FOCAL MECHANISMS OF SUBDUCTION ZONE EARTHQUAKES ALONG THE JAVA TRENCH: PRELIMINARY STUDY FOR THE PSHA FOR YOGYAKARTA REGION, INDONESIA

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ABSTRACT:

It is quite important for seismic hazard management to perform the Probabilistic Seismic Hazard Analysis. To do so first we need the prescription of the seismic source map. The focal mechanisms from the Harvard CMT catalog (1977-2006) of 263 events were utilized to evaluate the configuration of the subduction zone along the Java trench by dividing as shallow, intermediate and deep earthquake classes, and the fault plane solutions of the individual events were exploited. The cross-sectional vertical profiles of nine rectangular areas from Eastern to Western Java were developed to figure out the plate boundaries. The Java trench line was also located from the seismicity of the Java region, the bathymetric and satellite images of the present region. ***a***- and ***b***- values are determined by the seismicity of the Yogyakarta area assessed from the past seismicity occurred during 1970-2007/07, utilizing the earthquake catalogs of ANSS and NEIC (USGS), and BMG records. The focal mechanisms of shallow events mostly display thrust faulting mechanisms representing the interplate earthquakes and those of intermediate earthquakes represent thrust faulting and those with large strike-slip component, representing the intraplate ones. However, the focal mechanisms of deep earthquakes also give the appearance of thrust event in the shallower depth at around 100km, and at around from 300 to 650km, the focal mechanisms seem to be normal fault mechanisms, some with strike-slip ones. From this analysis the possible depth of the future subduction zone earthquake potentials was generally estimated for this region.

KEYWORDS*:* focal mechanisms, interplate earthquakes, seismicity, earthquake potentials.

INTRODUCTION

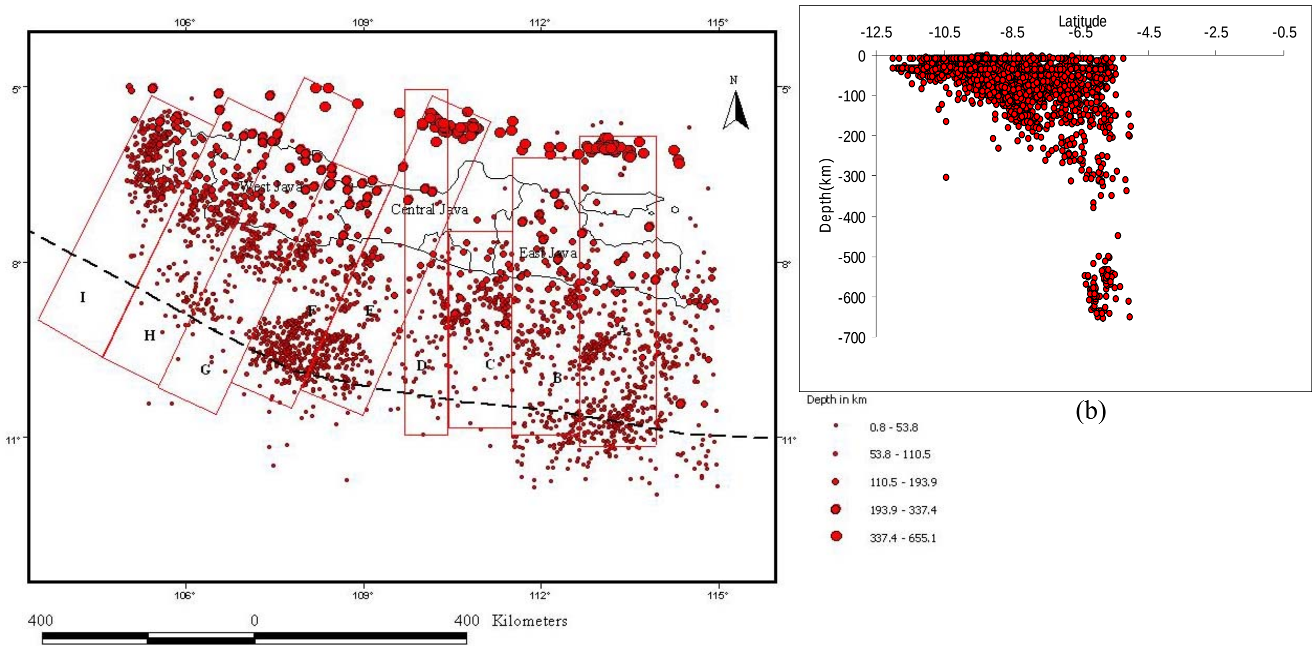
Although the Java region can be regarded as low seismicity region compared with the Sumatra subduction zone, historical and instrumental records show the occurrence of some fairly large earthquakes as 1943 (M 8.1) earthquake along the Java trench. The most resent two earthquakes happened in 2006 are May 27 Yogyakarta crustal earthquake and July 17 (S. of Java) that created tsunami. These two earthquakes alarmed to conduct the seismic hazard analysis for the regions located along the Java trench. Therefore, although the seismicity along the Java trench is relatively low, it can also be regarded as the considerable seismicity region. and the probabilistic seismic hazard analysis (PSHA) is necessary to perform. The present study concerns investigation on the seismicity along the Java trench and estimating the focal depth of the earthquake potentials from the off-shore region which will be delineated from the focal mechanisms of the interplate and intraplate earthquakes along the subduction zone and evaluation of the tectonic configuration of the Java trench in order to perform PSHA for Yogyakarta area, since the focal depth of each seismic sources is one of the important parameters for PSHA.

