

AVERAGE AND VARIATION OF FOCAL MECHANISM AROUND TOHOKU SUBDUCTION ZONE

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SUMMARY

Average and regional variation of stress pattern and focal mechanism are studied by analyzing accumulated CMT solutions to obtain basic source parameters and characteristics for future large earthquakes around Tohoku subduction zone, Japan. CMT solutions of 748 earthquakes for this area (latitude: 141E – 145E, longitude: 37N – 42N, depth < 100km, period: Feb.1997 – Feb.2004, moment magnitude > 3.5, CMT solution variance reduction > 70%) published by National Research Institute for Earth Science and Disaster Prevention, Japan, are used. Assuming that some characteristics of p-axis of focal mechanism represent an inter-plate earthquake, 379 earthquakes are selected from all data, and distribution of hypocenter, depth, principal stress vector, parameters of focal mechanism (strike, dip angle) are visualized on maps. These analyses show that average focal mechanism for this area has strike angle of N204E degree, dip angle of 25 degree, and rake angle of 90 degree. These parameters almost agree with the values of past large earthquakes, and likely to applicable to future ones. We also show the spatial distribution of inter-plate earthquakes, local variation of principal stress vectors and source parameters. Further, we calculate a simple FEM model to understand the anomaly of principal stress vectors for some area and show that the anomaly indicates existence of creeping interface. Those results will be useful information to determine locations and source parameters for future large inter-plate earthquakes around Tohoku subduction zone.

INTRODUCTION

Determining source parameters, including size and location of asperity, for future large earthquake to predict strong ground motion is important task for earthquake engineering. Usually various kinds of inversion results of past large earthquakes are used for this purpose. These are effective ways to determine source parameters if the next large earthquake will occur in the same position, by the same mechanism and has the same asperity. However we need enough data (waveform, deformation data, tsunami data, building damage records etc) of past large earthquakes to obtain focal mechanism and size and locations of asperity, and it is often difficult to gather old data with high reliability. On the other hand, focal mechanism of many local small earthquakes has been determined recently for some areas. For example,

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National Research Institute for Earth Science and Disaster Prevention (NIED) has routinely determined the CMT solutions for Mw>3.5 earthquakes in Japan using their full range seismograph network (F-net) data since 1997 and large mount of CMT solutions have been compiled and open for public (Fukuyama et al. 1998). Assuming small local earthquakes and large earthquakes in the same area occur under the same stress field, reviewing the mechanism data of local earthquake in a target area is another effective way to estimate source parameters of future large earthquakes. As these small earthquake data have various types of mechanism, to select enough number of target data from all the data is necessary to do a reliable research.

In Tohoku subduction zone, inter-plate earthquakes are one of the important types for earthquake engineering, because large inter-plate earthquakes repeatedly occurred around the area and gave huge human damage, building damage and so on by strong ground motion and/or tsunami (Usami 1996). In the past 100 years this area experienced such earthquakes like Sanriku-oki earthquake (1933; M=8.1, 1994; M=7.5), Tokachi-oki earthquake (1968; M=7.9, 2004; M=8.0), Miyagoken-oki earthquake (1936; M=7.5, 1978; M=7.4) for instance. Yamanaka and Kikuchi (2004) calculated source parameters for some large earthquakes in detail by waveform inversion and proposed asperity map of this area. In their study source parameters are determined for each earthquake. Yamashita et al. (2004) studied scaling relation (Mo – fc) of local earthquakes around this area and showed areas with high stress drops are located in and around asperities of past large earthquakes.

In this study, we try to obtain the average value and local variation of principal stress vector and source parameters of inter-plate earthquakes in Tohoku subduction zone by using CMT solutions archived by NIED in order to make a basic database for this region.

NIED ORIGINAL CMT DATA

NIED has calculated CMT solutions since Jan. 1997 using F-net for Mw>3.5 earthquakes around Japan. As the seismometer network has been getting high dense step by step and noise level of data has not always shown the same level, all the CMT solutions within the running period may not have the same quality. To avoid the solution with less quality, we use the data with CMT solution variance reduction > 70% using more than one observation station data. Target area of this study has latitude of 141E - 145E, longitude of 37N - 42N, and depth of 0-100km. This area almost includes main part of Tohoku subduction zone. Total number of CMT solutions used here is 748. Magnitude range is from 3.5 to 7.9(see Fig.1). These data includes 4 earthquakes whose magnitude is over 7.0. Spatial resolution of original data is 0.1 degree (= 10 km) for longitude and latitude, and 4 km for depth. Fig.2 shows the distribution of CMT solutions. Some offshore areas have no data, because the earthquakes, which are located over 400 km far from the F-net station, are not basically calculated. Since various kinds of mechanisms, such as inter-plate type and intra-plate type, are mixed in the data as is shown in Fig.2, we need to choose interplate type data from them.

SELECTION OF INTER-PLATE EARTHQUAKE DATA

To select data with inter-plate type mechanism from all the data, we assume some criteria which define characteristics of p-axis for inter-plate type earthquakes. Usually an inter-plate earthquake for this region is known to have a low-angle inverse fault whose strike direction is running along the trough of the Pacific plate. As the trough is running along approximately N180E-N200E direction around this region, p-axis trend of a typical inter-plate earthquake is assumed to be around N90E-N110E. Considering some variation and error, we select the data with p-axis trend of N70E-N180E and p-axis plunge under 45 degree as the first candidates for inter-plate earthquakes in this study. By this first step, we extract 498 CMT solutions from 748 data, however extracted data still have shallow intra-plate earthquakes located along longitude of 141.0E-141.1E. To omit these earthquakes from the data, earthquakes with depth < 20

km inside 141.0E-141.1E are removed as the second step. By the second step, 487 earthquakes are selected. Fig.3 shows the focal mechanism and distribution of selected earthquakes. Fig.4 shows averaged depth variation of the selected data. Most of the earthquakes show typical low-angle inverse mechanism and are located on the boundary between the Pacific plate and the Honshu plate. This indicates that most of the selected data have the characteristic of an inter-plate earthquake occurred between the plate boundary. Depth limit of inter-plate type is estimated to be 60-70 km by seeing Fig.4. Further, seismic area and aseismic area are clearly separated in Fig.3.Fault segments with large slip for Tokachi-oki earthquake and Miyagiken-oki earthquake derived by Yamanaka and Kikuchi (2004) are located in seismic areas.





