Project N. 037110

NEAREST

Integrated observations from NEAR shore sources of Tsunamis: Towards an early warning system

Instrument: STREP

Thematic priority: 1.1.6.3 GOCE (Global Change and Ecosystems)

D28: Validation of the model

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Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (Including Commission Services)	
RE	Restricted to a group specified by the Consortium (Including Commission Services)	
CO	Confidential, only for members of the Consortium (Including Commission Services)	**CO**

1. INTRODUCTION

All numerical models used in tsunami simulation must be subjected to a validation process to ensure that the model is able to reproduce observed data.

The two most basic steps required to ensure that a numerical model works for propagation and inundation computation are the “basic hydrodynamic considerations” (Synolakis et al., 2008): mass conservation and convergence; while the first step ensures that the model conserves mass, the second basic step checks the convergence of the numerical code to a certain asymptotic limit. Once these two basics steps are accomplished the numerical codes must be tested through analytical, laboratory and field data benchmarking.

The procedure used to validate the numerical model followed the tests proposed by Synolakis et al., (2007, 2008) and by Liu et al. (2008). A complementary check was obtained through the computation of the inundation map of the Boca do Rio; these esults were checked against historical data: run up and maximum inundation distance.

2. MODEL VALIDATION

2.1 The Catalina Island benchmarks

2.1.1 Benchmark #1

This analytical benchmark aims to investigate the dependence of the results on the parameters: beach slope, offshore wave height and bathymetry variation. This benchmark corresponds to a uniformly sloping beach, with no variation in the lateral direction, viz. a 2-D problem in the vertical plane. The initial-value-problem (IVP) technique introduced by Carrier et al. (2003) is used to produce the benchmark data. The beach slope is fixed at 10% and the initial free surface elevation is given. The assignment is to compute and present the snapshots of the free surface and velocity profiles at t = 160 sec., 175 sec., and 220 sec. Figure 1 presents the grid setup for the test: the large grid has 50m spacing while the nested grid has 10 m. In figure 1 the grid layout is presented.

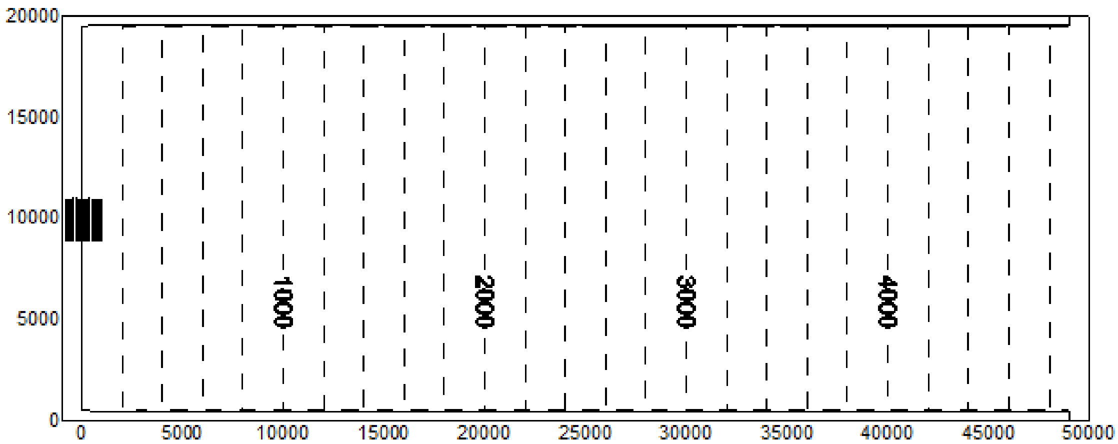

Figure 1: Grid layout for Benchmark #1. The initial location of the shoreline is plotted in solid line.

Figures 2 and 3 show the computed free surface profile; snapshots are plotted at t = 160 sec., 175 sec., and 220 sec.

