Detailed coseismic slip distribution of the 1944 Tonankai earthquake estimated from tsunami waveforms

by

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ABSTRACT

Coseismic slip distribution on the fault plane of the 1944 Tonankai earthquake is estimated from inversion of tsunami waveforms. The inversion result shows that a maximum slip of about 3 m occurred on the plate interface off Shima peninsula. The total seismic moment is estimated to be 2.0×10^{21} Nm (M_w 8.2). The result confirms that the 1944 Tonankai earthquake did not rupture the plate interface beneath the Tokai region and supports the existence of the seismic gap in the Tokai region. The slip of about 1.5 m on the plate interface beneath Atsumi peninsula, northeast of the large slip area, is necessary to explain the observed tsunami waveforms, although no seismic moment release was estimated from strong motion data by Kikuchi et al. [1999]. This may suggest that the rupture beneath Atsumi peninsula was slow.

KEY WORDS: The 1944 Tonankai Earthquake
Slip Distribution
Tsunami waveforms
Tokai Earthquake

1. INTRODUCTION

Great interplate earthquakes have repeatedly occurred along the Nankai trough with an interval of about 120 years [Ando, 1975]. The most recent events were the 1944 Tonankai and 1946 Nankai earthquakes. In this paper, we concentrate on the 1944 Tonankai earthquake.

Various instrumental data have been used to study the 1944 Tonankai earthquake. Kanamori [1972] used seismological data to estimate the focal mechanism, and inferred that the source area agreed with the one-day aftershock distribution off the Kii Peninsula. Recently, Kikuchi et al. [1999] estimated the seismic moment distribution using strong motion waveforms recorded by the Japan Meteorological Agency. Ando [1975], Inouchi and Sato [1975], and Ishibashi [1981] estimated the fault parameters using geodetic data. A more detailed study based on geodetic data [Sagiya and Thatcher, 1999] estimated the heterogeneous slip distribution on the down-dip side of the fault plane. However, the geodetic data do not have resolution to estimate the slips on the up-dip (offshore) side of the fault plane. In addition, the geodetic data cannot separate coseismic deformation due to the 1944 Tonaknai earthquake from that of the 1946 Nankai earthquake, because the postseismic geodetic survey was conducted after 1946. By using tsunami waveforms, we can estimate the heterogeneous slip distribution of the 1944 Tonankai earthquake independent to that of the 1946 Nankai earthquake.

In this study, we perform tsunami waveform inversion using a method similar to

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that used by Satake [1993]. The estimated slip distribution is compared with the results obtained by other studies [Kanamori, 1972; Sagiya and Thatcher, 1999; Kikuchi et al., 1999], and the differences and their significance are discussed. In particular, estimation of the detailed coseismic slip distribution in the northeastern end of the Nankai trough, the Tokai region, is important because the next large event is anticipated [Ishibashi, 1981]. The Japanese government started an extensive earthquake prediction experiment in the Tokai region [Mogi, 1981], and various instruments have been installed [Yokota and Yamamoto, 1989].

2. DATA AND METHOD

The fault located on the estimated upper surface of the slab is divided into 23 subfaults by varying the depth and dip angle. The subfault size is 45 km X 45 km, the strike is 240°, and the rake angle is 110° for all the subfaults. The strike and rake angles are the same as Satake [1993]. Tsunami waveform data recorded at the 10 tide gauge stations are used. The tsunami waveform for each tide gauge station consists of 40 to 110 min of data with a sampling interval of 1 min. The tsunami is numerically computed on actual bathymetry. The finite-difference computations for the linear long-wave equations are carried out. The grid size is basically 20 sec of arc (about 600 m), but finer grids (4 sec) are used. The time step of the computation is 1.5 s to satisfy a stability condition of all grid systems. The initial condition of tsunami propagation is an ocean bottom deformation, which is computed using the equations of Okada [1985]. Tsunami waveforms at the tide gauge stations are computed from each subfault with a unit amount of slip, and used as the Green's

function for the inversion. The method of tsunami waveform inversion is basically the same as that of Satake [1993]. The only difference is that positivity constraints are assigned for the slip estimates. For error analysis, the jackknife technique [see Tichelaar and Ruff, 1989] is applied.

3. SLIP DISTRIBUTIONS

Large slip (> 2 m) is estimated on three subfaults near Shima peninsula. The largest slip was estimated as about 3m off Shima peninsula. This large slip corresponds to the source region estimated from the one-day aftershock distribution by Kanamori [1972]. The inversion indicates that there was no slip was on subfaults beneath the Tokai region. This is consistent with the result of Ishibashi [1981], suggesting that the rupture of the 1944 Tonankai earthquake did not extend into the Tokai area which was previously ruptured by the 1854 Tonankai earthquake. The total seismic moment is calculated as 2.0×10^{21} Nm assuming that the rigidity is 5×10^{10} N/m².

