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ANALYSIS ON EARTHQUAKE DATABASES OF SABAH REGION AND ITS APPLICATION FOR SEISMIC DESIGN

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ABSTRACT

The general purpose of the present paper is to summarize the state-of-the-art of historical earthquake knowledge and research in the Sabah region, giving an account of the main references, the historical developments and the present situation of earthquake catalog. The most representative historical works for compiling earthquake data (catalog) up to 1900 are referred together with those of more recent investigations for the period 1900 - 1984. The seismicity around Sabah has a complex seismotectonic setting. Usually, the region has an earthquake pattern that clearly indicates the non-uniformity in the seismic activity. The seismicity rate around East Malaysia come from outside sources either from Kalimantan, Sulawesi and Southern Philippines and local sources that appear to be associated with some local faults and weak zones producing low-to-moderate magnitude of earthquakes. Updated databases on historical seismicity are presented, mentioning the most important achievements in relation to quality of information. The PGA values for 10% probability of exceedance is 170 cm/s^2 and 2% probability of exceedance is 300 cm/s^2.

1. Introduction

The knowledge of the historical evolution of catalog is extremely important to understand the origin of modern catalog. A detailed analysis of the ways the information contained in these catalog is transmitted over time helps to better interpret modern catalog and to be aware of the real problems they may hold. Leyu et al. (1985) gave a thorough outline of East Malaysia works related to historical earthquake data compilation and listed the main catalog produced until 1984. The most significant works reported in that study are mentioned here together with some of the new publications on particular events and some new earthquake catalog which have appeared in Sabah since then.

All these works lead to a quality improvement of the knowledge of the seismicity in our study area, Sabah, encompassing by latitudes 4^0S to 7.5^0N and longitudes 115^0E to 120^0E (Figure 1).

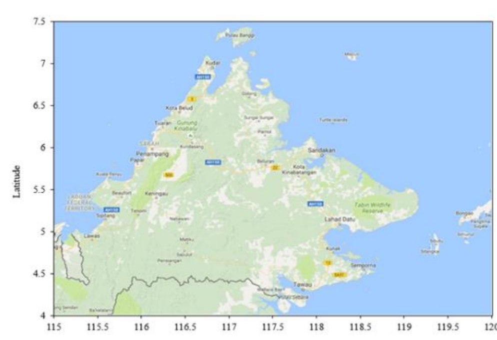

Figure 1: Map of Sabah State

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2. Testing and Observation

The intensity-based mapping of East Malaysia was early presented in a 1985 report prepared by Leyu et al. (1985). The report recorded all the information of felt areas across the region from 1884 to 1984. The information of all the earthquake in the report was gathered from newspapers, government gazettes, geological reports or journal, official or private correspondence and historical book. The findings seems the best source of information and provided a complete chronological documentation and description of the events. As a result, the report provides a preliminary complete coverage of earthquake information of East Malaysia. The earliest events of earthquake recorded for Sabah is from period 1884.

In this paper, all the events are checked with the earthquake list provided by the National Earthquake Information Service (NEIS), United States Geological Survey (USGS). If the earthquake is identified, the origin time together with epicentral and magnitude values as given by NEIS are used. However, if it is still not identified, the approximate local time at which the earthquake shock was reported felt is then given.

According to the historical records; there has been a low amount of moderate earthquake activity across the state that has caused casualties, damage to properties and created narrow fissures in the ground (Tjia, 2007, Leyu, 2009, Chai et al., 2009, Azhari, 2012, Mohd Hazreek et al., 2012). In accordance with Tjia (2007), Sabah experienced moderate seismicity in the active Mensaban, and Lobou-Lobou fault zones located in Kundasang, Ranau, which have brought earthquakes that caused light damage to infrastructures. The major faults around Sabah include the Belait Fault, Crocker Fault, Jerudong Fault, Mensaban Fault, Mulu Fault and the Pegasus Tectonic Line, and they can be illustrated in Figure 2.

