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Distribution of ground motion seismic surface wave of the 2015 shallow strong earthquake at Ranau central zone seismically active region, Sabah, Malaysia

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Abstract: Strong earthquake tremor with a magnitude of 6.0 M_L jolted Ranau, Sabah on 5 June 2015. The type of fault causing this strong earthquake tremor is normal left lateral oblique fault underneath the Lobou-Lobou Fault. Ground motion due to the strong Ranau earthquake showed seismic intensity VII in Kundasang and Ranau areas and up to VIII in the areas with loose soil properties, and for poorly built buildings and houses. Records of ground motion acceleration range from 0.01 g to 0.14 g. The highest value of PGA was recorded in Tuaran area and Lawa Mandau, Telipok, with values of 0.1452 g and 0.1351, g respectively. Based on the USGS database, the PGA in the epicentral area is 0.38 g. The ground motion acceleration shows amplification of ground motion seismic surface wave in the area underlain by sensitive geological materials and loose sediments such as slump breccias, peat deposit, swampy deposit, coastal plain and riverine alluvium, fill slope and reclaimed water bodies.

Keywords: Ground motion acceleration, seismic intensity, amplification, seismic surface wave, sensitive geological material, shallow strong earthquake

INTRODUCTION

Ranau area is situated in the central zone of Sabah, Malaysia and well known for being a seismically active region. The first recorded seismograph by USGS of an earthquake tremor in Ranau region was in 1966, with a magnitude of 5.3M_w and with a hypocenter depth of 52 km. The ground shaking due to the Ranau earthquake in 1966 was reported by Jacobson (1970). Since there was no heavy structures in Ranau during that time, there was thus no incident of casualty and damage reported. Twenty-five years later, another moderate earthquake jolted Ranau in 1991 with a magnitude of 5.1M_w and 5.4 M_w. Based on Lim (1992) technical report; a 4-storey teachers quarters had suffered considerable structural damage and many buildings in the Ranau region had appeared with minor cracks. The earthquake tremor also triggered landslide near Kampung Perapot hence causing development of tension cracks in the ground near Kampung Gaur, Bt. Kambura and Bt. Mitambang Ranau. One person was reported dead in Tuaran in relation to this earthquake tremor.

Twenty four (24) years after the moderate earthquake tremor, on 5th June 2015 Ranau region was once again struck by an earthquake, but this time with a stronger earthquake tremor with magnitude of 6.0 in Richter scale. The epicenter is located about 7 km northeast of Kundasang town, with an approximate hypocenter of about 10 km depth. Focal mechanism analysis shows that the type of fault that caused the earthquake is normal left lateral oblique of Lobou-Lobou Fault. The distribution of ground motion seismic surface wave can be felt in Kota Kinabalu, Penampang, Menggatal, Inanam, Telipok, Tuaran, Tamparuli, Kiulu, Tenghilan, Kota Belud, Kota Marudu, Telupid, Tambunan, Keningau, Tenom, Kinarut, Putatan, Papar, Kimanis and Beaufort.

The Jabatan Mineral and Geoscience (JMG) Sabah teams had carried out geoseismic survey in the areas affected by the ground motion seismic surface wave. Geoseismic mapping was carried out on site based on human response to ground shaking, damage observations and ground shaking effects which reflects the seismic intensity, expressed as Roman numerical number I, II, III, IV, V, VI, VII, VIII, X, XI and XII. Geoseismic mapping and ground acceleration data are two parameters describing the degree of ground shaking due to earthquake tremors. Geosesmic mapping was carried out by interviewing the population and assessing damage on site which corresponds to geological material. Whereas the ground motion acceleration was measured using strong motion instruments and is expressed in cm/s or g-value or as a percentage of Peak Ground Acceleration (PGA).

Site conditions that may influence the degree of ground shaking intensity are distance from epicenter, geological material, soil properties, ground water, geological structures, topography and slope morphology. Ground shaking will decay as the ground motion surface wave travels away from the earthquake epicenter, but will amplify on ground that is underlain by soft soil or loose geological material.

However, ground that is underlain by thick sandy material will be affected by liquefaction phenomena.

OBJECTIVE

The purpose of this short paper is to compile information on seismic intensity, ground acceleration and ground velocity from various sources such as JMG, MET Malaysia and USGS earthquake database related to the strong earthquake that jolted Ranau, Sabah on 5 June 2015. Well-known international and local studies will be referred and adopted with regard to earthquake ground motion. The distribution of PGA, PGV (Peak Ground Velocity) and ground motion surface wave amplification due to the 2015 strong Ranau earthquake will be plotted on Sabah map using GIS application. Variable values of ground motion data is evaluated to suit geological conditions of Sabah by incorporating gathered data into the geological map of Sabah. Final output products are PGA, PGV and Seismic Hazard Amplification maps of Sabah.

METHODOLOGY

The USGS historical seismicity database, MET Malaysia earthquake database, Mineral and Geoscience Department (JMG) geoseismic and seismotectonic data were the primary source for collecting data. Local or international research and well-known published papers were referred and adopted if suitable to the seismogenic setting of Sabah regions. Immediately after the 5 June 2015 strong Ranau earthquake, JMG teams were rushed to the field to carry out geoseismic mapping and gather data on human response to ground shaking, to observe the degree of infrastructural damages (such as cracks on concrete walls, ceilings, floors) and ground shaking effects such as landslides and ground crackings using JMG standard Modified Mercalli Intensity (MMI) forms. The result of geoseismic mapping will then be converted to ground motion acceleration using USGS standard chart.

Compilation of ground motion data due to the earthquake will be interpolated using ArcGIS and plotted on Sabah map to produce PGA, PGV and Seismic Hazard Amplification maps of Sabah. Compilations of historic earthquakes in Sabah since 1923 until 2015, analysis of isoseismal map due to moderate Ranau earthquake in 1991 by Lim (1992) and seismic intensity due to strong Ranau earthquake in 2015 will be used to produce Isoseismal Intensity Map of Sabah. These output of thematic seismic hazard maps can be used as a basic principle for probabilistic seismic hazard analysis by combining with other factors such as identified earthquake sources, characteristic of earthquake magnitude from each source, characteristic of distribution of source to site distances from each source and annual rate of exceeding for a given ground motion intensity.

Plots on GMPE chart for hard rock was carried out on well-known selected GMPE models (Somerville *et al.,* 2001; Silva *et al.,* 2002; Pezeshk *et al.,* 2011) as shown in Figures 1, 2 and 3 for comparison purpose. Meanwhile a plot on GMPE chart for soft rock adopting Atkinson & Boore (2006) is shown in Figure 4.

