DYNAMIC SOIL AMPLIFICATION FACTORS AND INFLUENCE OF SOIL CONDITIONS IN KOTA KINABALU, SABAH

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DECLARATION

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ABSTRACT

Sabah is a state located in the area of moderate earthquake intensity which mostly involves the region of Kundasang, Ranau. The magnitudeof M_w 6.0 earthquake damaged approximately 50 buildings including schools, hospital and mosque. This earthquake intensity was the highest in history that affected Malaysia. A city that was also affected by the M_w 6.0 is Kota Kinabalu, which is located 200 km away. The city comprises many mid- to high-rise buildings that were not designed based on seismic provision. In Kota Kinabalu, the geological types below the city show that there are two types of soil, namely the very loose sand and sensitive clay. These types of soils are liable to be transformed due to the earthquakeas they might lose their original soil structure thus undergo a compaction stage. Therefore, this study had been carried out based on three objectives. The first objective was to produce the contour map for Kota Kinabalu city in terms of site class B, C, D and E. The second objective was to determine the soil amplification factor for each soil type due to the earthquake magnitude of M_w 6.1 and M_w 5.9. Lastly was to determine the fragility curves from analysis of four high-rise buildings. Soil amplification factor, f is the ratio between the peak ground acceleration (PGA) and pseudo-spectral acceleration (PSA) of values. This value of f will be used in determining the pushover analysis. From the result, it is shown that 28% of soil is class B, 24% is class C, 25% is class D and 23% is class E. This study showed that the amplification factor for time history of M_w 5.9 at period t=0.01s is between 0.392 and 4.302. Meanwhile, the amplification factor for time history of M_w 6.1, t=0.01s is between 0.199 and 6.202.The base shear of fourbuilding models denoted by B1, B2, B3 and B4 shows that building B2 produced the highest displacement under both magnitudes ofM_w 6.1 and M_w 5.9.

ABSTRAK

FAKTOR AMPLIFIKASI TANAH DINAMIK DAN PENGARUH CIRI-CIRI TANAH DI KOTA KINABALU, SABAH

Sabah merupakan negeri yang berada di kawasan gempa bumi bersaiz sederhana yang kebanyakkannya berada di daerah Kundasang, Ranau. Gempa bumi bermagnitud M_w*6.0 telah mengakibatkan banyak kerosakan terhadap 50 buah bangunan termasuklah sekolah-sekolah, hospital dan masjid. Menurut rekod, kadar intensiti gempa tersebut merupakan yang tertinggi di Malaysia. Dalam jarak 200 km dari daerah Kundasang, terletaknya sebuah bandar Kota Kinabalu, di mana kawasan ini juga menerima kesan daripada gempa bumi bermagnitud* M_w *6.0. Bandar ini mempunyai bangunan-bangunan sederhana dan tinggi yang banyak namun ada yang tidak direkabentuk dengan bebanan seismik. Di bandar ini, jenis geologi di sekitar menunjukkan bahawa terdapat dua jenis tanah iaitu berunsur seperti pasir yang bersifat longgar dan tanah liat yang sensitif. Jenis-jenis tanah ini boleh berubah bentuk akibat gempa bumi yang akhirnya mengakibatkan kehilangan struktur asalnya dan akhirnya mengalami peringkat pemadatan. Oleh itu, kajian ini dijalankan berdasarkan tiga objektif. Objektif pertama adalah untuk menghasilkan sebuah peta kontur bagi setiap jenis tanah B, C, D dan E di Kota Kinabalu. Objektif kedua adalahuntuk memperolehi faktor amplikasi tanah bagi setiap jenis tanah yang terhasil daripada gempa bumi bermagnitud* M_w*6.1 dan*M_w*5.9. Akhir sekali adalah untuk menentukan keluk kerapuhan terhadap empat buah bangunan-bangunan. Faktor amplifiksi tanah, f adalah nisbah nilai pecutan tinggi tanah (PGA) dan pecutan pseudo-spectral (PSA). Faktor nilai* f *digunakan untuk analisis pushover. Hasil daripada keputusan menunjukkan bahawa, terdapat 28% adalah dari jenis tanah B, 24% jenis tanah C, 25% jenis tanah D dan 23% jenis tanah E. Kajian ini menunjukkan bahawa faktor penguatan untuk gerakan sejarah masa* M_w *5.9, tempoh masa, t = 0.01s berada dalam julat 0.392 dan 4.302 manakala untuk* M_w *6.1, t = 0.01s dalam julat 0.199 dan 6.202. Daya ricih asas untuk empat model ditandakan sebagai B1, B2, B3 dan B4 menunjukkan bahawa bangunan B2 menghasilkan nilai sesaran yang terbesar kesan daripada kedua-dua jenis magnitud,* M_w*6.1 and* M_w*5.9.*

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LIST OF ABBREVIATIONS

$d\gamma$	-	Strain increment of soil model
$d\tau$	-	Stress increment of soil model
f	-	Soil amplification factor
F_{cu}	-	Compressive strength of concrete
G_{max}	-	Maximum shear modulus
H	-	Tangential modulus of soil model
h_i	-	Height of soil layer of i
H_T	-	Total height of building model
M_W	-	Earthquake magnitude
n	-	Number of storey buildings
N	-	Total number of soil layers
N_{SPT}	-	The number of distribution with standard penetration test on a soil sample
PGA	-	Peak ground acceleration
PSA	-	Pseudo-spectral acceleration
S_a	-	Spectrum acceleration
S_d	-	Spectrum displacement
t_S	-	Time step
v_S	-	Shear wave velocity

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CHAPTER 1

INTRODUCTION

1.1 Background of The Study

In Sabah, the geological data show that the tertiary rocks are younger than sedimentary rocks in (Tongkul, 1990). Figure 1.1 shows the formation of tertiary rocks in the regions of Sabah such as sandstone and shale.

