Numerical Simulation of Tsunami Propagation and Runup: Case study on the South China Sea

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OBJECTIVES

1) Develop a Numerical Model for Simulation of Long Wave Propagation and Run up on beaches

2) Test the Model with Laboratory experimental data

3) Simulation of Tsunami on the South China Sea
MODEL

OKADA MODEL: (Tsunami generation)

Shallow Water Equation
Finite Volume Method
(Godunov-type Second order)

+ (Splitting + VOF technique)

Boussinesq Term
(Madsen et al., 1997)
Finite Difference Method
VOF – Like Technique

\[ \text{Need to adjust the outgoing fluxes} \]

\[ \text{FLUX}^y_{i,j-1/2} \]

\[ \text{FLUX}^x_{i-1/2,j} \rightarrow \text{FLUX}^x_{i+1/2,j} \rightarrow \text{FLUX}^y_{i,j+1/2} \]

\[ \text{VOF} = (h + \eta) \Delta x \Delta y \]

\[ \text{VOFOUT} = \text{FLUX}^x_{i+1/2,j} + \text{FLUX}^y_{i,j+1/2} \]

Limitation Coefficient (if VOFOUT > VOF)

\[ C_l = \frac{\text{VOFOUT}}{\text{VOF}} \]

\[ \text{FLUX}^x_{i+1/2,j} = \text{FLUX}^x_{i+1/2,j} / C_l \]

\[ \text{FLUX}^x_{i,j+1/2} = \text{FLUX}^x_{i,j+1/2} / C_l \]
Calculation of Numerical Fluxes

1) Godunov method: HLL (Harten, Lax and Vanleer) Riemann Solver for Calculation of Numerical Fluxes at cell Interfaces of Shallow water Equation (Toro, 1999);
2) Muscl-Hancock method and Roe Limiter to get the second order of accuracy in space and time (Toro, 1999);
3) Crank-Nicholson Scheme of the Finite difference method for the Boussinesq Term
MODEL TEST:

TEST 1: Solitary Wave Run up on a Plane Beach (Synolakis’s Exp., 1987)

TEST 2: Shock Wave Run up on a non-uniform Beach

TEST 3: Solitary Wave run up on a Conical Island (Briggs et al.’s Exp, 1995)
TEST1: SOLITARY WAVE RUN UP ON A PLANE BEACH

Long Wave Runup on a Plane Beach

Expt. Condition Similar to Synolakis's (1987)

A/d = 0.3

d

slope = 1/19.85

Experimental condition
Test1 - Results: WATER SURFACE DISTRIBUTION

\[ t^* \sqrt{g/d} = 15 \]
Test1 - Results: WATER SURFACE DISTRIBUTION

\[ t \ast \sqrt{\frac{g}{d}} = 35 \]

- Exp. data (Synolakis, 1987)
- Num. Results
Test1 - Results: WATER SURFACE DISTRIBUTION

\[ t \times \sqrt{\frac{g}{d}} = 45 \]

- Exp. data (Synolakis, 1987)
- Num. Results
Test1 - Results: WATER SURFACE DISTRIBUTION

\[ t^* \sqrt{\frac{g}{d}} = 55 \]

Exp. data (Synolakis, 1987)
Num. Results
Comparison with other numerical results

Test 1 - Results: WATER SURFACE DISTRIBUTION

$t \sqrt{\frac{g}{d}} = 25$

- Wei et al (2006)
- Li & Raichlen (2002)
- Titov & Synolakis (1995)
- Zelt (1991)
- Exp. Synolakis (1987)
- Present Result
Test2-Results: SHOCK WAVE RUN UP ON A NONUNIFORM BEACH
TEST3: SOLITARY WAVE RUN UP ON A CONICAL ISLAND
(Briggs et al., 1995)

$D_T = 2.2 \text{ m}$

$h_c = 0.625 \text{ m}$

$h = 0.32 \text{ m}$

$D_B = 7.2 \text{ m}$

$A \over h = 0.2$

$B = 30 \text{ m}$

$L = 25 \text{ m}$

Schematic view of the experiment
Test3-Results: WATER SURFACE ELEVATION

**gauge 1**

- **Num. NSW Model**
- **Num. Bouss Model**
- **Exp. Data (Briggs, 1995)**

**gauge 6**

- **Num. NSW Model**
- **Num. Bouss Model**
- **Exp. Data (Briggs, 1995)**
Test3-Results: WATER SURFACE ELEVATION

<table>
<thead>
<tr>
<th>Num. NSW Model</th>
<th>Num. Bouss Model</th>
<th>Exp. Data (Briggs, 1995)</th>
</tr>
</thead>
<tbody>
<tr>
<td>gauge 9</td>
<td></td>
<td></td>
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<tr>
<td>gauge 16</td>
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</tbody>
</table>
Test3-Results: WATER SURFACE ELEVATION
Test3-Results: Run up Height on Circular Island

Runup (m)

- Num. Result
- Exp. data (Briggs, 1995)

Angle (deg)

Right side
Lee side
Left side
Fore side

Incident direction
Remarks

• The Numerical Model can simulate well the propagation of long wave and run up on a sloping beach;

• The Boussinesq Term added to the shallow water model can improve significantly simulated results for water surface elevation of long waves;

• The numerical model should be considered to the next step of verification with field case studies;
SIMULATION OF TSUNAMI ON THE SOUTH CHINA SEA

• Consider Earthquake with Magnitude M=8.5 at the Manila Trench;
• Consider Tsunami-Travel Time;
• Maximum Wave Height Distribution;
Simulation Condition

Topography: ETOPO 2

Mesh: Regular

Initial condition: OKADA Model (1985) with the earthquake parameters:

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Magnitude</th>
<th>Strike (Deg)</th>
<th>Dip (Deg)</th>
<th>Rake (Góc tự) (Deg)</th>
<th>Depth of Epicentre (km)</th>
<th>Length of Fault (km)</th>
<th>Width of Fault (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.5</td>
<td>177</td>
<td>15</td>
<td>90</td>
<td>18</td>
<td>313</td>
<td>68</td>
</tr>
<tr>
<td>2</td>
<td>9.0</td>
<td>87</td>
<td>15</td>
<td>90</td>
<td>24</td>
<td>646</td>
<td>101</td>
</tr>
</tbody>
</table>
Simulation Results: Travel Time

![Map showing travel times with contour lines and geographic coordinates.](image-url)
Simulation Results: Maximum Tsunami Height

M=8.5 at Manila Trench
Simulation Results: Maximum Tsunami Height Distribution
REMARKS

😊 Boussinesq Equation is a good choice to improve simulation results for long wave propagation including tsunami;

😊 Tsunami travel time in the South China Sea is very short, only 20 minutes to reach the Taiwan Coast, 1.5 hours to Vietnam coast and immediately to Philippine Coast for the case of earthquake at the Manila Trench occurs;

😊 It is worth to build up maximum tsunami waning maps in advance before a real tsunami-earthquake occurs in the South China Sea in order to understand which area is potentially suffer from a destructive tsunami;

Thank you very much for your attention!
Data collected from 1600-2005, 5.0 < M < 8.0, dM = 0.1

\[
y = -0.8799x + 7.412
\]

\[
y = -0.7261x + 5.6848
\]

(earthquake data from 1600-2005, 5.0 < M < 9.0)
Log\( L = 0.55M - 2.19 \),
\[ 6.7 \leq M \leq 9.3 \]

Log\( S = 0.86M - 2.82 \),
\[ 6.7 \leq M \leq 9.2 \]

Relation between earthquake and rupture parameters