Amplitude of ground motion seismic surface wave will depend on the geological conditions, as in Figure 5. Bedrocks such as igneous rock, metamorphic rock and sedimentary rocks will be getting low to moderate amplitude. Whereas, loose geological material such as alluvial deposit, peat deposit, swamp deposit and residual soil from slump breccias weathering processes are prone to get high ground motion seismic surface wave amplitude. FEMA 310 (1998) has classified ground motion amplification which corresponds to seismic shear wave velocities where hard rock, rock, very dense soil, stiff soil and clay are having >5000 ft/sec, 2500-5000 ft/sec, 1200-2500 ft/sec, 600-1200 ft/sec, <600 ft/sec, respectively. Barounis *et al.* (2007) proposed the increase of seismic intensity which correspond to amplification factor after correction with ground water level as shown in Table

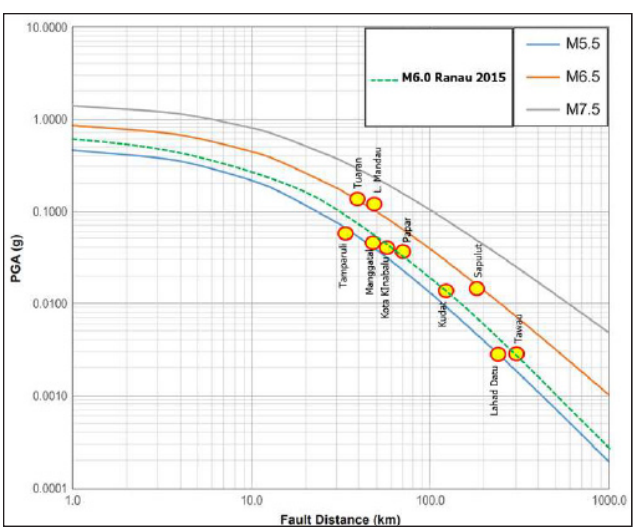

Figure 1: Comparison of PGA attenuation on hard rock of Silva *et al.* (2002) for M5.5, M6.5 and M7.5.

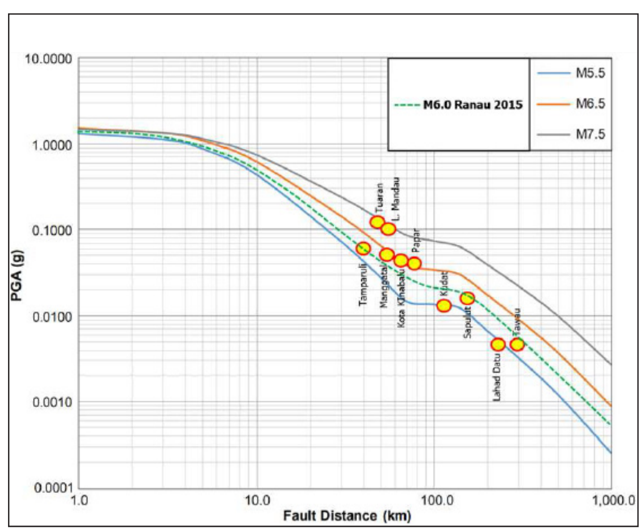

Figure 2: Comparison of PGA attenuation on hard rock of Pezeshk *et al.* (2011) for M5.5, M6.5 and M7.5.

1, whereas seismic amplitude in different rock strata is shown in Figure 5.

GEOLOGY AND TECTONIC SETTING

Sabah is adjacent to the Sundaland Block in the western part, Australian Plate in the south western part and Philippine Plate in the eastern part (Figure 6). Sabah is situated close to the most seismically active plate of Philippine Plate in the east, which was formed by the Philippine Subduction Trench. Sabah is also situated on the semi-stable South China Sea Basin, which to a certain extent is influenced by the active mobile belts in Sulawesi and Philippines. The active Sulu Trench subduction zone continues into East Sabah. GPS measurements show that three major plates are converging at each other from different directions at different rates (Michel *et al*., 2001). In this region, the faster moving Pacific-Philippine Sea Plate bends the Sunda Trench westward along the Sorong-Matano-Palu sinistral strike-slip faults (Ismail *et al*., 2015). The uplifting of Mount Kinabalu pluton may have disturbed the isostatic equilibrium and causes development of normal fault in the surrounding area such as Lobou-Lobou Fault, Mensaban Fault and Kedamaian Fault (Tjia, 2007).

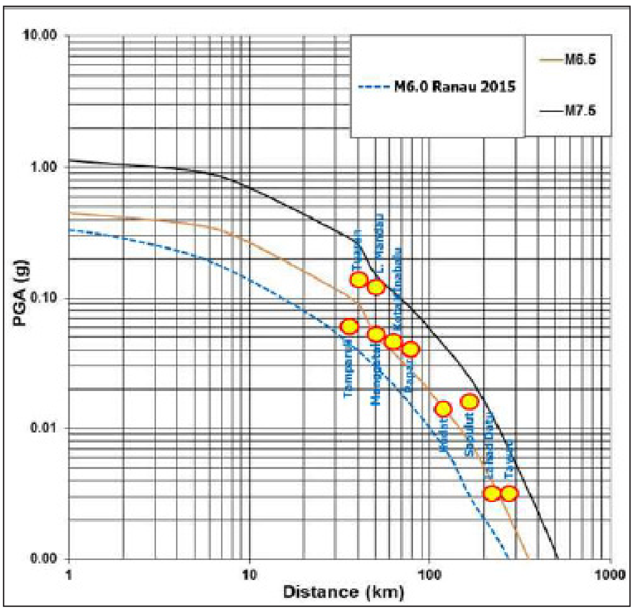

Figure 3: Comparison of PGA attenuation on hard rock of Somerville *et al.* (2011) for M6.5 and M7.5.

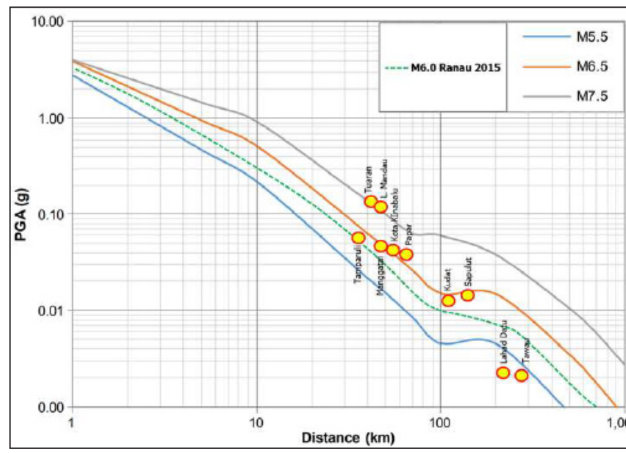

Figure 4: Comparison of PGA attenuation on soft rock of Atkinson & Boore (2006) for M5.5, M6.5 and M7.5.