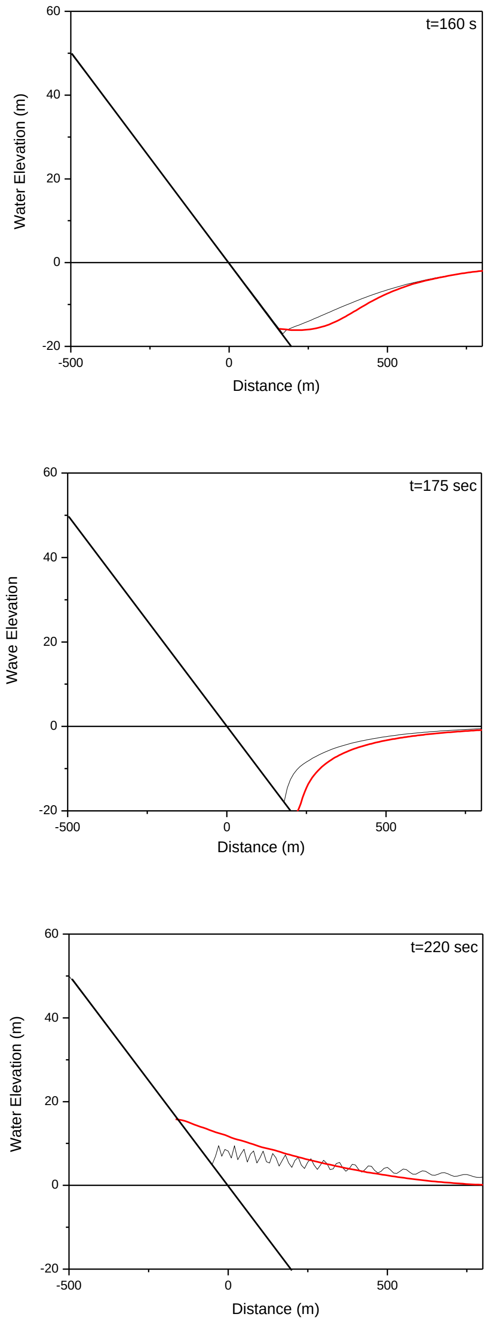

Figure 2: Comparison between the snapshots of the free surface and the theoretical value; red line- theoretical; black line –model for instants t = 160 sec., 175 sec., and 220 sec (Benchmark #1)

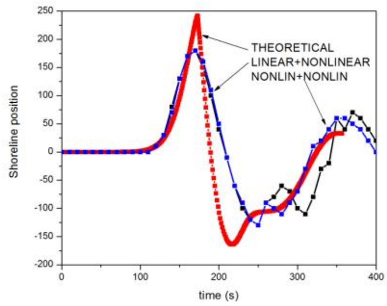

Figure 3: Comparison between the location of the shoreline (Benchmark #1);
red line theoretical; blue line – nonlinear shallow water equations; linear and non linear shallow

2.1.2 Benchmark #2

The 1993 Okushiri tsunami caused many unexpected phenomena. One of them was the extreme run up height of 32 m that was measured near the village of Monai in Okushiri Island. This tsunami run up mark was discovered at the tip of a very narrow gulley within a small cove. This benchmark problem is an 1/400 scale laboratory experiment of the Monai run up, using a large-scale

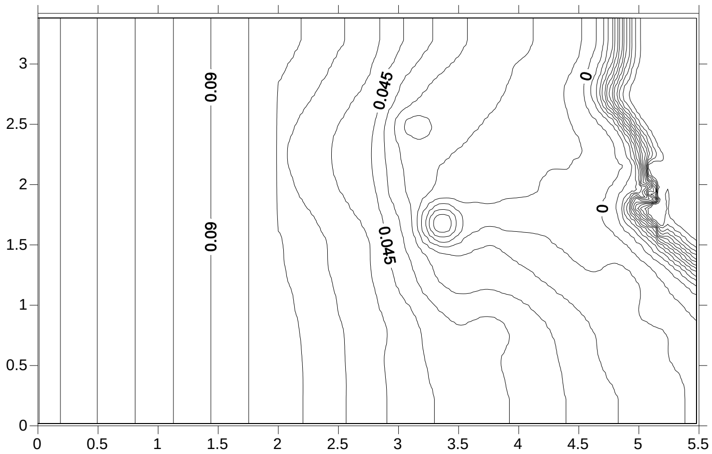

Figure 4 Grid setup for computation of benchmark #2

tank (205 m long, 6 m deep, 3.4 m wide) at Central Research Institute for Electric Power Industry (CRIEPI) in Abiko, Japan. It is emphasize that the problem is NOT to simulate the run up of the real event, but the laboratory measurements instead.