DATA

For configuring the tectonic profile for the Java trench, the focal mechanisms of about 263 events were utilized, and the earthquake catalogs of ANSS (1970-2007/07) and the NEIC, USGS (1973-2007/07) were used for the study on seismicity of the Java trench with the supplement of BMG, Yogyakarta record (2000-2004). The Harvard CMT catalog (1977-2006) was utilized for the analysis of the regional stress condition of the subduction zone earthquakes including both the interplate and intraplate earthquakes of shallow (0-40km), intermediate (>40-80km) and deep (>80km) foci and for delineation of the tectonic configuration of the region. The events happened along the Java trench, whose focal mechanisms are used for delineation of regional stress field and configuration of the regional tectonics, are considered by dividing nine rectangular zones and the vertical profiles of these zones are also applied for our purposes.

SEISMICITY OF THE AREA

As mentioned before the Java trench region shows low seismicity compared with the Sumatra subduction zone region but the destructive earthquakes occurred in the past. The earthquake of the M 8.1, 23 July 1943 happened at the epicenter of 8.6 S and 109.9E. It caused about 213 casualties, more than 3,500 injuries, and around 12,600 houses collapsed (Van Bemmelen, 1949). Among those numbers, Bantul had the largest damages with 31 people killed, 564 injuries, 2,682 houses collapsed and 8,316 houses damaged. There were several other highly deadly and destructive earthquakes which occurred in this region. The most two recent earthquakes happened in 2006. The 6.3 (Mw) earthquake struck in Yogyakarta region, central Java at the epicenter of 7.96S and 110.45E on 27 May 2006 (USGS). This earthquake caused more than 6,000 people killed, more than 35,000 persons injured and about 135,000 houses destroyed. The 17 July 2006 earthquake (Mw 7.7) occurred off the south coast of western Java, with the epicenter of 9.25S and 107.41E (USGS) and it generated tsunami which destroyed houses on the south coast of Java, killing about 668 people and leaving at least 65 people missing although there was no ground motion damage to structures.



(a)

Figure 1. (a) Epicenters distribution of the earthquakes with the magnitude of equal to or greater than 4.0Mb (Source–USGS,1973-2007/07), (b) the vertical profile of earthquake foci across Java, looking from east.

Figure 1 displays the seismicity of Java representing the location of the epicenters of the earthquakes occurred in 1970 - June, 2007 with the magnitude ≥ 4 Mb. According to the historical and instrumental records the seismicity of Yogyakarta depression area in the period of 1970-2007 was mostly confined to the offshore region of the Java trench. Therefore three areal sources were defined for the offshore region of Central Java, south of Yogyakarta area and then the seismicity rate of this area i.e. the ***a***- and ***b***- values are estimated by using the classical Gutenberg and Richter relation, and the maximum likelihood method of Aki (1965). However the sufficient data cannot be available for the present region and the ***a***- and ***b***- values are estimated as 4.321 and 0.809 for the offshore region after comparing the consequent values of those for each areal source. Although the earthquakes also caused in the crustal region of Yogyakarta depression area it is difficult to correlate the events and the existing fault. Therefore the ***a***- and ***b***-values for the individual fault cannot be determined because of lack of the sufficient data. Those for crustal faults are estimated as 1.8782 and 0.699 by utilizing the Gutenberg-Richter law from the seismicity of inland earthquakes of the depth ≤ 30 km (Figure 2).