Table 1: Engineering geology models for correction of seismic intensity. Reference rock granite with increase 0 (Barounis *et al*., 2007).

Mode I No	Representative Eng. Geology symbols	Geological description	Seismic Hazard: General classification	Seismic Hazard: Increase of intensity	Increase for G.W.L.
1		Granite or equivalents without erosion and fracturing	Safe foundation without plastic deformation when I ≤ 10	0	0
2		Thick sedimentary rocks limestones, sand or metamorphic quartzite or gneiss	Safe foundation but less than in case 1 subject to plastic deformation or fracturing	0,2-0,8	0
3		Sedimentary rocks of layered structure medium thick, porous of acute dip or schist foliated, tuffs, sandstone, shale or mica schist Mesozoic marls or gypsum	Not dangerous if W.L.> 5m	0,7-1,1	0
4		Dry clay schist or sandstone Paleogene flysch	Safe without water bearing stratum. Dangerous with GWL	1,2-1,6	0,5-1
5		Alternate marls sandstone and shale in flysch formation of dip or slope up to 45° in a dry state	Not very great seismic hazard without GWL	1,0-2,0	0,5-1
6		Thick bedded alluvial sediments sands, clay gravels with water level in depth below 5m	Not dangerous for water level >5m	2,0-2,5	1-1,2
7		Thick-bedded alluvial sediments, sand, clay, gravel with water table in depth less than 5m	Clay more dangerous than silt and sand	1,6-2,4	1-1,2
8		Alluvial of less than 5m in thickness over solid bedrock	Hazards especially on slopes. The hazards increase as the difference in hardness of alluvium to bed rock increases	2,3-3,0	1-1,2
9		Wet marsh lands	Very dangerous on slope and horizontal ground	2,3-3,9	1-1,5
10		Natural fills with mining waste at over 3-10m thickness	Very dangerous especially when not compacted	2,3-3,9	1-1,5
11		Alluvial cones on sloping bedrock	Very dangerous especially on sloping bed rock	2,0-3,9	1-1,5
12		Karstic limestone terrain without lithification of the filling	Very dangerous on active karst due to differential settlement	2,0-4,0	0,5
13		Contact of volcanic intrusions in sedimentary or metamorphic rocks	Very dangerous especially when there is great difference in mechanical properties	1,0-4,0	0,5
14		Old landslides, fills, marsh lands, sandy sediments prone to liquefaction a) with b) without GWL	Foundation on case (a) or case (b) need for soil improvement	1,0-4,0	1-1,5
15		Hard or semihard soil cover of active faults visible or not visible	Extremely dangerous due to vibration	3,0-4,0	1-1,5

Sabah mainland is considered to be seismically active due to the local active faults. Several active faults has been identified in Sabah particularly in Ranau Central, Lahad Datu Dent Semporna Peninsular and Labuk Bay. The identified active faults are Lahad Datu and Tabin Fault (Lahad Datu-Dent Peninsular), Terusan Fault (Labuk Bay), Mensaban Fault, Lobou-Lobou Fault, Mamut Fault, Parancangan Fault and Nalapak Fault (in Ranau area), Tambunan Fault (Tambunan area), Keningau Fault in Keningau area and Tenom Fault in Tenom area. A major fault i.e. Crocker Fault Zone (CFZ) which is trending NE-SW runs through the central part of Sabah starting from Tenom and pass through Keningau, Tambunan, Kundasang and up to Marudu Bay in Kota Marudu and Pitas. CFZ is believed to be active based on tectonic geomorphological features such as triangular facet, dissected river, beheaded stream, shutter ridge, wine glass and linear valley. Evidence on site such as displacement of normal fault in the Quaternary fluvial gravel in Apin-Apin, Keningau and Tenom (Tjia, 2007) and continuous ground movement in Kundasang area indicates that the CFZ is active. Several active fault segments run parallel NNE-SSW with CFZ such as Tenom Fault, Keningau Fault, Tambunan Fault and Lobou-Lobou Fault. The approximate length of CFZ is more than 170 km long and several kilometers wide (Tjia, 2007). Whereas Mensaban Fault which is trending E-W transects CFZ in the Kundasang area near the bridge in Kg. Lembah Permai. The epicentral of the strong Ranau earthquake on 5 June 2015 is located underneath Lobou-Lobou Fault in Kundasang area (Figure 7). Based on the focal mechanism by USGS, the type of fault that caused the strong Ranau earthquake in 2015 is normal strike slip oblique trending NNE-SSW and dipping 69^{o} to western side. Wang Y. *et al*. (2017) interpreted that the cause of strong Ranau earthquake is a blind fault underneath Lobou-Lobou Fault which is a reactivation of pre-existing normal fault. It is believed that the reactivation of blind pre-existing

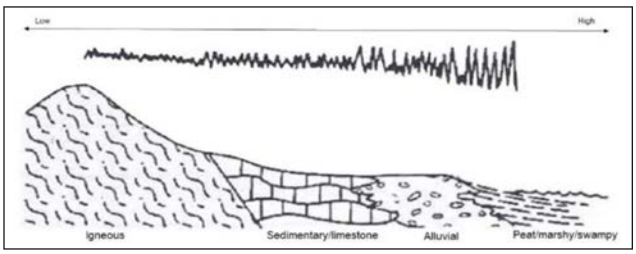

Figure 5: Seismic amplitude in different rocks (Barounis *et al.*, 2007).