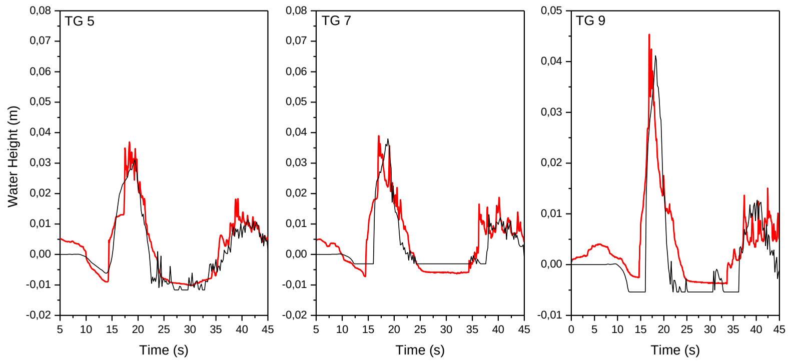

Figure 5: Experimental (read) and synthetic results (black)- Benchmark #2

2.1.3 Benchmark #3

The goal is to predict the free surface elevation and run up associated with a translating Gaussian shaped mass, initially at the shoreline. In dimensional form, the seafloor can be

$$h(x,t) = H(x) + h_o(x,t)$$

described by: $H(x) = x\tan\beta$

$$h_o(x,t) = \delta \exp\left[-\left(2\sqrt{\frac{x\mu^2}{\delta\tan\beta}} - \sqrt{\frac{g}{\delta}}\mu t\right)^2\right]$$

where δ = maximum vertical slide thickness, μ = thickness/slide length, and β is the beach slope. Once in motion, the mass moves at constant acceleration. The modellers are supposed to provide snapshots of the free surface at selected times. The following two setups must be benchmarked: Four comparisons should be made for each setup. Spatial snapshots of the free surface are given at four different non-dimensional times. Theoretical results are provided by Liu et al (2003).

The following parameters: tanβ/μ=10, β=5.7° (we used tan⍰=0.1), δ=1m, μ=0.01. The parameter $\sqrt{\frac{g}{\delta}}\mu t$ will take the following values 0.1, 0.5, 1.0, 1.5. Considering that our numerical layout has a time step of 0.02 sec, this will correspond to the following outputs:

CASE A					
$\sqrt{\frac{g}{\delta}}\mu t$	g	⍰	⍰	t	Step
0.1	9.81	1	0.01	3,192754	159,6377
0.5	9.81	1	0.01	15,96377	798,1886
1.0	9.81	1	0.01	31,92754	1596,377
1.5	9.81	1	0.01	47,89131	2394,566

Table 1 – Time steps of the model to be compared
with the given theoretical waveforms (Benchmark #3, Setup A)

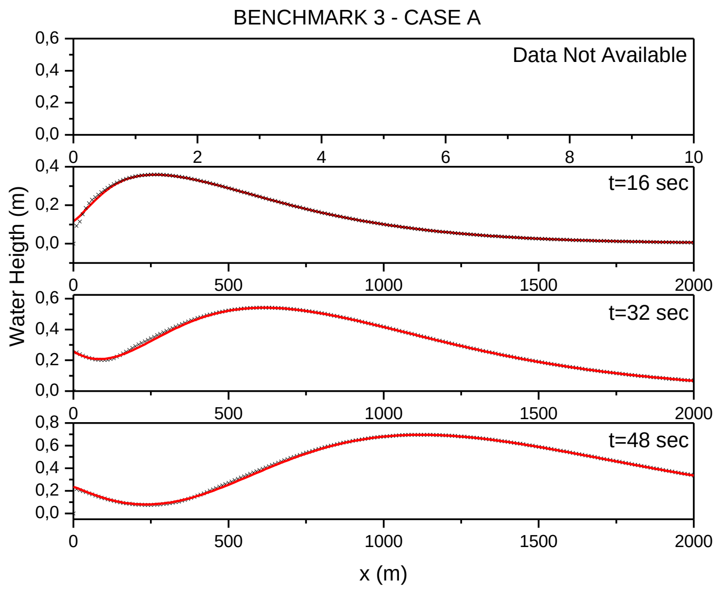

Figure 6: Comparison between experimental (read)
and synthetic (black crosses) waveforms (Benchmark #3, Setup A)