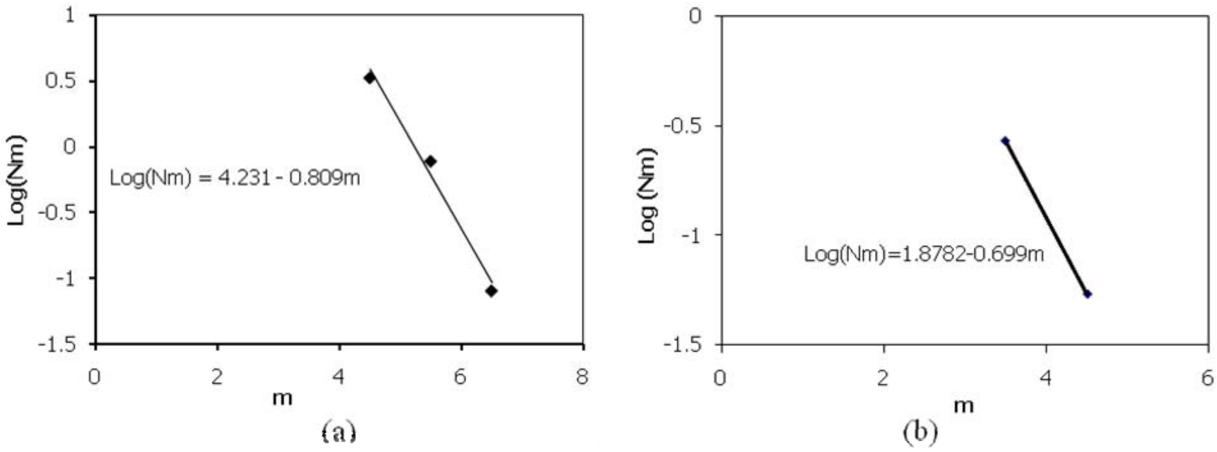


Fig 2. Gutenberg - Richter recurrence model for (a) offshore region and (b) inland region.

FOCAL MECHANISMS AND MECHANICAL BEHAVIOR OF EARTHQUAKES

Although fairly deep earthquakes happened along the Java trench, just two distinctive earthquakes were recorded in the Yogyakarta area; the M 8.1, 23 July 1943 with the depth of 90km and the M 6.5, 9 June 1992 earthquake with the depth of 106km. Moreover, the historical records show that most of the earthquakes that caused the considerable damages and casualties were shallow focus earthquakes not more than 40km depth. For present work, the data of focal mechanisms of the earthquakes happened during the period 1977-2006 (Harvard CMT catalog) are analyzed by dividing the earthquakes as three classes: shallow earthquakes with depth < 40 km, the intermediate earthquakes with the depth >40-80km and the deep earthquakes with the depth > 80km. The focal mechanisms of the shallow earthquakes are represented in Figure 3-a and these mechanisms show most of the shallow earthquakes correspond to the thrust mechanisms (reverse fault mechanisms) but some of them have strong strike-slip component and normal faulting mechanisms especially those close to the trench line. The focal mechanisms of the intermediate earthquakes show the existence of thrust faulting along the offshore region of Java trench and some with the considerable strike-slip components (Figure 3-b). The focal mechanisms of moderately deep earthquakes (80-150km) occurred mostly in the offshore region show thrust events and some with the considerable strike-slip component, the so called down-dip compression type while those of the very deep events (>550km) happened in the back-arc region predominantly represent the normal fault and some with the strike-slip component, the down-dip tension type (Figure 3-c).

