000) and Grilli and Watts (2005), who carried out the first experiments with a 2D semi-elliptical rigid slide, and by Enet and Grilli (2007) who faced the 3D problem. The density of the landslide is 1.83 t/m^3 for a total mass of 15.4 kg. The landslide has been built by using plastic material and an exterior layer of fiberglass, while the bottom is made up of steel. The landslide model is constrained to slide on rails placed along

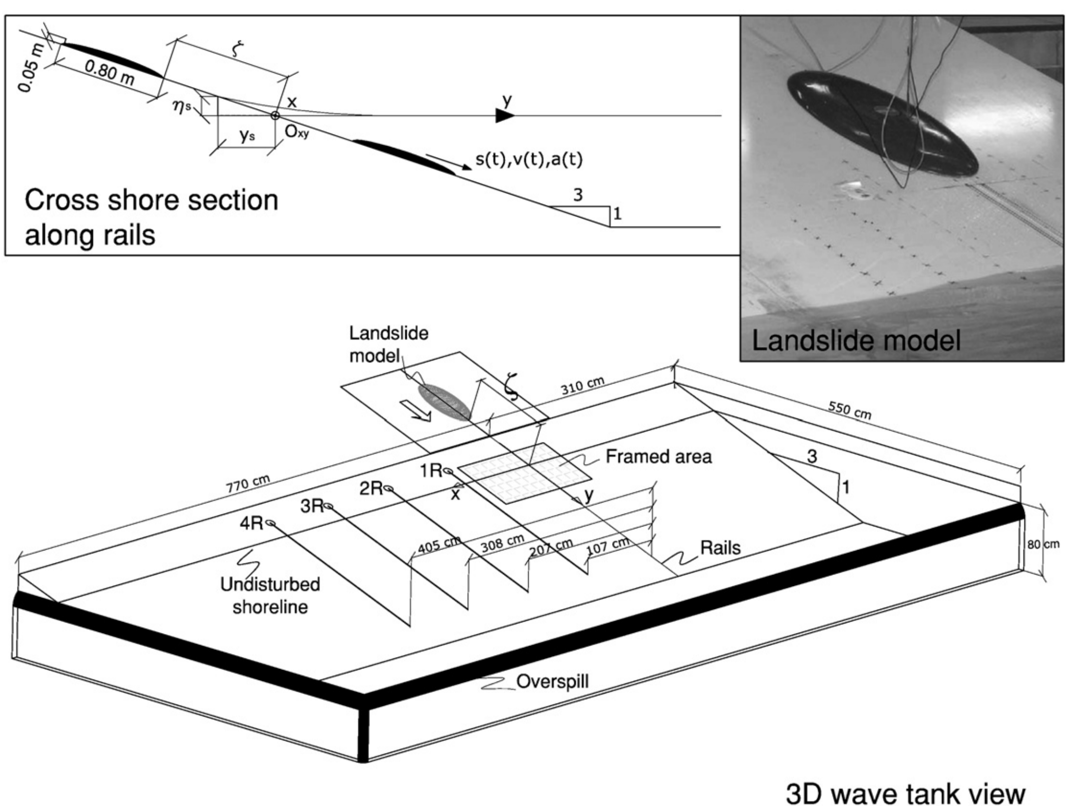

Fig. 1. Sketch of the wave tank.