Fig.2 Distribution of original CMT data



Fig.3 Distribution of selected CMT data



Fig.4 Depth variation of selected data

AVERAGE VALUE AND REGIONAL VARIATION OF SOURCE PARAMETERS

P-axis trend and plunge

Fig.5 and Fig.6 show histograms of p-axis trends and plunges. Average of trends and plunges are N114 E degree and 22 degree respectively. Standard deviations for both values are 14 degree and 8 degree. These averages almost agree with the value estimated from the trough form and direction. Fig.7 shows trend vectors and variation of plunges. We can see that trends rotate clockwise toward northwest-southeast direction in the northern area (latitude > 41N) and in the southern area (latitude < 38N) comparing with the middle area (38N < latitude < 41N) whose trend shows almost west-east direction. This change of value is basically explained by the direction of the trough. Except for this general trend, local vector anomaly can be seen in some areas such as the aseismic area around longitude of 143E and latitude of 38.4N. As for p-axis plunge, plunges get smaller in the offshore shallower part (depth < 20km). It is not natural, because plunges must be larger in the shallower part according to the shape of plate boundary. This indicates the shallower offshore earthquakes in Fig.7 may not occur "on" the plate boundary.









Fig.7 P-axis trend vectors and plunges

Strike, Dip and rake angle

Shallower earthquake (depth < 20km) data are removed from the 487 selected data, because change of paxis plunges in the offshore areas can not be explained by plate boundary shape in the shallow part. By this third step, 379 data are selected at last. Fig.8, Fig.9, and Fig.10 show histograms of strike angels, dip angles, and rake angles. Average of strike angles, dip angles, and rake angles are N204E degree, 25 degree, and 90 degree respectively. Standard deviations for those values are 30 degree, 10 degree, and 34 degree. Though average strike angle coincides with average p-axis trend, standard deviation of strike angle is much larger than the value of p-axis trend. This indicates p-axis trend is a better index to select inter-plate earthquakes than strike angle. Fig.11 and fig.12 show spatial variation of strike and dip angles. As same as p-axis case, strike angles rotate clockwise in the northern area (latitude > 41N) and in the southern area (latitude < 38N) comparing with the middle area. Local anomaly of strike angle around aseismic area is not clearly shown in Fig.11.



Fig.8 Strike angles (ave=204, sd=30)



Fig.9 D ip angles (ave=25, sd=10)



Fig.10 Rake angles (ave=90, sd=34)



Fig.11 Variation of strike angle

Fig.12 Variation of dip angle

EXPLANATION OF P-AXIS TREND ANOMALY BY FEM ANALYSIS

2-D FEM model

Local anomaly of p-axis trend is found around some areas in Fig.7. We assume that this anomaly is caused by underground irregular geology. In order to explain this, we analyze simple 2-D FEM model which has "soft" material inside "hard" material loaded with compression force. This model roughly represents a subduction zone with a creeping interface. Fig.13 shows model geometry using in this analysis. Elastic coefficient of hard material is 3.1*10**10 N/m2 and elastic coefficient of soft material is 3.1*10**10 N/m2 and elastic coefficient of soft material is 3.1*10**8 N/m2. Poisson ratio of both materials is 0.17. Left side of the hard material is fixed, and line static force (=0.75*10**6 N/m) is loaded in the right side of the hard material horizontally.

Results

Fig.14 shows variation of principal stress vectors in the model. We can see directions of principal stress vectors rotate along the material boundary, whose characteristic is almost similar to p-axis vector rotation around the aseismic area with longitude of 143E and latitude of 38.4N. Though this model is very simple, the result indicates this area may have a creeping interface inside coupling interface. This estimation may be supported by the fact that the area rarely has inter-plate earthquakes. But more analysis is necessary to estimate absolute value of the materials and size of the creeping area.



CONCLUSIONS

Average and variation of p-axis stress vector and focal mechanism of inter-plate earthquakes in Tohoku subduction zone are studied by using CMT solutions published by NIED. From 748 earthquakes (latitude: 141E - 145E, longitude: 37N - 42N, depth < 100km, period: Feb.1997 – Feb.2004, moment magnitude > 3.5, CMT solution variance reduction > 70%), 379 earthquakes are chosen as inter-plate earthquakes by the criteria using values of p-axis trends and depths. After analyzing these data, the following conclusions are obtained.

- Average focal mechanism for this area has strike angle of N204E degree, dip angle of 25 degree, and rake angle of 90 degree. These source parameters almost agree with the values of past large earthquakes.
- 2) Depth range of inter-plate earthquakes is about 20km-70km.
- 3) In the areas with latitude > 41N or <38N, p-axis trends tend to rotate clockwise toward northwest-southeast direction comparing with the average west-east trend.
- 4) Simple FEM analysis indicates some local anomaly of observed p-axis vector around aseismic area is probably caused by existence of creeping interface inside coupling interface.

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