World Academy of Science, Engineering and Technology
International Journal of Mechanical and Industrial Engineering
Vol:12, No:05, 2018

Nonlinear Modelling of Sloshing Waves and Solitary Waves in Shallow Basins

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Abstract : The earliest theories of sloshing waves and solitary waves based on potential theory idealisations and irrotational flow have been extended to be applicable to more realistic domains. To this end, the computational fluid dynamics (CFD) methods are widely used. Three-dimensional CFD methods such as Navier-Stokes solvers with volume of fluid treatment of the free surface and Navier-Stokes solvers with mappings of the free surface inherently impose high computational expense; therefore, considerable effort has gone into developing depth-averaged approaches. Examples of such approaches include Green–Naghdi (GN) equations. In Cartesian system, GN velocity profile depends on horizontal directions, x-direction and y-direction. The effect of vertical direction (z-direction) is also taken into consideration by applying weighting function in approximation. GN theory considers the effect of vertical acceleration and the consequent non-hydrostatic pressure. Moreover, in GN theory, the flow is rotational. The present study illustrates the application of GN equations to propagation of sloshing waves and solitary waves. For this purpose, GN equations solver is verified for the benchmark tests of Gaussian hump sloshing and solitary wave propagation in shallow basins. Analysis of the free surface sloshing of even harmonic components of an initial Gaussian hump demonstrates that the GN model gives predictions in satisfactory agreement with the linear analytical solutions. Discrepancies between the GN predictions and the linear analytical solutions arise from the effect of wave nonlinearities arising from the wave amplitude itself and wave-wave interactions. Numerically predicted solitary wave propagation indicates that the GN model produces simulations in good agreement with the analytical solution of the linearised wave theory. Comparison between the GN model numerical prediction and the result from perturbation analysis confirms that nonlinear interaction between solitary wave and a solid wall is satisfactorilly modelled. Moreover, solitary wave propagation at an angle to the x-axis and the interaction of solitary waves with each other are conducted to validate the developed model.

Keywords : Green–Naghdi equations, nonlinearity, numerical prediction, sloshing waves, solitary waves
Conference Title : ICFMHS 2018 : International Conference on Fluid Mechanics and Hydraulic Systems
Conference Location : London, United Kingdom
Conference Dates : May 14-15, 2018