In this case we consider the following parameters: tanβ/μ = 1, β= 5.7° (we used tan⍰=0.1), δ=1m, μ=0.1. The parameter $\sqrt{\frac{g}{\delta}}\mu t$ will take the following values 0.5, 1.0, 2.5, 4.5. Considering that our numerical layout has a time step of 0.01 sec, this will correspond to the following outputs:

CASE B					
$\sqrt{\frac{g}{\delta}}\mu t$	g	⍰	⍰	T	Step
0,5	9.8	1	0.1	1,596377	159,6377
1	9.8	1	0.1	3,192754	319,2754
2,5	9.8	1	0.1	7,981886	798,1886
4,5	9.8	1	0.1	14,36739	1436,739

Table 2 – Time steps of the model to be compared with the given theoretical waveforms (Benchmark #3, Setup B)

The results corresponding to the four situations are presented below:

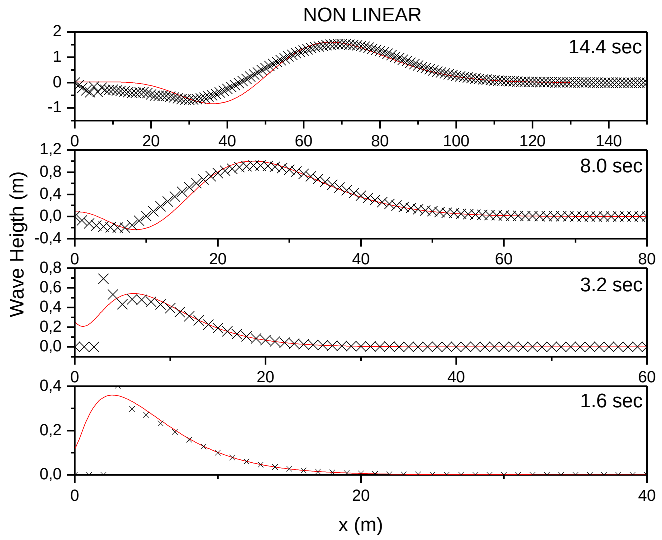

Figure 7: Comparison between experimental (read) and synthetic (black crosses) waveforms (Benchmark #3, Setup B) using Non Linear Shallow Water equations

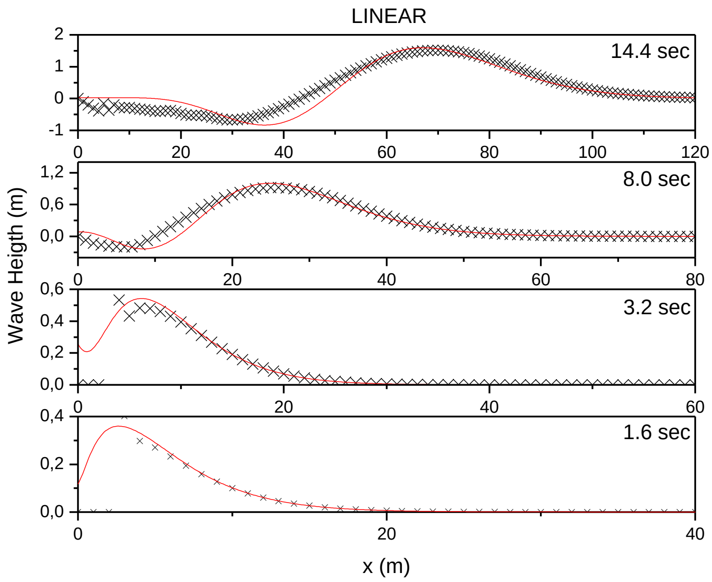

Figure 8: Comparison between experimental (read) and synthetic (black crosses) waveforms (Benchmark #3, Setup B) using Linear Shallow Water equations