4. DISCUSION

The large (> 2 m) slip region is consistent with the large moment release region estimated from strong motion seismograms by Kikuchi et al. [1999], and also consistent with the large slip region near Shima peninsula estimated from geodetic data by Sagiya and Thatcher [1999]. In general, the slip and moment distribution patterns estimated for the 1944 Tonankai earthquake from three data sets, seismic waves, tsunami, and geodetic data sets, are similar although the seismic moments estimated from each data set have some differences. In detail, there is a discrepancy near the Atsumi peninsula where our estimated slips on two subfaults are 1.5 m and 1.7 m, respectively. Using strong motion data, Kikuchi et al. [1999] estimated no

seismic moment release beneath the Atsumi peninsula, while Sagiya and Thatcher [1999] estimated slip of 1.2 m, similar to our result. Inouchi and Sato [1975] and Ishibashi [1981] also indicated that slip beneath the Atsumi peninsula is necessary to explain the geodetic data. The discrepancy may suggest that a slow rupture of the plate interface beneath the Atsumi peninsula excited the tsunami but not short period seismic waves.

5. CONCLUSION

The slip distribution of the 1944 Tonankai earthquake estimated from tsunami waveforms shows that a maximum slip of 3.3 m occurred on the plate interface off Shima peninsula. The large slip is consistent with other results obtained from strong motion data by Kikuchi et al. [1999] and from geodetic data by Sagiya and Thatcher [1999]. Slip of about 1.5 m on the plate interface beneath the Atsumi peninsula is necessary to explain the tsunami waveforms.

The result confirms that the 1944 Tonankai earthquake did not rupture the plate interface in the northeastern end of the Nankai trough beneath the Tokai region which was ruptured by the penultimate earthquake in 1854. The result supports the existence of seismic gap suggested by Ishibashi [1981]. Therefore, continuation of the extensive earthquake prediction experiments in the Tokai region conducted by the Japanese governments, such as the Japan Meteorological Agency [Yokota and Yamamoto, 1989], is important to the hazard mitigation.

REFERENCES

1. Ando, M., Source mechanisms and tectonic significance of historical earthquakes along the Nankai trough, Japan, *Tectonophysics, 27*, 119-140, 1975.

2. Inouchi, N, and H. Sato, Vertical crustal deformation accompanied with the Tonankai earthquake of 1944, *Bull. Geogr. Surv. Inst. Jpn., 21*, 10-18, 1975.

3. Ishibashi, K., Specification of a soon to occur seismic faulting in the Tokai district, central Japan, based upon seismotectonics, in *Earthquake prediction: An International Review, Maurice Ewing Ser.*, vol. 4, edited by D.W. Simpson and P.G. Richards, pp. 297-332, AGU, Washington, D.C., 1981.

3. Kanamori, H., Tectonic implications of the 1944 Tonankai and the 1946 Nankaido earthquakes, *Phys. Earth Planet Inter., 5*, 129-139, 1972.

4. Kikuchi, M., M. Nakamura, M. Yamada, and K. Yoshikawa, Source process of the 1944 Tonankai earthquake inferred from JMA strong motion records, *Programme and Abstracts*, The seismological society of Japan Fall Meeting, A57, 1999.

5. Mogi, K., Earthquake prediction program in Japan, in *Earthquake prediction: An International Review, Maurice Ewing Ser.*, vol. 4, edited by D.W. Simpson and P.G. Richards, pp. 635-666, AGU, Washington, D.C., 1981.

6. Okada, Y., Surface deformation due to shear and tensile faults in a half-space, *Bull. Seismol. Soc. Am., 75*, 1135-1154, 1985.

7. Sagiya, T. and W. Thatcher, Coseismic slip resolution along a plate boundary megathrust: The Nankai Trough, southwest Japan, *J. Geophys. Res., 104*, 1111-1129, 1999.

8. Satake, K., Depth distribution of coseismic slip along the Nankai Trough, Japan, from

joint inversion of geodetic and tsunami data, *J. Geophys. Res., 98*, 4553-4565, 1993.

9. Tanioka, Y and K. Satake, Coseismic slip distribution of the 1946 Nankai earthquake and aseismic slips caused by the earthquake, *Earth Planets Space*, *53*, 235-241,2001.

10. Tichelaar, B. W., and L. J. Ruff, How good are our best model? Jackknifing, bootstrapping, and earthquake depth, *Eos, 70*, 593, 605-606, 1989.

11. Yokota, T., and M. Yamamoto, On the Earthquake Phenomena Observation System (Outline of the system) (in Japanese), *Quarterly J. Seismology, 52*, 89-99, 1989.