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Run-up of tsunamis and long waves in terms of surf-similarity

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In the aftermath of the Indian Ocean tsunami on December 26, 2004, there was a lesson to be learned from the impact on the Thailand beaches: Flat beaches such as Patong, Kalim, Kamala, Bang Tao and Khao Lak generally experienced major destruction, while steeper beaches such as Surin, Karon, Kata, Kata Thani and at the Similan Islands were left almost untouched. Although local focusing, refraction and diffraction do play an important role, the beach slope plays an even greater role in the magnification of the incoming tsunami. Furthermore, it is not just the nearshore height of the tsunami, which makes it so devastating - after all even extreme wind waves of up to 20m or extreme tides of up to 13m make no or little damage on our coastlines. While the relative short wind waves break and dissipate completely before they reach the shoreline, the extremely long tidal waves respond to any beach slope as a wave to a vertical wall i.e. with full reflection and extremely small nearshore flow velocities. Tsunamis, on the other hand, may under certain circumstances generate huge run-ups with associated extreme flow velocities, and their impact will depend on the beach slope versus the wavelength, which may be characterized in terms of the surf-similarity parameter.

In this work, we first re-examine the classical analytical solutions for run-up of periodic long waves on an infinitely long slope as well as on a finite slope attached to a flat bottom (Green, 1838; Lamb 1932; Carrier & Greenspan, 1958; and Keller & Keller, 1964). Both cases provide simple expressions for the maximum run-up and the associated flow velocity in terms of the surf similarity parameter and the amplitude to depth ratio determined at some offshore location. We use these analytical expressions to analyze the impact of tsunamis on beaches and relate the discussion to the recent Indian Ocean tsunami from December 26, 2004. The theoretical solutions are compared to numerical results obtained with a high order Boussinesq formulation (Madsen et al. 2002, 2006).

As an alternative to periodic long wave theory, it is very common to apply solitary wave theory as input to laboratory or numerical wave tanks for the study of tsunami run-up. At a first glance, this appears to be an obvious choice, considering the fact that typical tsunamis in coastal areas have associated Ursell numbers, which are huge (several thousands or hundreds of thousands). We are, however, not convinced that solitary waves (or cnoidal waves) are necessarily reasonable models of tsunamis, and we shall discuss our main concerns about this popular approach. The discussion will be backed up by measurements and numerical results.

Finally, we apply the periodic long-wave run-up solutions to measured run-up of breaking and non-breaking irregular waves on steep impermeable slopes (Hughes, 2004). For the non-breaking waves, the theoretical curves turn out to be superior to state-of-the-art empirical estimates.

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