SEISMOTECTONICS

The focal mechanisms of the earthquakes studied in this work are shown in Figure 3 and 4. The main geological feature is the Java trench with the length of about 1,100km, a segment of the Sumatra-Java subduction zone which extends over 5,600km, resulting from the convergence of the Indo-Australian plate and Eurasia plate. The direction of the convergence is normal to the arc near Java (Newcomb and McCann, 2001, Megawati et al., 2005). The rate of convergence is 6-7cm/yr (Wagner et al., 2007) and the age of the subducted oceanic slab is 96-140 Ma below Java (Widyantoro and Hilst, 2001). The depth of the Wadati- Benioff Zone is 650 km beneath Java (Fitch, 1970 and Lasitha et al., 2006). Based on the epicentral deistribution, the Java trench can be generally regarded as passing through the coordinates around 105°E/ 8.63°S in the western Java and around 114.57°E/11.62S in the Eastern Java. According to the focal mechanisms of the shallow earthquakes three types of faulting can be found as thrust faulting, those with the large strike-slip component, and the normal faulting mechanisms. Most trends of the faults strike in parallel or nearly parallel to that of the Java trench with slip direction in NNE and NE quadrant and their ***P***-axis is also normal or nearly normal to the trend of the subduction zone. Therefore most of these events are agreement with the interplate earthquake mechanisms which follow the main geological structures of the region, although there are some earthquakes with normal and strike slip mechanisms whose trends are in considerable oblique to the subduction zone.