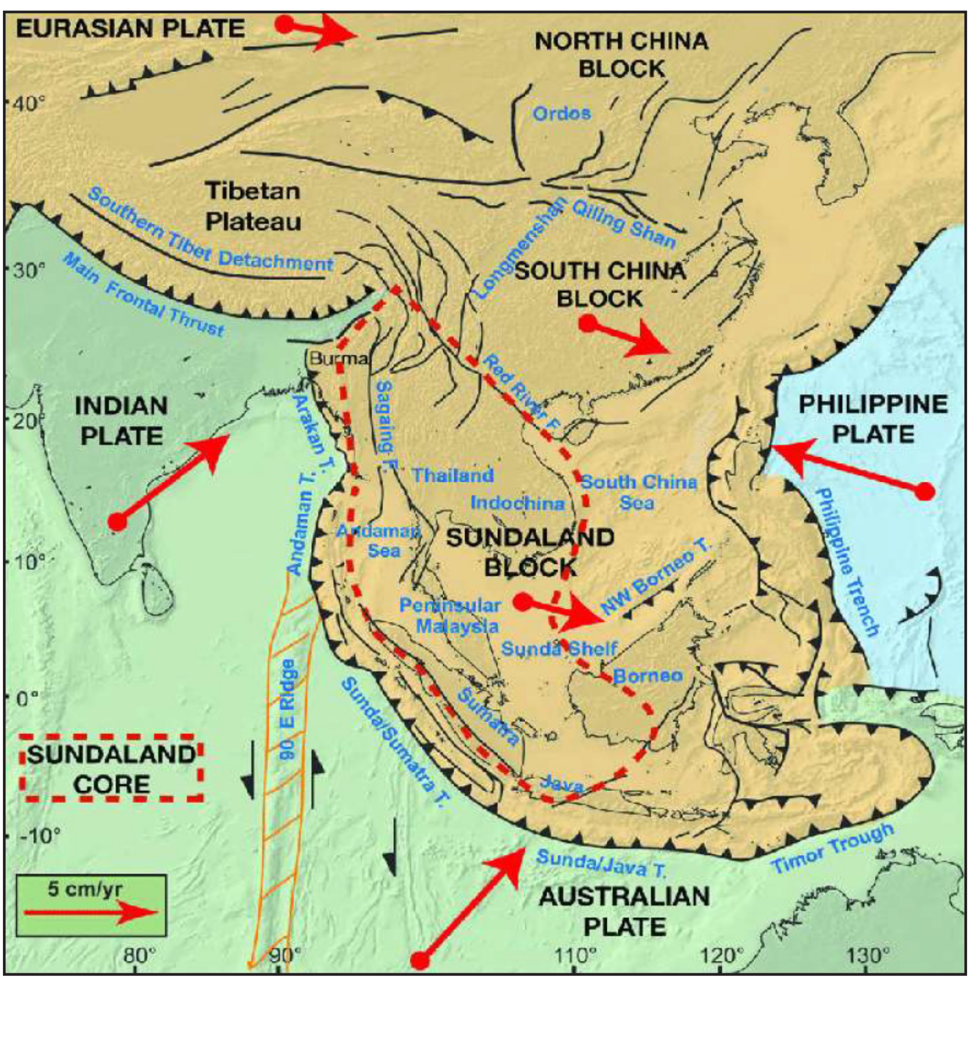

Figure 6: Main active faults around Malaysia (Simons *et al.*, 2007; Metacalfe, 2011a; 2013a; 2017).

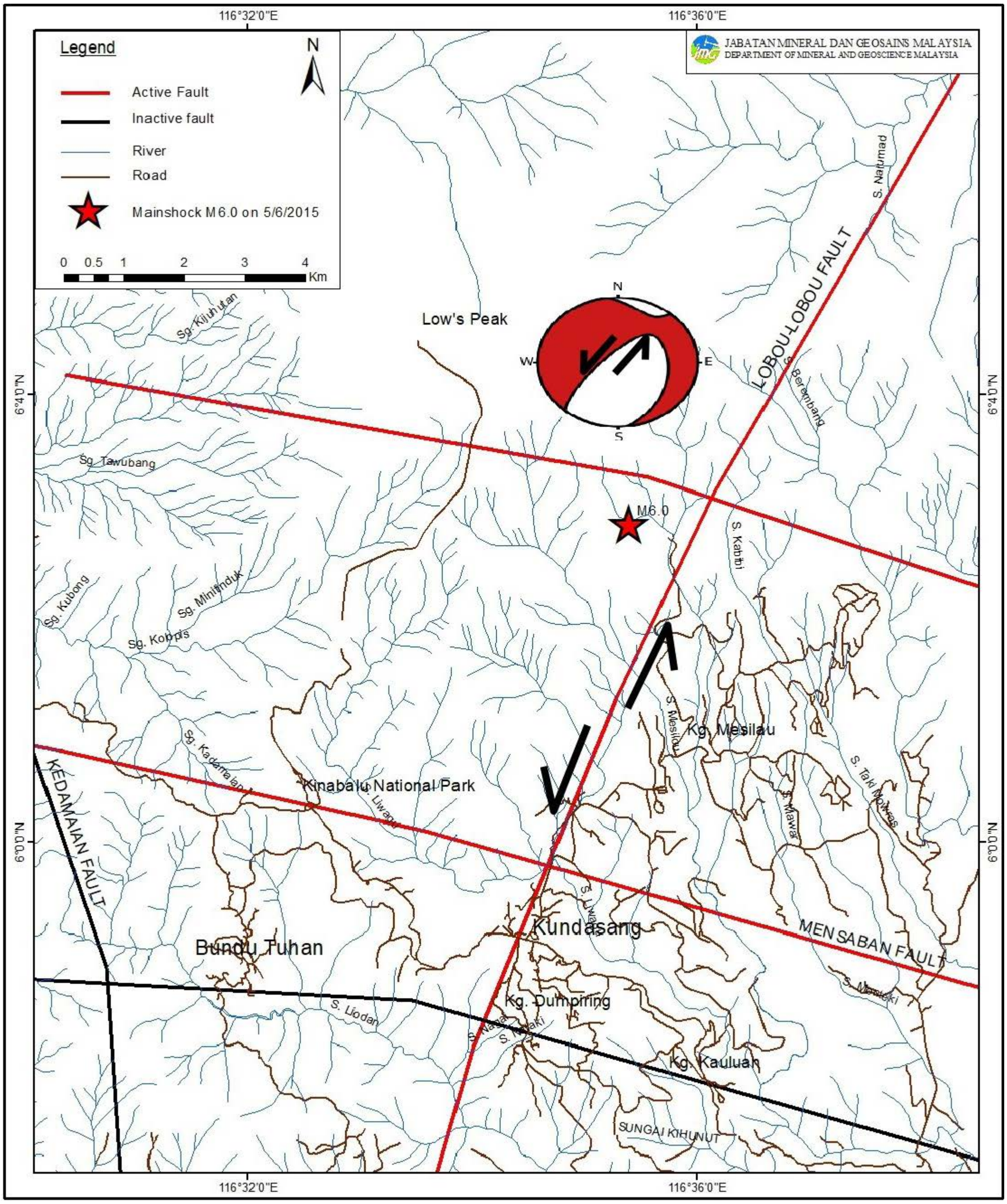

Figure 7: Active fault of E-W Mensaban Fault transecting active fault of Lobou-Lobou Fault at the bridge in Kg. Lembah Permai, Kundasang. Main shock M6.0 on 5 June 2015 is located 7 km NE of Kundasang town.

normal fault underneath Mount Kinabalu ruptured due to the movement of Lobou-Lobou Fault that dipped towards east, thus causing the strong Ranau earthquake.

