W Phase Inversions and Seismic Tsunami Warning System in Taiwan for Manila Trench Earthquakes

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Outline

- Motivation
- Unit tsunami method
- Source inversion of W phase
- Conclusions
Soloviev and Go (1974); 許明光，李起彤 (1996)
Steps for classical tsunami simulation (Okal, 2008):

1. Consider model of Earthquake Rupture (GCMT too slow, solution: source inversion of W phase)

2. Compute Static Seafloor Deformation (quickly done by Okada (1985))

3. Interpret the deformation as Initial Condition for Vertical Surface Displacement with Zero Initial Velocity

4. Simulate its Propagation (time consuming, solution: unit tsunami method)
Propagation

wavelength $\gg$ water depth

The tsunami propagation on open seas is well modelled by the shallow water wave wave equation.

However, this is the most time consuming stage in tsunami simulation.
Runup

Linear v.s. Nonlinear

Linear approximation breaks down when the amplitude is greater than 0.1 water depth.

If we only wish to forecast the amplitudes of the approaching tsunamis. The Runup stage can be excluded and the system is linear.
Unit tsunami method

- For a linear system, the tsunami waves can be expressed as a linear combination of unit tsunamis (Lee et al., 2005).
unit tsunami event
32 tidal stations
We apply COMCOT (Liu et al., 1998) to simulate the propagation of unit tsunami by solving linear shallow water wave equation in Spherical coordinates.

- Grid size : 1 min.
- Time step : 1 sec
- Radiation on map boundary
  - Total reflection on ocean-land boundary
- Total time run time : 4hr
08_06; y-axis: cm; x-axis: min
$14_{10}$; y-axis: cm; x-axis: min
Arrival time in minutes
unit tsunami event
Scenario earthquake at 121°E, 20°N, 25 km
Mw=9.0, strike 10°, dip 20°, rake 90°
Real simulation
Maximum amplitudes

Unit Tsunami method

Real simulation
Source inversion of W phase (Kanamori and Rivera, 2008)

• A long-period phase, up to 1000 s, arrives before S phase.

• In ray theory, superposition of long-period P, PP, SP and S.

• In normal model theory, superposition of the fundamental mode, first, second and third overtones of spheroidal modes at long period.

Figure 1. W phase from the 2001 Peruvian earthquake ($M_w = 8.4$) recorded at HRV, and the synthetic W phase computed by mode summation using the GCMT solution.
• the long period information
• faster speed than the traditional surface waves
suitable for rapid and robust determination of
seismic source parameters for tsunami warning
purposes
(Kanamori and Rivera, 2008)
Regional Distance $(\Delta \leq 12^\circ)$

Using F-net data

(Kanamori and Rivera)
Portable broadband seismic network in Vietnam for investigating tectonic deformation, the Earth’s interior, and early-warning systems for earthquakes and tsunamis

Bor-Shouh Huang, Tu Son Le, Chun-Chi Liu, Dinh Van Toan, Win-Gee Huang, Yih-Min Wu, Yue-Gau Chen, Wen-Yen Chang
Broadband Array in Taiwan for Seismology (BATS)
1996~

Mw > 6.5

16 events
1. The vertical components of BATS data is deconvolved to displacements with a pass-band of 0.0167 Hz (600 s) to 0.01 Hz (100 s), using a time domain recursive method (Zhu 2003).

2. A time duration from the beginning of P to $15 \triangle$ s is windowed to contain the most of the W-phase energy.

3. Time windows of the observed waveforms are concatenated for inversion.
An example of waveform (filtered, windowed, and concatenated)
4. We compute the theoretical W phase using normal mode summation with pre-computed modes stored in database.

5. The synthetic waveforms are filtered, windowed and concatenated, the same as observed.

6. A linear inversion is performed to obtain the seismic moment tensor using a given hypocenter location and the origin time.
$Gm = d$

\[
\begin{pmatrix}
  u_{w1}^{1,1} & u_{w1}^{2,2} & * & * & * & u_{w1}^{2,3} \\
  u_{w2}^{1,1} & u_{w2}^{2,2} & * & * & * & u_{w2}^{2,3} \\
  u_{w3}^{1,1} & u_{w3}^{2,2} & * & * & * & u_{w3}^{2,3} \\
  * & * & * & * & * & * \\
  * & * & * & * & * & * \\
  * & * & * & * & * & * \\
  * & * & * & * & * & * \\
  * & * & * & * & * & * \\
  * & * & * & * & * & * \\
  * & * & * & * & * & * \\
  u_{wN}^{1,1} & u_{wN}^{2,2} & * & * & * & u_{wN}^{2,3} \\
\end{pmatrix}
\begin{pmatrix}
  u_{w1} \\
  u_{w2} \\
  u_{w3} \\
  M_{11} \\
  M_{22} \\
  M_{33} \\
  M_{12} \\
  M_{13} \\
  M_{23} \\
  M_{23} \\
  u_{wN} \\
\end{pmatrix}
\begin{pmatrix}
  * \\
  * \\
  * \\
  * \\
  * \\
  * \\
  * \\
  * \\
  * \\
  * \\
\end{pmatrix}
\]
20061226 Pingtung (0.00167 Hz - 0.01 Hz, n = 4, W)

Red: synthetics
Black: observations
Keep stations of good fitting
Two scenarios

\[ t_s = \frac{D}{V_r} \]

fault area

Centroid Location

PDE Location
Centroid Location (II)

9  2001.001.06.51  Mw=7.4  \(t_p=12.0\)
10  2001.352.03.57  Mw=6.8  \(t_p=7.1\)
11  2002.064.21.10  Mw=7.5  \(t_p=12.9\)
12  2002.090.06.46  Mw=7.1  \(t_p=10.1\)
13  2003.344.04.32  Mw=6.8  \(t_p=6.2\)
14  2006.360.12.20  Mw=7.0  \(t_p=7.6\)
15  2006.360.12.29  Mw=6.9  \(t_p=6.9\)
16  2008.063.14.06  Mw=6.9  \(t_p=6.7\)
1996~
Mw > 6.5
16 events
Using GCMT Centroid

log10(M0) from W phase

log10(M0) from GCMT
PDE Location
(I)
1996~
Mw > 6.5
16 events
Using PDE Centroid

log10(M0) from PDE vs. log10(M0) from GCMT
Portable broadband seismic network in Vietnam for investigating tectonic deformation, the Earth’s interior, and early-warning systems for earthquakes and tsunamis

Bor-Shouh Huang\textsuperscript{a,*}, Tu Son Le\textsuperscript{b}, Chun-Chi Liu\textsuperscript{a}, Dinh Van Toan\textsuperscript{c}, Win-Gee Huang\textsuperscript{a}, Yih-Min Wu\textsuperscript{d}, Yue-Gau Chen\textsuperscript{d}, Wen-Yen Chang\textsuperscript{e}
Conclusions

- Database of unit tsunamis is able to predict arrival times to tidal stations immediately after the occurrence of earthquake.
- With earthquake parameters, the database can also quickly predict maximum tsunami amplitudes of tidal stations.
- W phase inversion can rapidly provide earthquake source parameters. The construction of extended BATS would enhance its future application.