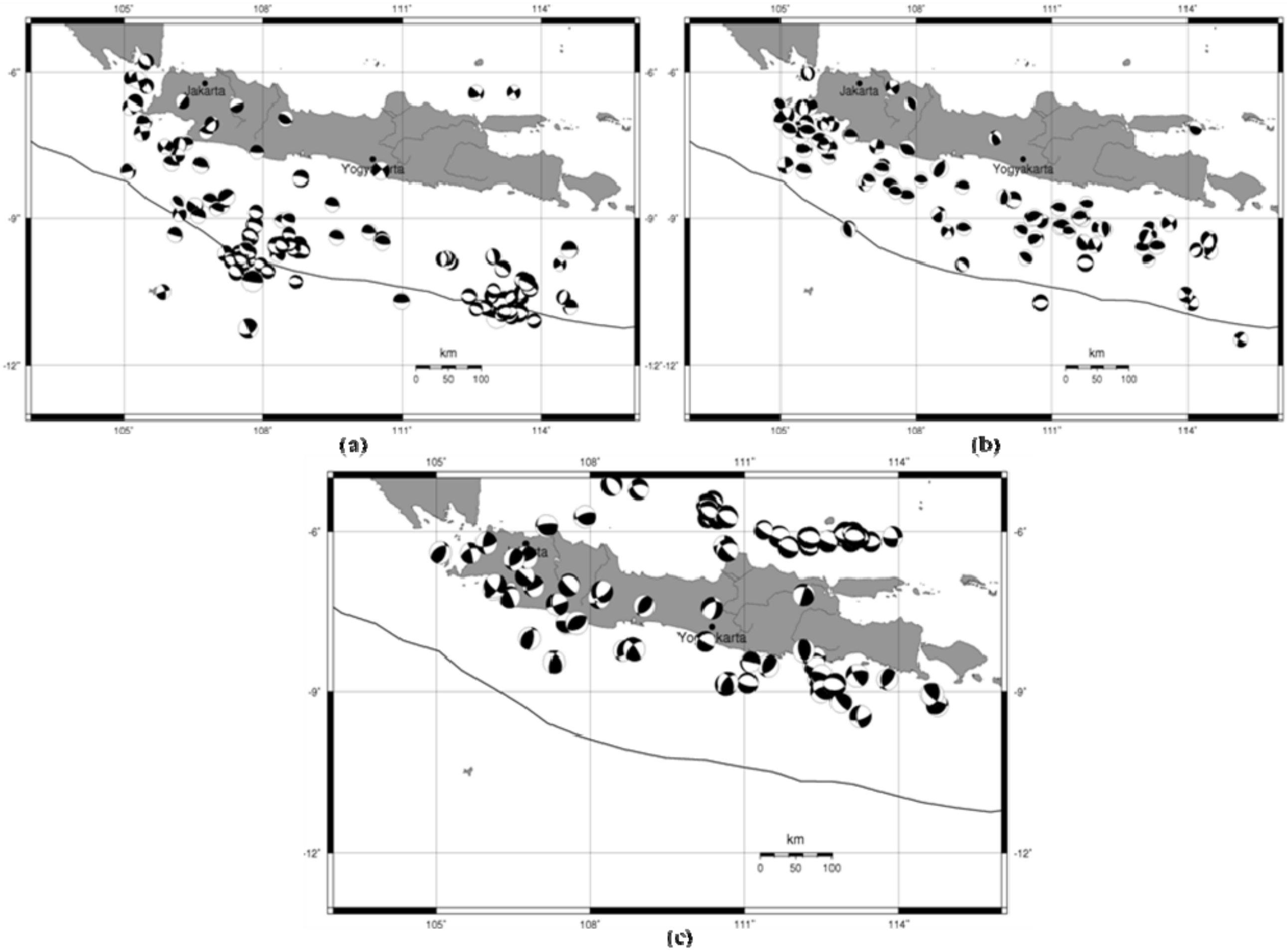


Figure 3. Fault plane solutions of (a) the shallow earthquakes (≤40km), (b) the intermediate depth earthquakes (> 40km - ≤80km) and (c) the deep earthquakes (>80km) occurred during the period 1977-2006 (Source- Harvard CMT catalog), Circles increases in size with increasing the magnitude.

For the intermediate depth earthquakes, their focal mechanisms represent the thrust faulting and some with large strike-slip component. These faulting also strike parallel or nearly parallel to the subduction zone trend although some thrust faulting with strike-slip component seems to run in the considerable oblique to the trend of the Java trench. While the strike of most faults generally runs in NW-SE direction, their dips are generally in NE orientation. These parameters of the focal mechanisms correspond to the tectonic characteristics of the region.

When the direction of the movement in strike-slip components are chosen it is difficult to do, but the right lateral motion with the northern block moving east, seems more plausible. The focal mechanisms of most intermediate depth earthquakes also coincide with the interplate events of the subduction zone.

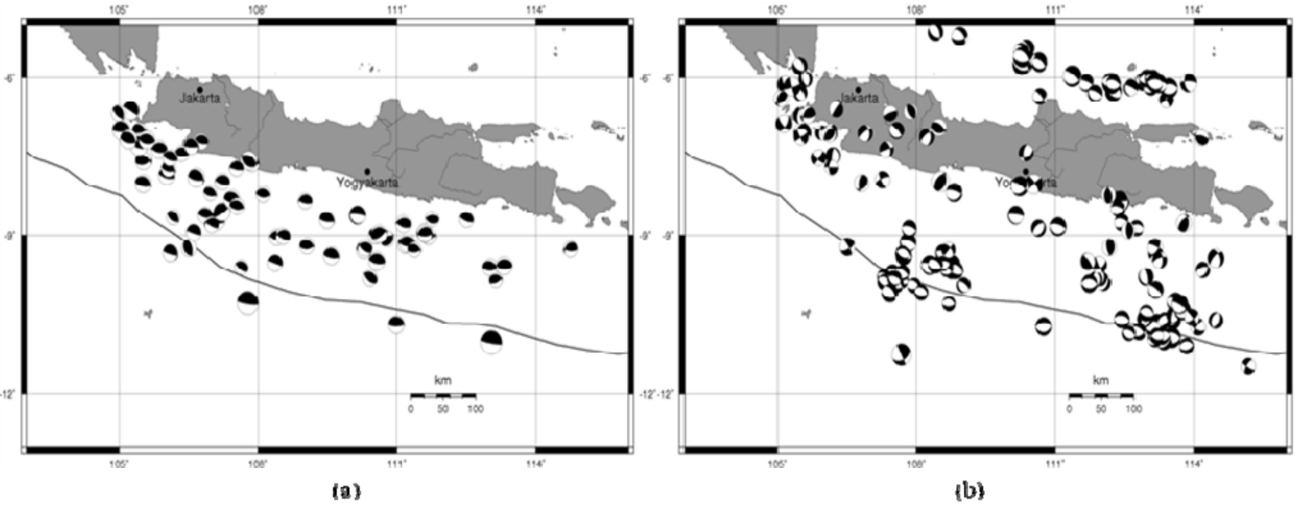


Figure 4. Focal mechanisms of (a) the interplate earthquakes and (b) the intraplate earthquakes occurred during 1977-2006 (Source- Harvard CMT catalog), Circles increases in size with increasing the magnitude.