The statistics for an updated earthquake recorded from 1884 through 2016 represented by magnitude indicates a large increment of earthquake events for the last 140 years (Figure 3). The whole catalog shows that for the period 1900 to 1976, the data's poor quality may be due to a lack of observations. However, it can be observed that a moment magnitude greater than 4.7 was reported in this period. The incompleteness catalog from local earthquake of Sabah is shown by Figure 4. The red line shows the starting period of the earthquake catalog is complete. The result of the analysis indicates that magnitude less than 3.5 are completely reported only during the most recent 12 year interval since 2004. The events between magnitudes 3.5 to 5.0 are completely reported for the whole of the 116-year sample only has a missing link between years 1940 to 1957. The earthquake events are completed starting in year 1923 for magnitude more than 5.0.

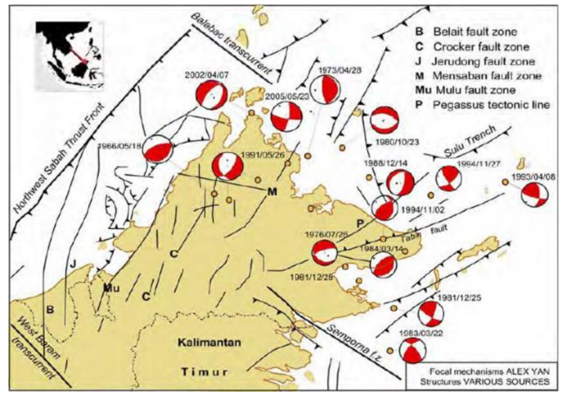

Figure 2: Seismic geometry of local earthquake around Sabah (Alexander et al., 2006)

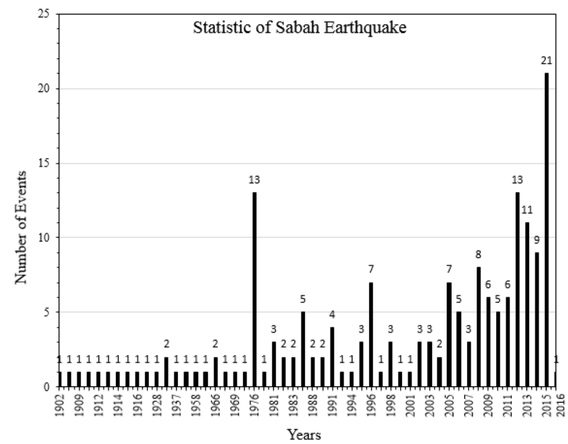

Figure 3: Number of local earthquakes with a magnitude greater than 2.0 reported in each decade (1900-2016) around Sabah

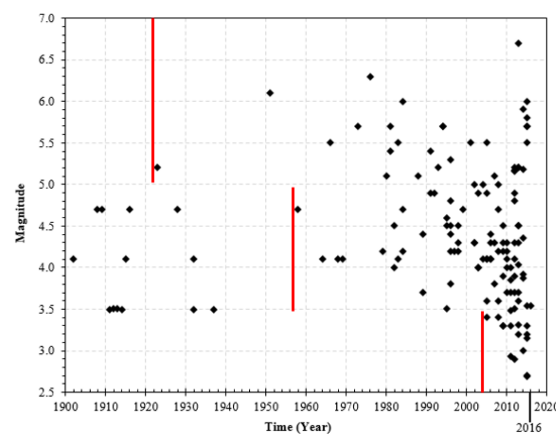

Figure 4: Distribution of catalog of local background earthquakes from the completeness analysis

3. Sabah Fault Delineation

Adnan et al. (2008) has mentioned the local background source having occurred across East Malaysia and the lack of information regarding the events. Previous studies by Leyu et al. (1985), Alexander et al. (2006) and Mohd Hazreek et al. (2012) have mentioned some local earthquakes having occurred from local active faults. In Leyu (2009), the seismicity that was scattered heterogeneously was grouped by the same seismic characteristics in a space. The earthquake scattered around Sabah is divided into three seismic zones: Central-North, Labuk Bay-Sandakan Basin, and Dent-Semporna Peninsular (Figure 5).