Ranau area is prone to seismic activities due to its complex geological setting and presence of active faults that run through Ranau region. The geological setting of Ranau comprises of igneous rocks, sedimentary rocks, meta-sedimentary rocks, moraine deposit of Pinosuk Gravel, alluvium plain and terrace deposit. The Trusmadi Formation is of Palaeocene-Eocene age and mainly comprises of dark coloured argillaceous rocks, siltstone, slate, phylite and sandstone. The Crocker Formation of late Eocene to early Miocene age comprises mainly of thick bedded to massive sandstone interbedded with red and grey shale and thin siltstone. Pinosuk Gravel which overlies the Trusmadi Formation and Crocker Formation comprises of granodiorite and adamellite boulders and gravels. The low lying area is covered by riverine alluvium. Foot slopes of the hilly terrain are covered with terrace deposit due to either sedimentation of riverine alluvium or debris of moraine debris, or colluviums as a result from scree material due to paleo landslip. The alluvium plain and terrace deposit consist of boulders and cobbles while the matrix is mainly sand, silt and clay over the alluvium plain. The colluvium deposit meanwhile consists of loose material of angular to sub angular rocks. Triangular facet and linear ridge flanking Ranau plain indicates active faults that run through the Ranau area. Igneous rocks such as ultrabasic rock, granodiorite and associated acid rock intruded into the sedimentary rock of Trusmadi Formation and Crocker Formation during late Eocene to early Miocene, forming hilly terrain in Ranau area and Mount Kinabalu in Kundasang area. The boundary between igneous rock and sedimentary rock is believed to be a fault contact. The compression due to tectonic movements of the Phillipine plate and Eurasion plate would cause displacement within fault contact and produce seismic activity from time to time in the Ranau region.

ISOINTENSITY SEISMIC HAZARD OF SABAH

Based on the history of earthquakes in Sabah starting from 1923 to 2017, there are five areas affected by seismic hazard intensity, these are classified as Zone V, Zone IV, Zone III, Zone II and Zone I (Figure 8). Zone V and Zone IV would be affected by very strong ground motion intensity, Zone III by strong ground motion intensity, Zone II by moderate ground motion intensity, and Zone I by low ground motion intensity. Whereas, for the potential threat of horizontal ground shaking, Zone V, Zone IV, Zone III, Zone II and Zone I is facing extremely high shaking, very high shaking, high shaking, moderate shaking and low shaking, respectively. However, the ground motion shaking and acceleration is based on the bedrock condition. For areas underlain by loose geological material such as sandy deposit, peat deposit, swamp deposit, colluviums, loose slump breccias, thick to very thick fill slope and reclaimed water bodies, they will be affected by ground motion surface wave amplification.

RESULTS

The incident of strong Ranau earthquake (6.0 M_L) revealed some common features of ground motion. The nearest "strong" station which recorded the acceleration (cms^{-2}), g-value and velocity ($cms^{-}1$) is in Lawa Mandau at Kota Kinabalu, 43.40 km from the earthquake epicenter. Other nearby strong stations are Bakun (456.22 km from epicenter), Kudat (106.28 km from epicenter), Lahad Datu (229.21 from epicenter), Sibu (625.75 km from epicenter), Sapulut (143.49 km from epicenter) and Tawau (235.75 km from epicenter).

For strong earthquake event of 6.0M_L with depth of hypocenter at 10 km, Lawa Mandau seismic station had recorded higher ground motion amplitudes compared to vertical ground motion amplitude where hozizontal ground

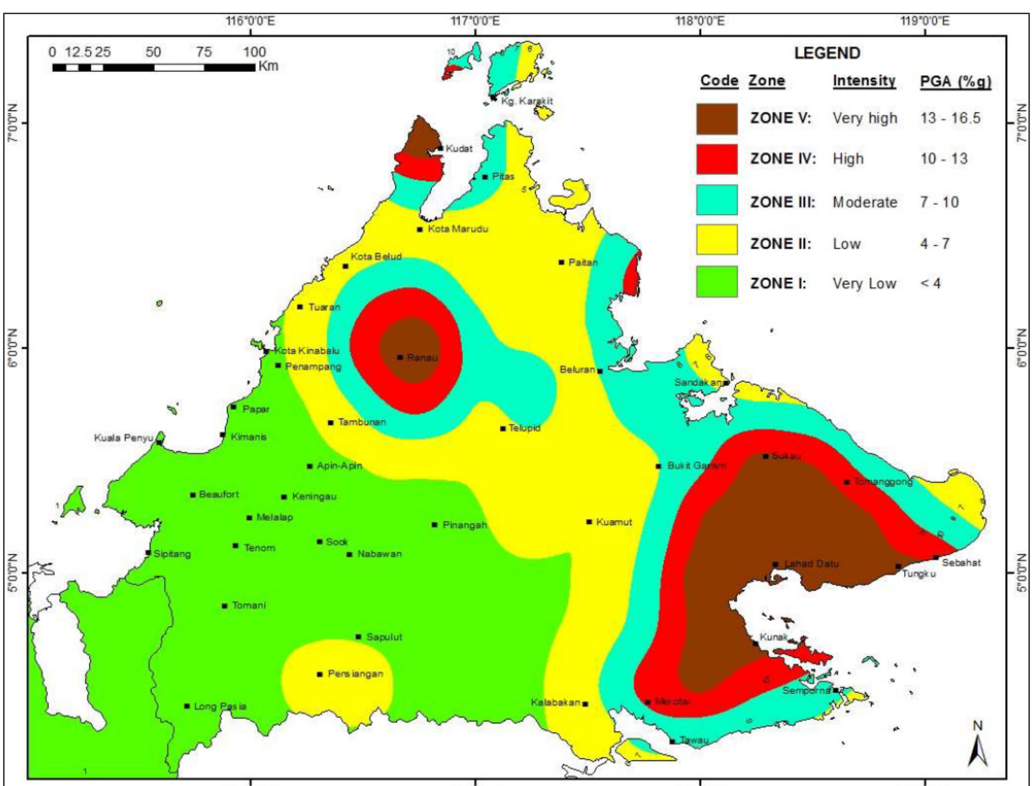

Figure 8: Isoseismal Intensity Map of Sabah based on Sabah historical earthquake from 1923 to 2015.

motion showed PGA, g-value and PGV of 132.3696 cms^{-2}, 0.1351g and -2.42 cms^{-1}, respectively. Low ground acceleration and ground velocity value reading in other seismic stations caused by decaying of ground motion seismic surface wave due to increased distance from the earthquake epicenter. The seismic station in Lawa Mandau is situated on a narrow hill crest with a thrust fault running parallel with the ridge. Based on hand auger and Macintosh Probe investigations, the thickness of residual soil in the seismic station compound is determined to be shallow, ranging from 0.3 m to 3.50 m. The strength of the in-situ residual soil is competent or stiff, and the soil properties are made up of dense silty sand and dense sandy clay. Outcrop adjacent to Lawa Mandau seismic station is highly jointed. Thus, it is believed that the topography and geological setting play a significant factor in causing the high reading of ground motion acceleration in Lawa Mandau area.

