

**BENCHMARK PROBLEM -3-  
TSUNAMI GENERATION AND RUNUP DUE TO A 2D LANDSLIDE**

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**Abstract** The objective of this problem is to predict the free surface elevation and runup associated with translating a Gaussian shaped mass which is initially at the shoreline. The problem description of Benchmark Problem 3 (BM3) can be found in Part I Section 2 of this proceedings. A detailed analytical solution of the problem is described in Philip Liu, Lynett and Synolakis.<sup>3</sup>

Two problems are given in BM3 to be solved:

A.  $\tan \beta/\mu = 10$ . Where:  $\beta = 5.7^\circ$ ,  $\delta = 1m$  and  $\mu = 0.01$

B.  $\tan \beta/\mu = 1$ . Where:  $\beta = 5.7^\circ$ ,  $\delta = 1m$  and  $\mu = 0.1$ ,

where  $\delta$  is the maximum vertical slide thickness,  $\mu = \delta/L$  is the slide thickness-length ratio, and  $\beta$  is the slope angle.

To solve BM3 two approaches have been carried out:

- (1) First order approximation in time
- (2) Full Navier-Stokes (FNS) approximation aided by the Volume of Fluid (VOF) method to track the free surface.

Approach 1) uses one-dimensional linear and nonlinear shallow water wave theories, (LSW) and (NLSW) respectively. The finite difference solution of equation of motion and the continuity equation is solved on a staggered grid, Kowalik and Murty.<sup>4</sup> This method has second order approximation in space and first order in time. More detailed information is indicated in Benchmark Problem 1 by Kowalik *et al.*

The two-dimensional FNS-VOF solution has been included to visualize differences against the shallow water solutions. The FNS-VOF method uses the full nonlinear Navier-Stokes equation to models two-dimensional transient and incompressible fluid flow with free surfaces. The finite difference solution is obtained on a rectilinear mesh. The model has been extended to deal with rigid moving objects in the computational domain. Since FNS equation includes the vertical component of velocity/acceleration, some differences are expected if nonhydrostatic effects are strong.

## 1. Full Navier-Stokes Approach and VOF Method Including Moving Objects

Equation of continuity for incompressible fluid and the momentum equation,

$$\nabla \cdot \vec{u} = \frac{1}{V} \frac{dV_o}{dt} = \phi \quad \text{and} \quad \frac{\partial \vec{u}}{\partial t} + \nabla \cdot (\vec{u}\vec{u}) - \phi \vec{u} = -\frac{1}{\rho} \nabla p + \nu \nabla^2 \vec{u} + \vec{g}, \quad (1)$$

are solved in the rectangular system of coordinates. Where  $\vec{u}(x, y, t)$  is the instantaneous velocity vector,  $\rho$  is the fluid density,  $p$  is the scalar pressure,  $\nu$  is the kinematic viscosity,  $\vec{g}$  is the acceleration of gravity and  $\phi(\vec{x}, t)$  is a moving object internal function needed to force zero divergence in the computational control volume  $V$ . The momentum and continuity equations take into account the conservation mass due to the incursion or retreat of a moving object in the domain.

Solution of the equations is searched using the two-step method (Chorin<sup>1</sup> and Harlow & Welch<sup>2</sup>). The time discretization of the equations is similar to that described in Benchmark Problem 1 by Kowalik *et al.*

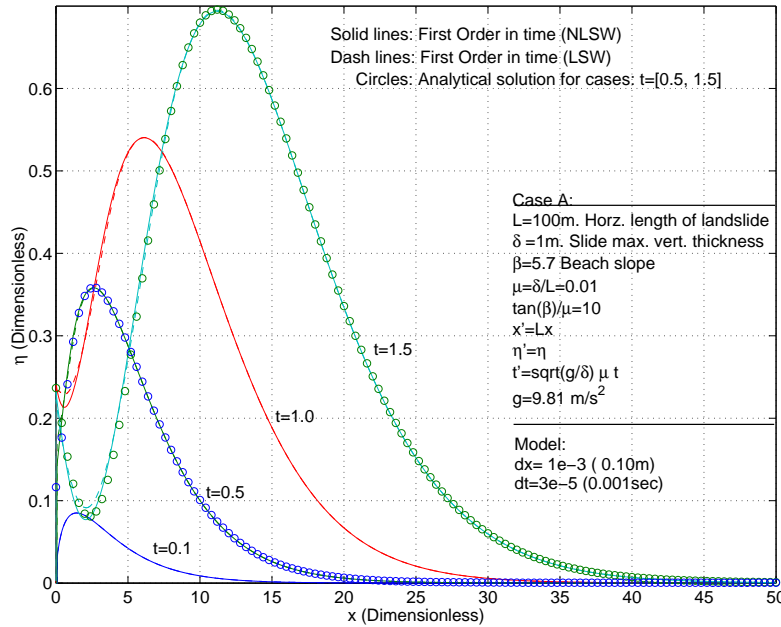


Fig. 1. CASE A: ( $\tan\beta/\mu = 10$ ). Free surface comparison.