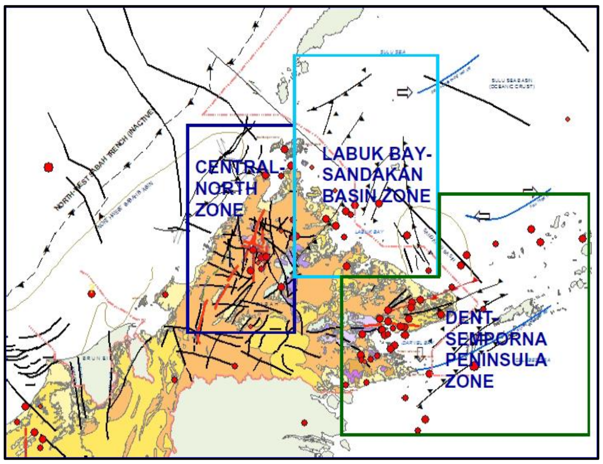

Figure 5: Three seismic zones: Central-North, Labuk Bay-Sandakan Basin, and Dent-Semporna Peninsular

The seismicity around Sabah has a complex seismotectonic setting. Usually, the region has an earthquake pattern that clearly indicates the non-uniformity in the seismic activity. The local earthquake particularly around Sabah is characterized by more earthquake concentration in the three areas of the Central North Zone, Labuk Bay Sandakan Zone and Dent-Semporna Peninsular Zone (Alexander et al., 2006). Cheng (2016), however, has quantified the possibility of high potential for induced seismicity within Labuk-bay Sandakan. In this area, it is very unlikely for large earthquakes to occur, and taking larger magnitudes into account would give an overestimation of the seismic hazard. The nature of the fault can be identified by few parameters such as slip rate, amount of fault displacement, length of fault rupture, earthquake size and earthquake recurrence interval.

The seismicity for an unknown location can be based on the historical catalog as referred to by Leyu et al. (1985), Hendriyawan (2006) and (Alexander et al., 2006) where the source zones are drawn around the seismicity and the tectonic provinces of East Malaysia. Some of the small earthquakes are not recorded, with a few of these events not being well determined in terms of location and magnitude due to the small amount of information. Thus, it is very difficult to define the zone boundaries and to obtain the coefficients of the recurrence relation. In order to consider the spatial variation in the seismicity, the study area is divided into several possible seismic sources including Upper Borneo, Sarawak, Central Sabah, Labuk-bay Sandakan and the Dent Semporna zones. By analyzing the correlation between the tectonic features and the available data on past seismicity, the pattern of seismic event distribution have been identified. The identified seismic source are shown in Figure 6.

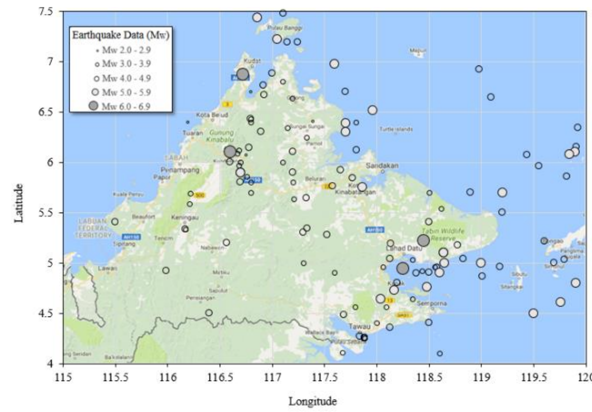

Figure 6: Earthquake events distribution map in the study area from year 1900 to 2016

4. Seismic Hazard Analysis

Using the past earthquake data, the seismicity of the area around the region has been evaluated by defining a- and b- value from the Guttenberg and Richter recurrence relationship. Two hazards are being analyzed inside probabilistic seismic hazard analysis (PSHA), such as 10% and 2% probability of exceedance in 50 years ground motions or corresponding to 500 and 2,500 years return periods of earthquakes respectively using the compiled catalog in Sabah.