For moderate aftershock event with magnitude 5.1 M_L and hypocenter depth of 10 km, the seismic station in Lawa Mandau recorded PGA, g-value and PGV of 47.5 cms^{-2}, 0.048g and 0.69 cms^{-1}, respectively. Whereas, the Ranau seismic station which is located closest to the earthquake epicenter (approximate distance of about 15 km) had recorded PGA of 79.8 cms^{-2}, g-value of 0.0814 g and PGV of 1.9 cms^{-1}. For light aftershock event with magnitude 4.0 M_L and depth of hypocenter of 10 km, the seismic station in Lawa Mandau recorded higher reading than the Ranau seismic station with PGA, g-value and PGV of 13.4 cms^{-2}, 0.014g and 0.2 cms^{-1}, respectively.

The result of PGA and PGV as analysed by USGS is shown in Table 2 where the PGA value is ranging from 0.0299 g to 0.1452 g. The highest peak ground acceleration analysis is located in Tuaran with 0.1452 g. It can be concluded that the alluvium plain in Tuaran has contributed to the amplification of ground acceleration and velocity. The PGA value of 0.0388 g in Papar area was due to soil amplification in the alluvium deposit. The result of acceleration in other areas showed some tendency of wave amplification in the alluvium plain, fill area and thick residual soil, for instance in Menggatal, Teluk Salut Tuaran, Kampung Kolopis Penampang and Kota Kinabalu Airport with each having PGA of 0.0676 g, 0.046 g, 0.0464 g and 0.0414 g, respectively.

However, the earthquake ground motion data from USGS showed that Gaya Island in Kota Kinabalu experienced PGA of 0.0299 g, which is lower than that at Kota Kinabalu Airport. The PGA value in Tuaran, Menggatal, Teluk Salut Tuaran and Kampung Kolopis Penampang should be comparatively lower than the value in Kampung Kauluan Tamparuli (located 35.2 km from epicenter) because these areas are much further from the epicenter. Each area is located 39.8 km, 42.5 km, 44.5 km and 42.9 km, respectively from epicenter. Variable geological site conditions may cause amplification on ground motion seismic surface wave, therefore the result of PGA will be variable in value which corresponds to distance from earthquake epicenter. The PGA and PGV maps for Sabah due to the strong Ranau earthquake in 2015 are shown in Figures 9 and 10.

Plotted ground motion acceleration due to strong Ranau earthquake in 2015 with a magnitude of 6.0 M_L to well-known GMPE model of Ambrasey *et al.* (1996) shows an attenuation curve which corresponds to the decaying of ground motion acceleration to distance from epicenter as indicated by the black dotted line (Figure 11). The plot of ground acceleration which is higher than the predicted curve indicates ground motion seismic surface wave acceleration amplification in that particular area. The attenuation curve shows that the ground motion acceleration in Tuaran, Lawa Mandau, Papar, some areas in Ranau, Menggatal and Penampang is above the predicted attenuation curve. Thus, it can be concluded that the alluvium deposit underlying Tuaran, Menggatal, Penampang and Papar areas has caused the amplification of ground motion acceleration. The other areas which received lower PGA values ranging from 0.01 g to 0.06 g showed low significance of amplification due to these areas being underlain either by competent soil/ stiff soil or competent bedrock. Overlying the shear wave velocities downloaded from USGS earthquake database with the geological map of Sabah shows results which corresponds to the geological conditions. Areas covered

Table 2: Ground acceleration caused by 6.0 ML Ranau earthquake as given by United States Geological Survey.

Location	Distance from epicenter (km)	PGA	Geology
Kampung Kauluan Tamparuli	35.2	0.0489	Residual soil of sandstone origin
Tuaran	39.8	0.1452	Alluvium
Menggatal	42.5	0.0676	Residual soil-fill area
Teluk Salut	44.3	0.046	Alluvium
Kampung Kolopis Penampang	42.9	0.0464	Alluvium
Gaya Island	52.2	0.0299	Thin residual soil of sandstone origin
Kota Kinabalu Airport	52.6	0.0414	Alluvium
Papar	67.3	0.0388	Alluvium

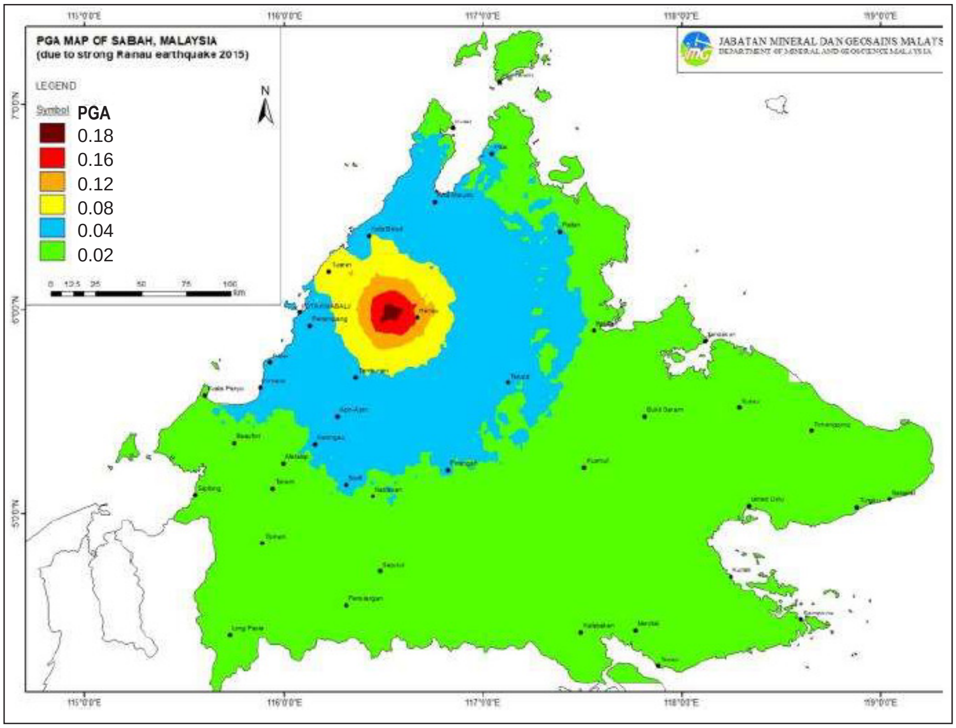

Figure 9: PGA Map of Sabah due to strong Ranau earthquake 2015 (USGS data).

