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Fast-Transient Three-Dimensional Discrete-Element Model for Simultaneously Simulating the Development of Landslides and the Associated Tsunami Waves and Flows

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A fast-transient three-dimensional Discrete-Element Model (DEM) has been developed and utilized, for simulating, realistically, the landslide conditions of partially solid-and-granular-type material of the sea floor, and simultaneously, the detailed flow conditions, associated with the tsunami that would be locally being established by the landslide in open-sea regions, and also, in closed-sea regions, with complex-geomety shoreline boundaries. The DEM considers the seawater and the material of the sea floor as being the two components of a special pseudo-fluid mixture. The seawater is considered as the single-phase-liquid component, with the conventional fluid-physics properties, including the turbulence characteristics. Whereas, the material of the sea floor is considered as the two-phase component, with its solid-phase, which behaves according to a nonlinear-elastic submodel, and its fluid-phase, which behaves according to a special, relatively simple, viscoelastic granular submodel. The marked-element framework of the DEM simultaneously generates results for the fast-transient, three-dimensional flow conditions, associated with the transport of the single-phase liquid seawater component, and the two-phase solid-and-granular-material component of the fluid mixture.

During the development of the landslide conditions and the associated tsunami wave and flow conditions, the standard framework of the DEM can accurately simulate the fast-transient two-dimensional surface-wave phenomena, on the horizontal water-

surface plane (x,y), and also, all possible fast-transient, three-dimensional Large-Eddy Simulations (LES), Attached LES (ALES), Detached LES (DLES), and Shedding LES (SLES), in all horizontal planes (x,y), and importantly, in all vertical planes (x,z) and (y,z). The DEM incorporates a unique, fully-2nd-law-conformant formulation of the z-component of momentum equation, which does not introduce any computational conflict between accurate simulations of the surface-wave and the LES type of flows that can result during tsunamies in different flow subregions, including the ones containing only seawater, and the ones containing the landslide, with special pseudo-fluid mixtures, consisting of both the seawater, as the single-phase-liquid component, and the two-phase solid-and-granular-material component.

In order to test its advanced computational capabilities, the DEM was first applied to the simulations of the water-tank experiments which considered sliding solid-wedge experiments with known results. The simulations of the experiments indicated that the development of the transient surface-waves and the three-dimensional flow conditions could be modelled, without considering explicit specification of the sliding conditions of the solid-wedges, which required specification of submodels for different surface-friction conditions with different viscous and Coulomb friction characteristics. The DEM was also applied to the simulations of various hypothetical, but realistic, high-probability landslide conditions in the closed region of the Sea of Marmara, with complex bathymetry conditions, which include three major deep basins (created by the activity of the Main Marmara Fault), reaching depths of 1200 m. For the various hypothetical landslide events, the detailed results of the DEM simulations of the transient, three-dimensional landslide conditions, the tsunami wave, and the related flow conditions, were generated and were used for indicating the locations of critical runup conditions along the shoreline of the Sea of Marmara.