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Modeling of tsunami waves using waves induced by high-speed ferries in Tallinn bay, Baltic Sea

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As observations of the characteristics of the potentially hazardous incident waves far from the shore are difficult, costly, and often dangerous, it is an attractive idea to study such waves under controlled conditions. Waves dynamically similar to hazardous long waves are frequently generated by high-speed ferries. Tallinn Bay, a semi-enclosed body of water, approximately 10×20 km in size in the Baltic Sea, is one of the few places in the world where high-speed ferries continue to operate at or close to service speeds close to the shoreline, with up to 70 sailings per day in the past.

A large part of the ship tracks in the bay go over depths ranging from 20 m to 40 m, where the ships sail in near-critical regime and generate packets of large, solitonic, very long and long-crested waves. During calm conditions, vessel generated waves of up to 1.5 m, with periods of 10–13 seconds frequently occur in the nearshore, about 2700 m from the sailing line and about 100 m from the coast at a water depth of $\tilde{2}$.7 m. The typical daily highest ship wave is approximately 1.2–1.3 m. Combined, wind and vessel generated waves resulted in waves of $\tilde{1}$.7 m. The periods of leading vessels waves reach up to 15 s, which are much larger than the wave periods of 3–6 s, typically found for conventional ship wakes or for wind-generated waves in this sheltered body of water.

Many ship wakes are therefore effectively long waves (wavelengths up to 250 m) at depths down to 10–20 m. In many aspects, these wakes can be used as a dynamically similar input allowing modeling and measurements of the shoaling and runup properties of extreme, long, large-scale ocean waves and tsunami waves in safe conditions. Tallinn Bay therefore can be used as a natural laboratory for these waves. The properties of corresponding tsunami waves can be found with the use of geometrical similarity. The vessel waves in question correspond to waves with a length of 50 km and a period of 10 min in a typical water depth 4 km in the World Ocean, which can be recognized as tsunami waves.

Modeling of realistic tsunami wave dynamics in the open sea (wave refraction, diffraction and sea-bottom interaction) by means of vessel-induced waves, however, is only possible in calm wind wave conditions. Since periods of full-scale tsunami waves and wind waves in the open ocean are completely separated, no interaction between these structures occurs. On the other hand, the periods of vessel and wind waves are not separated enough to exclude their interactions.

Another important parameter characterizing the dynamical similarity of wave processes in nearshore is the breaking parameter Br. It depends on the wave period, bottom slope and maximum runup height. For ship waves in the Tallinn Bay Br$\tilde{4}$0. Similar values of the breaking parameter are found for tsunami waves caused by landslides. For example, at the depth of 2.5 m it corresponds to a tsunami wave with a period of about 1 min and wavelength of 300 m, which may cause a 25–30 m high wave runup on the beach. A tsunami wave with the listed parameters was observed in Nizhny Novgorod (Russia) in 1597, when the whole Pechersky monastery (200 m to 300 m) with all its buildings slid down into the Volga River. The resulting tsunami caused a wave runup up to 25 m (Didenkulova et al., 2003; Didenkulova and Pelinovsky, 2006).