The two main uncertainty parameters ground motion prediction equation (GMPE) and maximum magnitude, Mmax are incorporate the hazard estimate by using the logic tree of model-variable alternatives to avoid conservative being over- or underestimated the PGA values. Three models have been used in current study including Sadigh et al. (1997), Fukushima and Tanaka (2002) and Abrahamson and Silva (2008). The PGA values are approximately 170 cm/s^2 at 10% probability of exceedance that will be exceeded in a period of 500-years. The highest PGA values obtained is approximately 300 cm/s^2 for 2% probability of exceedance in 2,500 years return period.

The PGA maps of Petersen et al. (2007, 2008) show that the PGA trends are between 1.0 and 294 cm/s^2 for 2% PE and between 19.6 and 98.1 cm/s^2 for 10% PE.

Adnan et al. (2008) presents the hazard map for 2% PE being between 160 and 220 cm/s^2 and for 10% PE trends being between 60 and 120 cm/s^2 by applying the seismotectonic area within Sulawesi and Kalimantan. In the USGS hazard map, the 10% PE shows the PGA values being between 29.4 and 147.2 cm/s^2. Concerning the latest PGA analyzed by Hee (2014) by applying the Preliminary Hybrid Seismic Response Spectrum Model, the 2% PE is given between 100 and 180 cm/s^2 (with no further result on 10% PE).

Low-to-moderate numbers from M_W 2.8–7.4 shallow-depth earthquake events of the Modified Mercalli Intensities Scale range from III to VIII (Majid et al., 2007; United States Geological Survey, 2008; OCHA, 2011). A statement made by Delavaud et al. (2012) mentioned that the conditions with low magnitude may have a significant impact on the hazard level. The range of intensity approximately correlates with peak ground acceleration in the range of 150 to 160 cm/s^2. However, the MMI scale was increased to VIII, where the PGA was predicted as being between 340 and 650 cm/s^2. Table 1 shows the summary of PGAs estimated from different publications with 10% and 2% probability of exceedance for an exposure time of 50 years, which corresponds to a return period of 500 and 2,500 years, respectively, with site classification being bedrock.

Table 1: PGA predicted values for 10% and 2% probability of exceedance in Sabah

Reference	10% (cm/s^2)	2% (cm/s^2)
Giardini et al. (1999)	80.0 –2 40.0	-
Petersen et al. (2007, 2008)	19.6 – 98.1	1.0 – 294.0
United States Geological Survey (2008)	29.4 – 147.2	-
Adnan et al. (2008)	60.0 – 120.0	160.0 – 220.0
Hee (2014)	-	100.0 – 180.0
This Study	170.0	300.0

5. Summary and Conclusions

The seismic activity in East Malaysia has been increased since 1900, while damaging earthquakes are fortunately rare in East Malaysia, the region already experienced devastating earthquake with a magnitude of M_W 5.8 on 26th July 1976 centered in Lahad Datu, and just recently a M_W 6.0 on 05 June 2015 in Ranau. At first, the fault characteristics that able to produce earthquake is investigated. Although some zone boundaries are fairly well known, much more geological and geophysical knowledge is required to define each single zone with a large uncertainty. The seismicity rate around East Malaysia come from isolated sources either from Kalimantan, Sulawesi and Southern Philippines and local sources that appear to be associated with some local faults and weak zones producing low-to-moderate magnitude of earthquakes. In order to consider the spatial variation in the seismicity, the study area is divided into several possible seismic source to cover all potential earthquakes that affect the region.

Past seismicity is one of the keys to predicting future earthquakes, therefore, the more reliable picture of the past can successfully predict a better future seismicity. Since, there are some reported earthquakes recorded before 1900, a continuing monitoring by collecting data in the form of seismograph records, photographs, scientific papers, maps, reports, etc. that help to analyzing historical earthquakes will help to bring insight to this issue. In moderate seismicity region, the active faults are poorly known. It is considered one of the major challenges in seismic hazard analysis to identify the source of earthquakes. An additional study and further research for the exact location and characteristics of faults would probably enable one to improve the zonation model. This will be helpful in reducing the uncertainty due to variation of seismicity parameters.

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