The focal mechanisms of the events of the focal depth in the range of >80km~150km show the thrust mechanisms and those with the large strike-slip component, while those of the events occurred in the depth of greater than 500 km represent the normal faulting and the one with the large strike-slip component. Although the trend of most events occurred in the eastern part of the offshore region are parallel or nearly parallel to the trend of the Java trench, those of the events in the western region run making the acute oblique angle, some in nearly orthogonal, to the trend of the subduction zone. But the trend of the normal faulting by which the earthquakes occurred at the depth range in greater than 500 km is mostly parallel to that of Java trench. These events can be assumed as the intraplate, down-dip extension earthquakes. Although the deep earthquakes occurred until around the depth above 650km, the region during the depth of around 350km~500km shows very low seismicity and it can be regarded as the low seismicity or aseismic zone. Figure 5 demonstrates the cross-sectional profiles of each rectangular zones presented in Figure 1 with these events. The occurrences of the interplate earthquakes representing thrust faults which dip in NNE to NE direction with varying amount 3° to 52° can be observed at the depth range in 15km~100 km and these events are also overlapped by the intraplate ones. They occurred as down-dip compression earthquakes while the down-dip tension events occupied at the depth greater than 500 km.

When the nature of subducting Indian-Australian Plate under Eurasia Plate along the Java trench is figured out, the normal focal mechanisms of the oceanic intraplate events correspond to the bending of the Indian-Australian Plate before it subducts and can be regarded as the outer rise events. The thrust mechanisms of the earthquake events happened in shallow and intermediate depth can be regarded as the interplate subduction events. Moreover, several fore-arc events are also present and most of these events display the strike-slip fault mechanisms. The Wadati-Benioff zone events in the Java region takes place until the depth of 650km, most of which representing the normal fault mechanisms and some with strike-slip component. The distribution of the epicenters of the past events displays that the dip of the subducted slab varies from around 10° (nearly horizontal in eastern Java region), gradually increasing and in the north of Java (Back-arc region) its dip becomes as steep as nearly 70° when the depth reaches 500km or deeper. Therefore the earthquake potentials for the present area can be expected as thrust events from the depth in the range in 15km~100km with the maximum magnitude of M8.1 from the offshore region as the subduction zone events.

