論文内容の要旨

Source process of the 1946 Nankai earthquake estimated from seismic waveforms and leveling data

（地震波形と水準測量データから見た1946年南海地震の震源過程）

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The rupture process of the 1946 Nankai earthquake on December 21 is estimated by using teleseismic and near-field strong-motion waveforms and leveling survey and tide-gauge data. From the inversion analysis of seismic waveforms, two large-slip areas are obtained, i.e., one on the west of the epicenter determined by JMA (Japan Meteorological Agency) and the other on the south of Cape Muroto. The result of simultaneous inversion of the seismic waveforms and the leveling and tide-gauge data shows that the two areas considered as asperities are more confined. The geodetic data are important because the near-field waveform data for this earthquake are not sufficient to reveal the detailed slip distribution. We obtained the total seismic moment $Mo=5.5\times10^{21}$Nm, the moment magnitude Mw=8.42, and the maximum slip of 5.1m.

In the conventional scheme of waveform inversion, it is often assumed that the strike and the dip angle of subfaults are the same. However, in our inversion we assume spatially varying strike and dip angle by fitting the strike, dip and depth of each subfault to the actual complicated shape of the upper surface of the Philippine Sea plate in the Nankai Trough region. We also tried to invert waveforms by assuming that the strike and dip angle of subfaults are the same. It is important to use the subfault geometry which sufficiently approximates the actual shape of the plate boundary. The synthesized waveforms for the model obtained by the varying strike and dip angle,

better explain the observation.

The maximum slip of 5.1m was obtained at a point to the south of Cape Muroto, where almost no slip was estimated by the previous tsunami inversions. The slip distributions previously derived from geodetic data are generally consistent with our model, although they include the effect of the 1944 Tonankai earthquake and thus a direct comparison with our result is difficult. Our result is in agreement with the results obtained by Hashimoto and Kikuchi in 2002 and Cummins et al. in 2002, who showed an existence of two subevents.

The estimated slip distribution in the west side of the fault plane appears somewhat complicated, but it well explains the vertical deformations of Tosashimizu and around Inomisaki. One might argue that the westernmost part slipped slowly after the earthquake in a day or days, weeks, and months, as an afterslip, because the seismic waveforms can be mostly explained without the slip on the westernmost area. However, in order to explain the displacement recorded by the tide-gauge at Tosashimizu, it is concluded that the western part slipped simultaneously with the earthquake. In our model we did not consider any splay fault, which was introduced in studies by Kato in 1983 and Sagiya and Thatcher in 1999. A comparison between a model with splay faults and our model should be carried out in the future to resolve the detailed feature of slip distribution in the westernmost area.

The areas which slipped more than 3m are shallower than 20 km and correspond to the locked zone of the plate boundary where temperature is less than 350 ℃ as was proposed by Hyndman et al. in 1995. The subducting seamount discovered by previous seismic reflection surveys is located between the two asperities of our model. It is likely that the occurrence of the 1946 Nankai earthquake is somehow related to the seamount. Although we do not know the exact mechanism how the asperities are related to the seamount, this may suggest the importance of the subducting seamount in the rupture process of a great interplate earthquake.

The result in this study explains the seismic waveforms, leveling data, and tide-gauge records comprehensively. We did not use the horizontal displacement data estimated by the triangulation survey in our analysis. However, we calculated the horizontal displacements from the slip distribution of our model and Baba et al.'s tsunami-based model in 2002. The comparison with the observed horizontal displacements, especially with those on and near the southern coast of Shikoku, shows the excellence of our model over Baba et al.'s model. This is probably due to the difference in distribution of slip between both the models in Shikoku.

Since another Nankai earthquake is anticipated to occur not in the distant future, the estimation of the slip distribution on the fault plane based on seismic waveforms is essential for damage prediction and disaster measures. Along the Nankai Trough, the earthquakes are occurring with a recurrence interval of about 100 – 150 years. The latest event is the focus of our study, i.e., the 1946 Nankai earthquake (M_{jma}=8.0).

Various fault models have been proposed for the 1946 event. However, our study differs from the previous ones and represents the first study of inverting both teleseismic and near-field waveforms for the rupture process. The waveforms were used to estimate the location of subevents in previous studies. But there were no theses for inversion analysis using the waveforms to estimate the slip distribution.

Most of the previous studies are based on the geodetic data obtained from leveling and triangulation measurements. However, the geodetic data contain the pre-seismic crustal deformations, which include those caused by the 1944 Tonankai earthquake, and the post-seismic deformations. It is not simple to exclude those effects from the observed data.

Tsunami data are free from those effects. However, because of poor spatial resolution, the resolvable size of the subfaults is much larger than our model. Moreover, time resolution is poor, and not less than several hundreds of seconds.

Based on the waveform inversion method developed by Kikuchi et al. in 2003, we developed a program code for joint inversion of the teleseismic waveforms, strong motion records, and crustal deformation data. We estimated the moment release on each subfault as unknown parameters by the non-negative least squares method. Here, we impose two constraints. The slip angle is restricted within ±45° of the direction of relative motion of the Philippine Sea plate to the Eurasian plate. The other constraint is the smoothness of the slip in time and space. We also assumed a maximum rupture velocity of 3.4km/sec which does not exceed the S-wave velocity on most of the fault plane. The slip-rate function on each subfault was expanded into a series of 20 triangle functions of rise time of 4 sec.

For the teleseismic data, we used seven P-waveforms, that are four vertical and three horizontal components, and five S-waveforms, that are three SH and two NS components at the seven stations; College, Pasadena, Honolulu, Riverview, Christchurch, Bombay and De Bilt. For the strong motion data, we mainly used the horizontal components of the displacement seismograms at the eight stations; Owase, Tokushima, Kyoto, Tsuruga, Mishima, Hamada, Fukuoka and Miyazaki. Moreover, in addition to the vertical displacements of 47 benchmarks on Shikoku and Kii Peninsula, we used the coseismic vertical changes in sea level obtained from tide-gauges at Tosashimizu and Uragami.