Tsunami Generation Procedure using Navier-Stokes solver and an Investigation into the Run-up

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ABASTRACT

In the investigation of tsunami waves impacting on the coast and coastal structures, the generation of tsunami waves with long wavelengths and leading troughs in both laboratory experiments and numerical simulations is challenging. In this study, we propose a tsunami generation procedure for the free generation of tsunami waves using Navier--Stokes solver. The time series of the tsunami surface elevation and derived wave velocity are interpolated in an open-source Navier-Stokes solver - *interFoam* -- for the generation of tsunami waves. The analytical function form deriving the wave velocity is:

$$u(x,t) = u(x,t-\Delta t) \pm \sqrt{\frac{1}{2}\left(\frac{h(x,t)}{h(x,t-\Delta t)}+1\right)\left(\frac{h(x,t)}{h(x,t-\Delta t)}-1\right)^{2}\left(\frac{h(x,t)}{h(x,t-\Delta t)}\right)^{-2} gh(x,t)}. \quad (1)$$

The wave records of the 2004 Indian Ocean and 2011 Tohoku tsunami events are reproduced by the Navier-Stokes solver for the first time. In addition, the credibility of the model for long-wave generation, propagation, and run-up is validated against laboratory measurements. The general results suggest that the tsunami generation procedure is feasible and that *interFoam* is an excellent option for tsunami wave modeling. Without the linear shallow water approximation, the procedure can be used to model leading-depression tsunami waves of high nonlinearity.

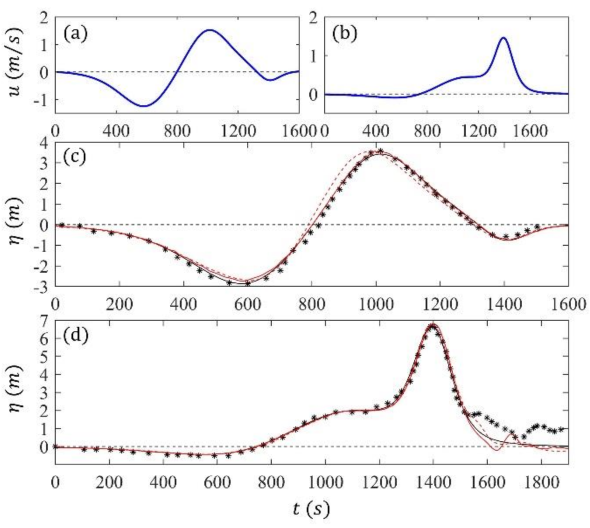

Figure 1 - Derived wave velocities based on Equation 1 of the wave records in the (a) 2004 Indian Ocean and (b) 2011 Tohoku tsunamis. Comparisons of surface elevations of the (c) 2004 Indian Ocean and (d) 2011 Tohoku tsunamis. Star symbol: field-measured wave-height record; black curve: fitted wave-height function; red solid curve: transient variation in the modeled surface elevation at the wave entrance; red dashed curve: transient variation in the modeled surface elevation at a distance of 5 km from the wave entrance.

The run-up mechanism of the leading-depression tsunami waves is investigated. Spatial and temporal variations in the surface elevation, flow contour, and velocity field are presented. The results indicate that a stronger leading trough may induce a longer wave recession distance before the elevated wave arrives and a higher wave run-up at a later time. With the increase of the trough amplitude, the seaward and landward velocities of the wave are both intensified. The leading trough steepens the wave front of the elevated wave and potentially triggers wave breaking during the run-up.

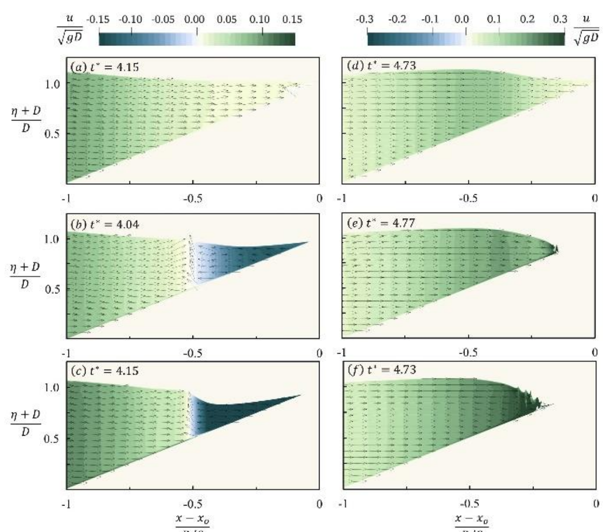

Figure 2 - Panels (b) and (c) depict the flow contours and velocity fields when the wave front of the elevated wave occurs at half of the slope for $A_t/A = 0.5$ and 1.0, respectively. A_t is the depth of the leading trough. A is the height of the wave crest. Panels (e) and (f) depict the flow contours and velocity fields when a maximum receding distance is reached. Panels (a) and (b) for $A_t/A = 0.0$ are plotted for contrast. The plots are not to scale.

Furthermore, our investigation delves into the wave run-up

height of tsunami waves, specifically considering the influence of varying wave non-linearity H / D, where H represents the initial wave height, and D stands for the initial water depth. The outcomes of our study reveal a crucial dependency on the precise on-site measurements of both wave height and period for accurate predictions. Employing this specific data, we can successfully employ the analytical solution developed by Madsen & Schäffer (2010) to forecast wave run-up height.

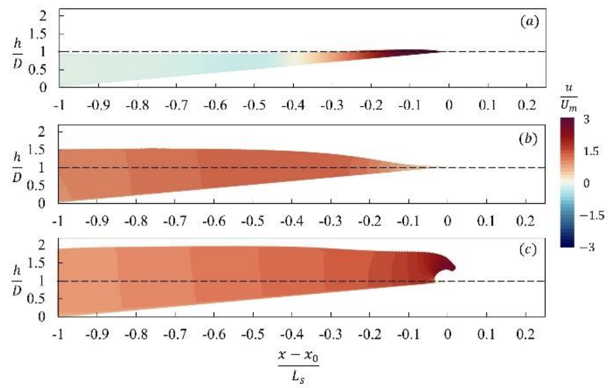

Figure 3 – The wave shapes and velocity contours during the run-up of tsunami waves on a constant slope. The wave non-linearities are $H/D =$(a) 0.1, (b) 0.5 and (c) 1.0.

Bibliography

Madsen, P. A., Schaeffer, H. A. (2010). Analytical solutions for tsunami runup on a plane beach: single waves, N-waves and transient waves. Journal of Fluid Mechanics, 645, 27-57.

REFERENCES

Peiwei Xie, Yan Du (2023): Tsunami Wave Generation in Navier-Stokes Solver and Investigation of Runup of Leading-depression Wave, Coastal Engineering, ELSEVIER, 182-104293