2.1.4 Benchmark #4

This problem requires the modelling of a sliding mass down a 1:2 plane beach slope and compares the predictions with laboratory data. Large-scale experiments have been conducted in a wave tank with a length 104 m, width 3.7 m, depth 4.6 m and with a plane slope (1:2) located at one end of the tank. A solid wedge was used to model the landslide. The triangular face has the following dimensions: a horizontal length of b = 91 cm, a vertical face a = 46 cm high and a width of w = 61 cm. The wedge was instrumented with an accelerometer to accurately define the acceleration-time history and a position indicator to independently determine the velocity- and position- time histories. The wedge travelled down the slope by gravity rolling on specially designed wheels (with low friction bearings) riding on aluminium strips with shallow grooves inset into the slope. A snapshot of the wedge motion is shown in the figure below.

A sufficient number of wave gages were used to determine the seaward propagating waves, the waves propagating to either side of the wedge, and for the submerged case, the water surface-time history over the wedge. In addition, the time history of the run-up on the slope was accurately measured. The modellers are asked to model the flow with the wedge starting from two different initial elevations; one submerged the other sub aerial and will be given the block motions recorded. The modellers will have to provide time histories of surface elevation at selected locations in the channel and the shoreline motion. An animation of the results is encouraged. Modellers can use both 2 D and 3D codes.

2.1.5 Benchmark: Boca do Rio (SW Portugal)

The flooding of Boca do Rio is used to validate the model against historical information and paleo – tsunami evidence.

Figure 9.Location of test area and view of Boca do Rio Valley

The bathymetric model was generated from GEBCO bathymetric contours and includes land elevations from the Global Land 1-km Base Elevation (GLOBE) database. The deep multibeam bathymetric data in the Gulf of Cadiz was obtained between 2000 – 2005. The DTM was interpolated from raw soundings to search for errors. Data were filtered and interpolated at nodes of a regular-spacing grid. The final grid limits are 34^{o}N – 38^{o}N; 12.5^{o}W - 5.5^{o}W.

The nested grids resolution is 0.008^{o}, 0.002^{o} and 0.0005^{o} in order to assure a good description of bathymetric and topographic effects near shore. The finer grid is focused at Boca do Rio (test area) where there is very good historical data as well as sedimentalogical evidence of the 1755 tsunami. The grids are in UTM 29.

For the Lisbon Event we use the source terms documented in DEFRA report (June 2006); the parameters of the model earthquake are Fault Plane Strike / Dip / Rake: 340 / 45 / 90; Fault centre Lat / Lon: 37.0^{o}N / 9.75^{o}W (Southwest of Lisbon); L = 210 km ; W = 75 km ; D = 13.6 m.

The historical reports descriptions found in Pereira de Sousa (1919) and Silva Lopes (1841) report for Boca do Rio: " ... the sea surged out of its limits, ejecting sand from a nearby beach located close to a narrow opening (*inlet*) that allows the tide to rush in... It uncovered foundations of a large settlement that extended farther seawards...today this place is again covered with sand as it was before...At the coast...is located the Almadena fort, built under King Filipe III...the sea invaded the fresh water creek that outlets there into the sea, for more than 1/2 league (*circa 2500-3000m*) with a water height of 10-12 "varas" (*circa 11-13m*) destroying some large "medôes" (*foredunes*) and carrying along 50 of the heaviest anchors more than 1/4 league inland.The historical data is summarized in the following table:

Inundation Parameters	Inundation Parameters Inferred from the historical reports	Synthetic Inundation Parameters
Run up	11- 13 m	10 m
Maximum Inundation Distance	2500 m	2000 m