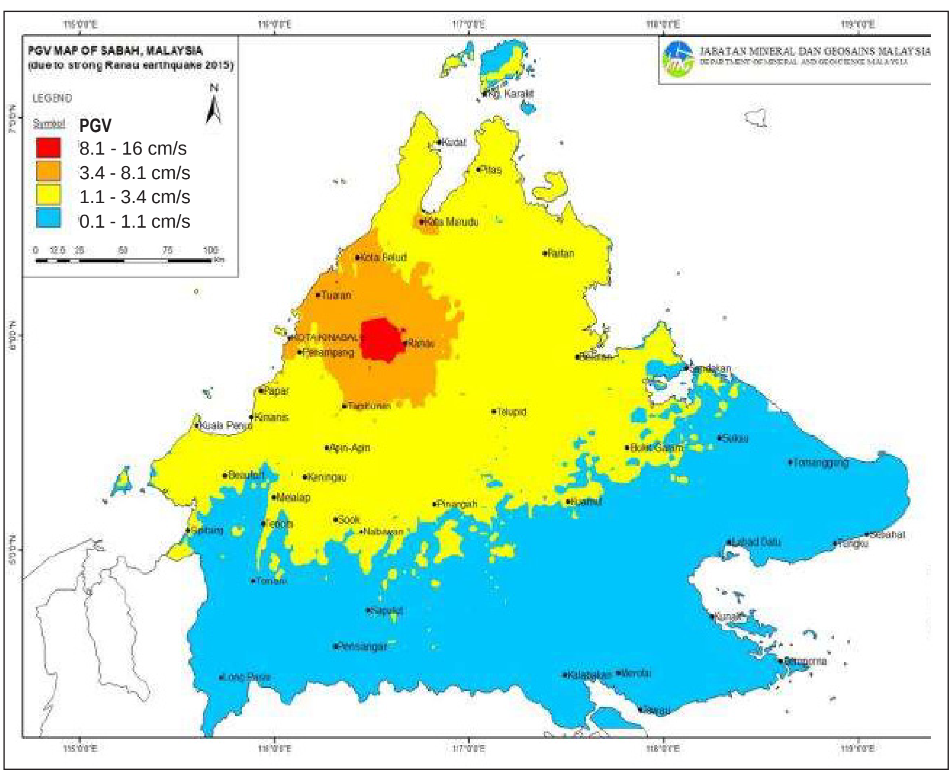

Figure 10: PGV Map of Sabah due to strong Ranau earthquake 2015 (USGS data).

by alluvium, peat deposit, swampy area and loose soil of slump breccias are prone to ground motion seismic surface wave amplification, shown in the high to very high zones (Figure 12). Whereas areas underlain by sedimentary rock, igneous rock and metamorphic rock show low to moderate degree of amplification.

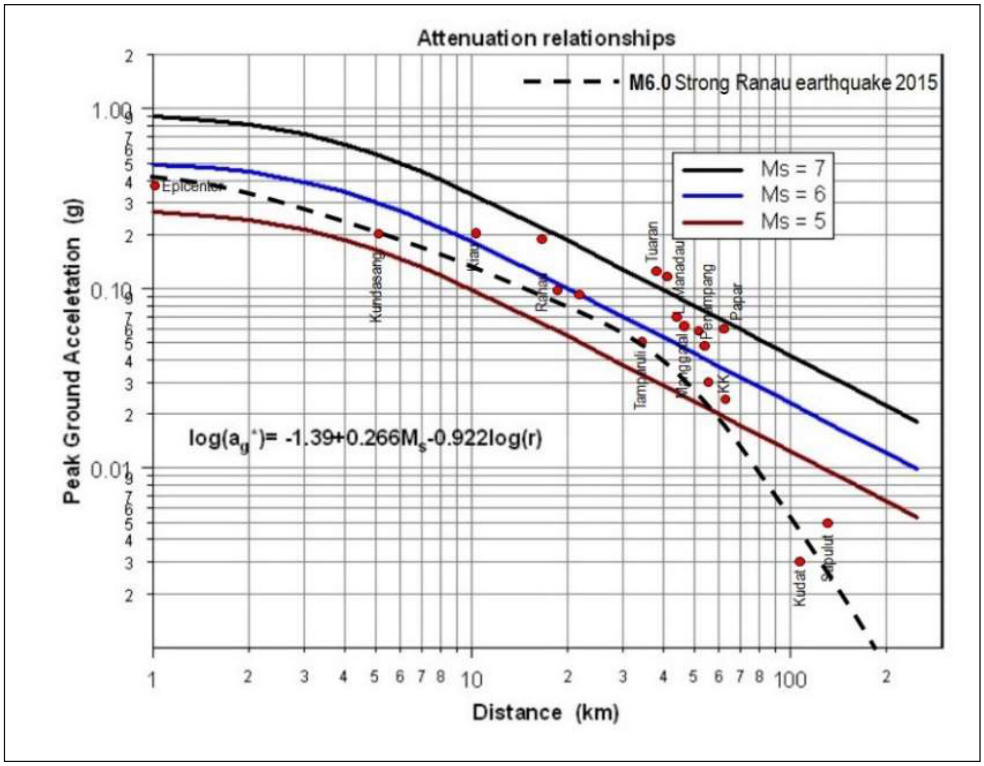

Figure 11: Plot of PGA due to strong Ranau earthquake in 2015 on attenuation relationship by Ambrasey *et al*. (1996).