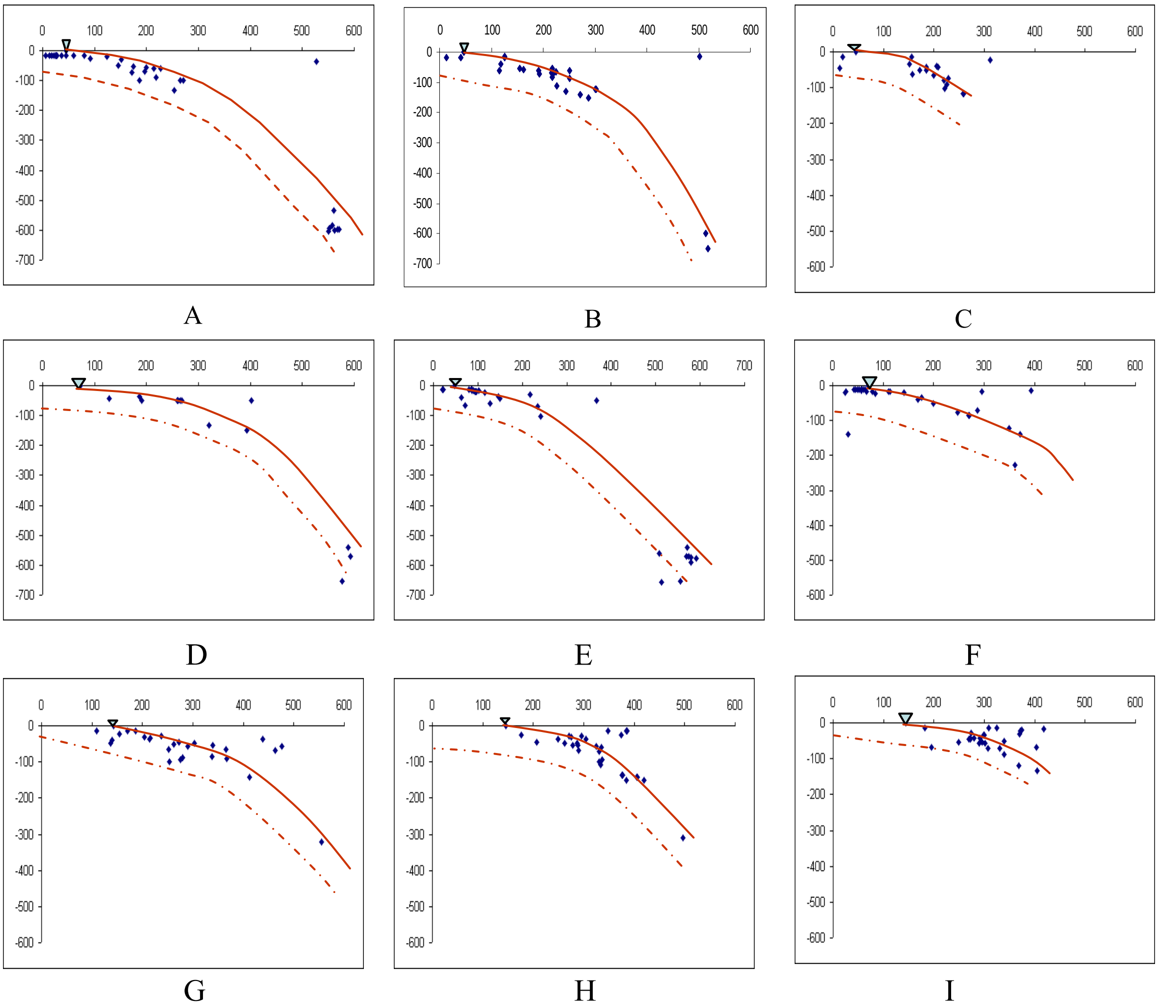


Figure 5. Vertical cross section of the hypocenters of the earthquakes, focal mechanisms of which are used in this study, through the rectangles A to I shown in Figure 1.

CONCLUSION

For the present study the focal mechanisms are collected from Harvard CMT catalog (http://neic.gov.). According to the fault plane solutions, most of the trends of the faults are parallel or nearly parallel to that of the subduction zone, Java trench. The direction of the ***P*** - axis is also nearly normal to the trend of the subduction zone; however the ***T***-axes orientations run oblique to the trend of ***P***-axes making the acute angles to each other. The data analysis was conducted for three classes of earthquakes as shallow, intermediate and deep earthquakes. Most of the fault plane solutions show the thrust mechanisms or reverse fault slip (sometimes with strike slip components) for the shallow earthquakes. But these thrust focal mechanisms still correspond to the intermediate earthquakes. So the shallow earthquakes, the intermediate ones and several moderately deep earthquakes occurred at depth around up to 150km can be regarded as interplate earthquakes.

For the deep earthquakes, the focal mechanisms give evidences of the reverse oblique fault mechanisms with the normal slip component representing the transition zone of tensional zone. But there are very little seismic events at the portion between the location of 350 km depth and that of 500 km depth along the subduction zone and this portion can be concluded as the aseismic slip zone. The focal mechanisms of the very deep earthquakes (>500km) happened mostly in Java sea, showing the normal fault mechanisms. The dipping angle of the interface of the subduction gradually increase from about 10° in fore-arc region to nearly 70° in the north of

Java, back-arc region, Java sea. The earthquake potentials can be generally expected to happen in the shallow depth environment of the subduction zone, off-shore region at around 30km in depth. But fairly intermediate deep earthquakes can also cause in the fore-arc basin, close to the onshore region. From Figure 5 we can see around 100km depth of subducting slab below the onshore region of Java Island. According to the seismicity of the Java region the focal depth of the subduction zone earthquake potentials can be regarded as around 45km with the expectation of thrust events of the magnitude M8.1 on the average. The ***a***- and ***b***-value are estimated as 4.231 and 0.809 for off-shore region, and 1.8782 and 0.699 for crustal faults (inland earthquakes) by utilizing the seismicity of the region and Gutenberg-Richter recurrence relation. The present study leads to conduct the probabilistic seismic hazard analysis for Yogyakarta region for constructing the hazard maps representing the peak ground acceleration in the return periods of 50, 100, 200 and 500 years respectively.

ACKNOWLEDGEMENT

The authors thank to Badan Meteorologi and Geofisika (BMG), Yogyakarta for providing the earthquake data. This study is partially supported by the ASEAN University Network / South East Asia Engineering Education Development Network – Japan International Cooperation Agency (AUN/SEED Net- JICA).

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