Table 3. Inundation parameters at Boca do Rio

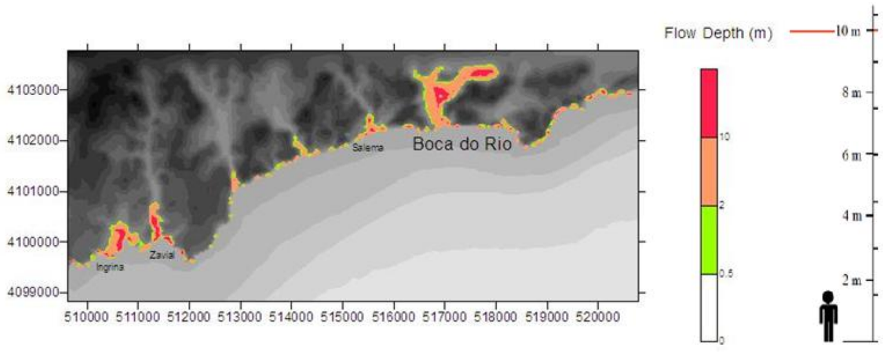

Figure 10. Inundation map of Boca do Rio and surrounding beaches

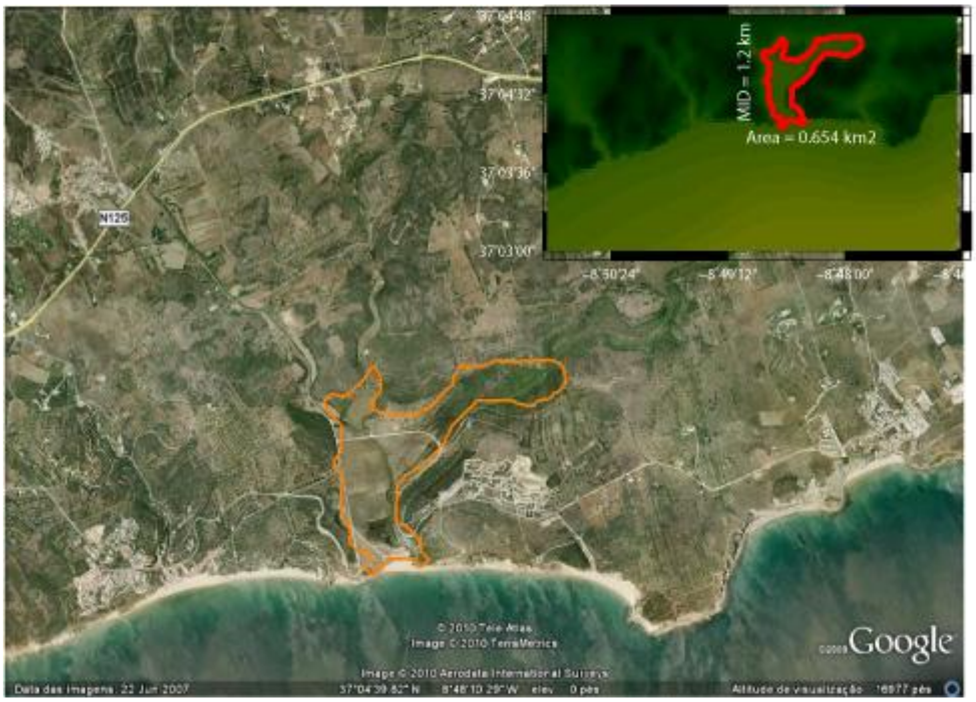

Figure 11. Inundation limit – orange contour
inset (right top corner): area and maximum inundation distance MID

The results presented in figures 10 and 11 show that the model produces inundation along Boca do Rio and surrounding beaches: Salema, Zavial and Ingrina. Tsunami flow depths estimates vary from about 2 to 8 meters in Boca do Rio valley, reaching a maximum flow depth of about 10 m. The maximum inundation distance (MID) in Boca do Rio valley is 1,2 km and the inundation area (red polygon in figure 11) is 0.654 km^{2}. The lithostratigraphic investigations carried out by Dawson et al. (1995) indicate that the MID is circa 1km of run-in

3. CONCLUSIONS

It was observed that the model reproduces acceptably the benchmarks results for tests #1, #2 and #3, the ones relevant for this study, in terms of maximum run up/ drawdown for the case of Benchmark test #1, using a step size of 50m, as used here. The model reproduced well the inundation produced by a 1755 like event

. 4. REFERENCES

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