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Fast-Transient Three-Dimensional Fully-2nd-Law-Conformant Discrete-Element Model for Simulating Tsunami Flows in Regions with Severe Depth Variations

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A fast-transient three-dimensional Discrete-Element Model (DEM) has been developed and utilized, for simulating all the required flow conditions associated with flows that can be generated by tsunamies in open-sea regions, and also, in closed-sea regions, with complex-geomety shoreline enclosures. The DEM has the unique capability for generating results for the controlling "wave", "advection", and "diffusion" phenomena, with 2nd-order computational accuracies in time, $O(\Delta t^2)$,and space $O(\Delta x^2, \Delta y^2, \Delta z^2)$. Therefore, it can accurately simulate the conventional 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 tsunamis, particularly in regions of severe depth variations. The DEM also considers a novel Properly Averaged (PA) turbulence model, which realistically establishes the required turbulent-stress components, the turbulent-thermal-diffusion-flux components, and the turbulent-mass-diffusion-flux components. The closure of the turbulence model utilizes a novel formulation based on a set of local vorticity-

component-dependent turbulence-Reynolds numbers, which, collectively, represents an approach, similar (conceptually only) to the algebraic Smagorinsky closure hypothesis.

The DEM was applied to the simulation of a water-tank experiment for longitudinal flow over a bottom surface, which contained a submerged laterally extending wedge, with a cone in the middle, as a highly idealized representation of an undersea developing island on an undersea mountain range. The results were generated for the fast-transient, three-dimensional, free-surface flow conditions, which also included the important shedding-eddy formations, in the vertical plane (x,y), downstream of the wedge-cone formation. The comparisons of the SLES results with the available data from the experiments clearly validated the computational capabilies of the DEM for simulating fast-transient, three-dimensional flow conditions that can establish over severely varying depth conditions.

The DEM was also applied to the simulations of various hypothetical tsunami conditions in the predominantly closed region of the Sea of Marmara, with complex bathymetry conditions, which include three major deep basins(Çinarcik, Central and Tekirdag Basins), with steep very steep slopes, especially to the north. At various locations, the bottom conditions, forming the basin slopes, indicate depth variations from 40 m to 1200 m, approximately, within 2 km horizontal distances, which, during a tsunami event, can establish appreciable vertical-flow conditions, with related temporal and spatial variations of the z-component of momentum that must be accurately incorporated in the development of the DEM for the closed-sea region. For various hypothetical tsunami events, the detailed results of the DEM simulations of the tsunami wave, and the related transient, three-dimensional flow conditions, were generated and were used for indicating the locations of critical runup conditions along the shoreline (especially north) of the Sea of Marmara.