Earthquake and tsunami scenarios constructed based on mechanical modeling: The Nankai Trough, southwestern Japan

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Background and Issues

At the 2011 Tohoku tsunami, we underestimated coastal tsunami height.

We did not suppose M9 earthquakes in this region before 2011.

We overestimated our tsunami monitoring ability for M9 earthquakes.

It is important to create various earthquake scenarios and to correctly evaluate our monitoring ability using synthetics of scenarios.
Our target: The Nankai Trough, huge earthquakes repeatedly occurred

Objectives
• Construct various rupture scenarios using slip deficits and an energy conservation law
• Create synthetics of observable tsunami records using elastic-fluid dynamic wave propagation simulation
We estimated the shear stress accumulation based on the slip deficit-rate distribution assuming the time interval of 200 years.

1854 Ansei Nankai earthquakes (M 8.4 and 8.4) occurred.
A method for creating a rupture scenario

Shear stress accumulation → Set rupture areas → Slip distribution estimated from shear stress release

Shear stress [kPa]

Coseismic stress drop [MPa]

Coseismic slip [m]
Rupture scenarios

Rupture senarios based on earthquake mechanics and GNSS observations

Historical-earthquake data are limited but this method can create different scenarios reasonaly based on earthquake mechanics using GNSS records.
Even though there is slip deficit, multi-segment ruptures are not realizable because strain energy is too small.

Possibility of each rupture scenario

Accumulation time: 200 years

Released strain energy – dissipated energy on the fault < 0

Energetically unrealizable scenarios

Accumulation time: 300 years

All the scenarios are realizable

When the strain energy is stored enough, multi-segment ruptures can occur.

Noda et al. (EGU2020-12581)
Tsunami simulations: Generation

Numerically calculate the vertical displacement by the finite difference simulation.

The permanent vertical displacements $u_z(x, y, z_{sur}, t = \infty)$ at the sea surface work as an initial tsunami height distribution

$$\eta_0(x, y) = u_z(x, y, z_{sur}, t = \infty)$$

Equations of seismic waves

$$\rho \frac{\partial v_i(x, t)}{\partial t} = \tau_{ij,j}$$

$$\frac{\partial \tau_{ij}}{\partial t} = \lambda \delta_{ij} v_{k,k} + 2\mu (v_{i,j} + v_{j,i})$$

Finite Difference Simulation

$dx = 0.5$ km, $dz = 0.25$ km, $dt = 0.01$ s
Tsunami simulations: Propagation

Initial height distribution -> Tsunami propagation

Time-dependent initial tsunami height distribution

\[ \Delta \eta_0(x, y, t) = \Delta u_z(x, y, z_{sur}, t) \]

2-D dispersive tsunami propagation equations

\[ \frac{\partial \nu_i^{av}(x, y, t)}{\partial t} + g_0 \frac{\partial \eta}{\partial x_i} = \frac{h}{3} \frac{\partial^2}{\partial t \partial x_i} \left( \frac{\partial}{\partial x_k} (h \nu_k^{av}) \right) \]

\[ \frac{\partial \eta(x, y, t)}{\partial t} + \frac{\partial}{\partial x_k} [h \nu_k^{av}(x, y, t)] = 0 \]

Finite Difference Simulation
\[ \Delta x = 500 \text{ m}, \Delta t = 1.0 \text{s} \]
Tsunami simulations

This result is preliminary. High-resolution simulations (50 m) are planned.
Synthetics of ocean-bottom pressure change

1st step: Seismic-wave simulation
Input: kinematic rupture model
output: At the sea bottom: velocity $v_{z \text{bot}}$, displacement $u_{z \text{bot}}$, and pressure $\sigma_{zz \text{bot}}$
At the sea surface: velocity $v_{z \text{sur}}$

2nd step: Tsunami simulation
Input: velocity $v_{z \text{sur}}$ at the sea surface
output: tsunami height $\eta$

Calculation of the sea bottom pressure change
$\rho_e = \rho_{\text{static}} + \rho_{\text{dynamic}}$
$\sim \rho_0 g_0 (\eta - u_{z \text{bot}}) + \sigma_{zz \text{bot}}$

Static pressure change originates from gravity
Dynamic pressure change is independent of gravity

Synthetics of ocean-bottom pressure change

Seismic waves dominate in raw records

Our synthetics include both seismic waves and tsunamis
When a station is inside the focal area, seismic waves overlap tsunami signals (elapsed time < ~200s).

A lowpass filter cannot completely remove the seismic waves.
Summary

A method for constructing earthquake-tsunami scenarios based on mechanics of multi-segment ruptures and elastic-fluid dynamics of wave propagation

We made rupture scenarios for huge earthquakes in the Nankai Trough, Japan, based on the observed shear-stress accumulation rate on the plate boundary.

Based on an energetic consideration, we evaluated the possibility of the multi-segment ruptures (the details found in Noda et al. EGU2020-12581). If the accumulation time is longer, multi-segment ruptures can occur.

We evaluated the tsunami height along the coasts for rupture scenarios and also simulated observable records (pressure change) including both seismic waves and tsunamis.

Basically, a low-pass filter could not completely remove the seismic waves in the records of pressure gauge sensors. The seismic waves can be noise for tsunami signals.

In order to evaluate our tsunami monitoring ability, the synthetics created in this study are useful.