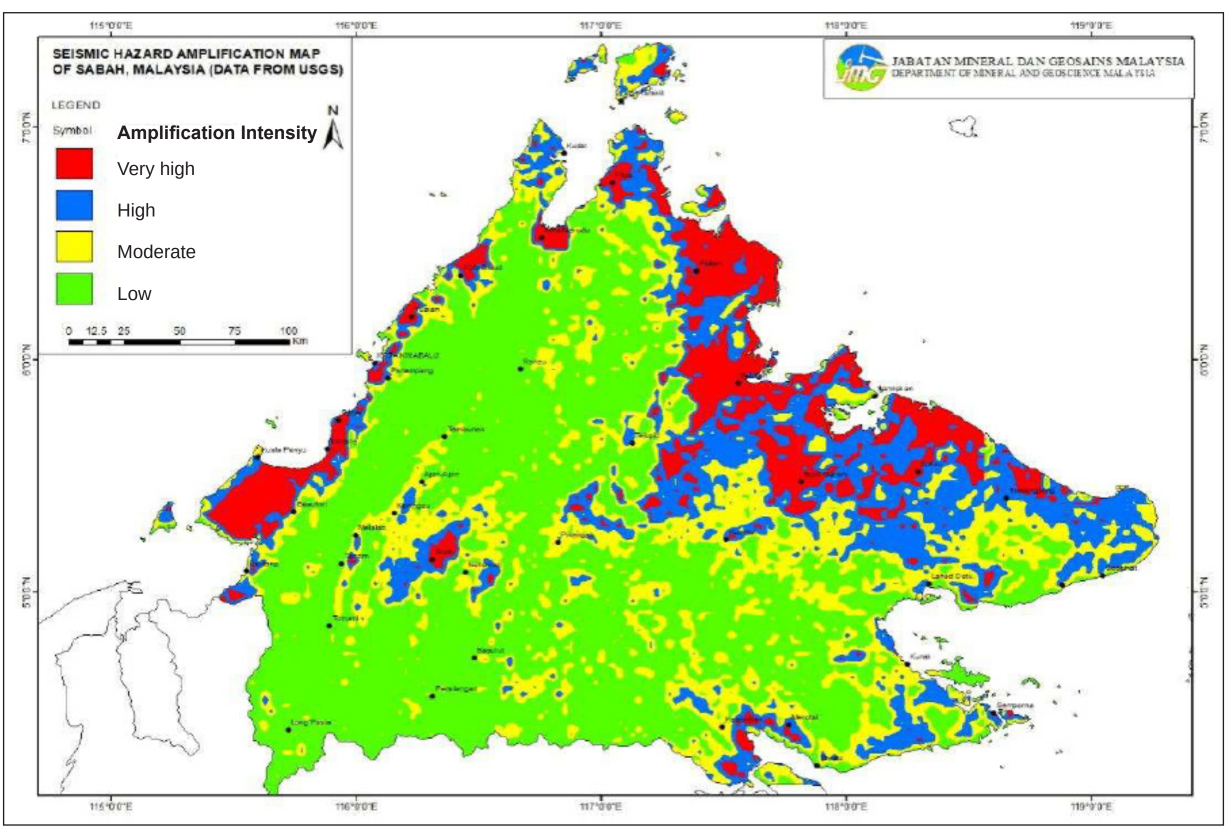

Figure 12: Seismic Hazard Amplification Map of Sabah, Malaysia due to strong Ranau earthquake 2015.

Table 3: USGS Shakemap (Source: USGS - NEIC).

Perceived shaking	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
Potential damage	None	None	None	Very light	Light	Moderate	Moderately heavy	Heavy	Very heavy
Peak acceleration (%g)	<0.17	0.17- 0.14	1.4 - 3.9	3.9 - 9.2	9.2 - 18	18 - 34	34 - 65	65 - 124	>124
Peak velocity (cm/s)	<0.1	0.1 - 1.1	1.1 - 3.4	3.4 - 8.1	8.1 - 16	16 - 31	31 - 60	60 - 116	>116
Instrumental intensity	I	II - III	IV	V	VI	VII	VIII	IX	X^+

Shallow strong Ranau earthquake had caused substantial damages to houses and buildings in the Ranau area. Buildings that were affected by the strong Ranau earthquake tremor included the Ranau police quarters, Hospital Ranau quarters, SMK Ranau quarters, and SMK Mohamad Ali and SK Kundasang teachers quarters. The earthquake tremors had also caused collapse of the Ranau Mosque tower and the concrete ceiling partition in the library of SMK Mohamad Ali. It was fortunate that nobody was inside the mosque and the libray during the incident. Many people within 40 km radius of the epicenter panicked and ran out of buildings and their homes.

Based on the USGS data, it was reported that a peak ground acceleration of 0.38 g had occurred in the epicentral area. The ground shaking experienced at Ranau area was reported strong and according to USGS Shakemap, this is equivalent to a peak ground acceleration of 9.2-18% g (Table 3).

RECOMMENDATIONS

The PGA and PGV data recorded at MET Malaysia seismic stations was not sufficient to carry out analysis of isoseismal ground acceleration, ground velocity and seismic hazard amplification in all parts of Sabah region. Therefore, it is pertinent to install additional seismic stations so that more data on ground acceleration and velocity can be recorded in the future. The installation of accelerometer tools should be located in different geological strata and in various soil properties.

Real-time Global Navigation Satellite System (GNSS) with a combination of seismo-geodetic monitoring will also need to be installed in order to obtain data on yearly slip rate of active faults so that the maximum energy of peak ground acceleration and ground velocity released by an earthquake tremor can be analyzed. GNSS and sesimogeodetic monitoring should be installed at both sides of active faults to determine the type of fault movement, i.e. transform, thrust or a normal fault.

CONCLUSION

Sabah is affected by five seismic hazard intensity, which are Zone V, Zone IV, Zone III, Zone II and Zone I. Zone V and Zone IV would be affected by very strong ground motion intensity, Zone III strong ground motion intensity, Zone II moderate ground motion intensity and Zone I low ground motion intensity. The type of fault that caused strong Ranau earthquake on 5 June 2015 is NNE-SSW normal left lateral oblique fault which runs through Mount Kinabalu area. Ground motion due to the strong Ranau earthquake showed seismic intensity VII in Kundasang and Ranau area and up to VIII at areas with loose soil properties. Records of ground motion acceleration range from 0.01 g to 0.14 g. The highest value of PGA was recorded in Tuaran area and Lawa Mandau, Telipok with values of 0.1452 g and 0.1351 g respectively. Based on the USGS database, the PGA in the epicentral area is 0.38 g. Ground motion acceleration shows amplification of ground motion seismic surface wave in the area underlain by sensitive geological material and loose sediment such as slump breccias, peat deposit, swampy deposit, coastal plain and riverine alluvium, fill slope and reclaimed water bodies.

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ABBREVIATIONS

M_b: Magnitude Body Wave
M_L: Magnitude Richter Scale
M_w: Magnitude Moment Wave
PGA: Peak Ground Acceleration
PGV: Peak Ground Velocity
MMI: Modified Mercalli Intensity
USGS: United States Geological Survey
JMG: Jabatan Mineral dan Geosains Malaysia

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