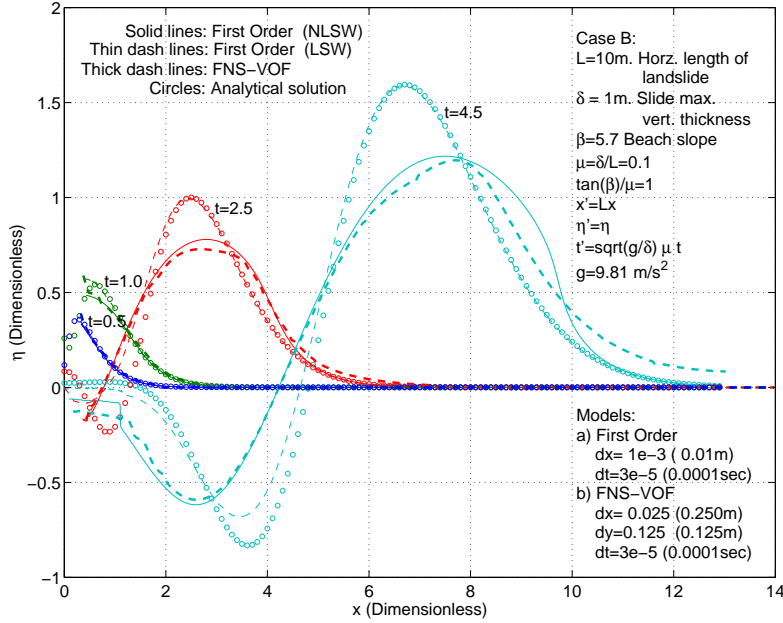


Fig. 2. CASE B:  $(\tan\beta/\mu) = 1$ ). Free surface comparison.

## 2. Discussion and Conclusions

Results obtained using first order numerical model and LSW analytical solution are depicted in Fig. 1 for Case A. Agreements of the numerical model results (NLSW and LSW) with the analytical solution are quite good. The analytical solution does an excellent job in predicting wave runup and wave propagation for thin slide, i.e.,  $\tan\beta/\mu = 10$ .

For thicker slide, Case B, omission of nonlinearity leads to disagreements in later stages of wave propagation, i.e.,  $t > 1.0$  (see Figs. 2 and 3). Note that the LSW numerical result follow very well its analytical solution.

A FNS-VOF solution is presented for case B in order to compare with the NLSW model solution. The FNS-VOF solution is ideally suited for this case, where relatively high vertical acceleration occurs. Due to dispersion effect FNS-VOF method predicts a wave a little bit more elongated, skewed but slightly less tall than the NLSW model, i.e. at  $t = 2.5$  and  $t = 4.5$ . All numerical models and analytical solution agreed very well at earlier time (i.e.,  $t = 0.5$  and  $t = 1$ ).

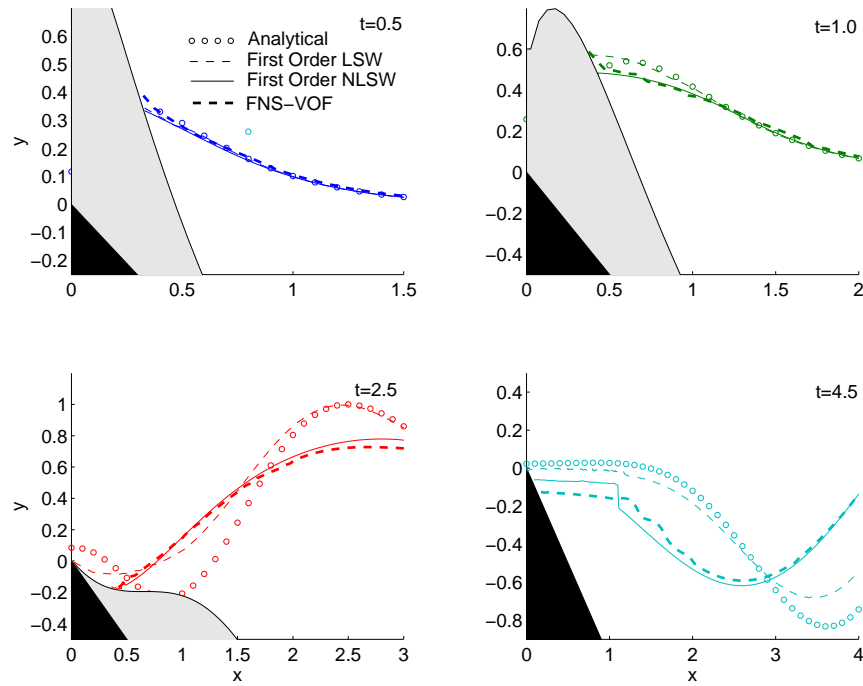


Fig. 3. Case B: ( $\tan\beta/\mu = 1$ ). Shoreline location comparison.

## References

1. A.J. Chorin. Numerical solution of the Navier-Stokes equations. *Math. Comp.*, **22**:745–762, 1968.
2. F.H. Harlow and J.E. Welch. "Numerical calculation of time-dependent viscous incompressible flow of fluid with a free surface". *The Physics of Fluids*, **8**:2182–2189, 1965.
3. Philip L.-F Liu, Patric Lynett, Costas E. Synolakis, "Analytical solution for forced long waves on a sloping beach", *Journal of Fluid Mechanics*, **478**, 101-109, 2003.
4. Z. Kowalik, and T. S. Murty, *Numerical Modeling of Ocean Dynamics*, World Scientific, :481, 1993.