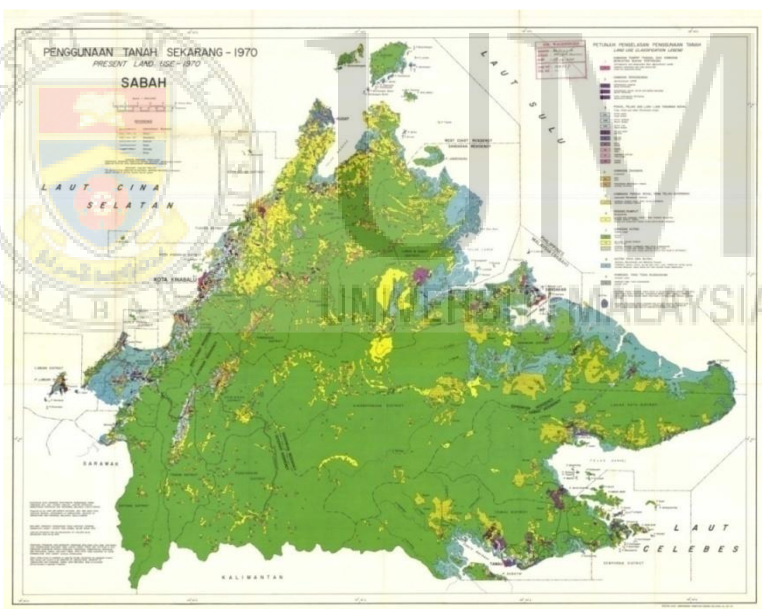

Figure 1.1: The soils of Sabah published for Land Resources Division, Overseas Development Administration of England on 1974

Source: ESDAC (2017)

From the figure, the region of Sabah consists of various soil characteristics. It is rich with forest area in the interior region; while the coastal areas generally consist of swamps, marshlands and wetland forests including mangrove, and other wetland forest types (Tating, 2015). From the distribution of these wetland soils in most urban areas such as Kota Kinabalu, Sandakan and Tawau, it is believed that these areas contain sand, clay and silt soil layers. Sandakan and Tawau districts located at the east coast of Sabah consist mainly of series of parallel linear ridges mostly oriented about northeast to southwest (NE - SW). The west coast of Sabah is made up of flat swampy areas, coastal plains, valleys and some isolated hills. Moreover, the coastal plains and valleys vary from 2 to 5 kilometres in width while the linear belt of hills is about a kilometre wide. Those coastal terrains and valleys underlain by Quaternary deposits, consist of unconsolidated to semi-consolidated sedimentary layers of sand, silt, clay and peat. Figure 1.2 shows the region of Kota Kinabalu which is composed of various soil characteristics.

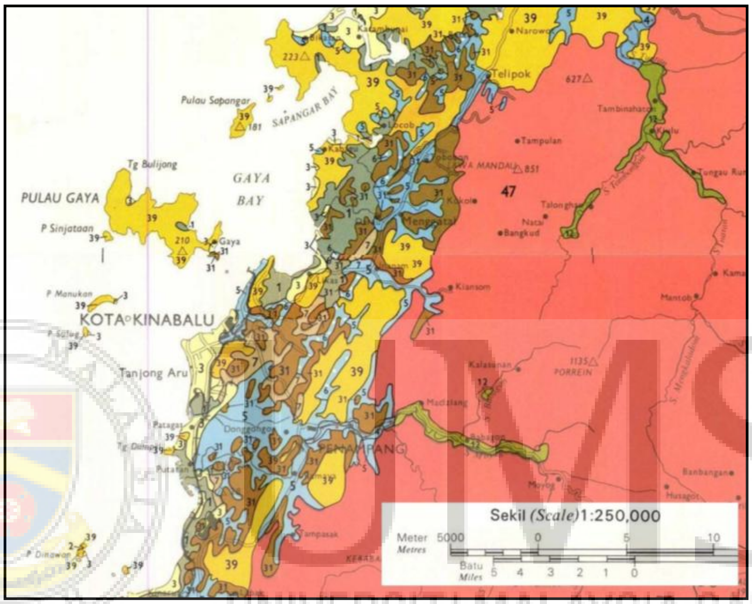

Figure 1.2: The soils of Kota Kinabalu region of Sabah published for Land Resources Division, Overseas Development Administration of England on 1974

Source: ESDAC (2017)

The soil map in Kota Kinabalu region can be referred with the soil information as shown in Table 1.1.

Table 1.1: The soil type and bedrock for Kota Kinabalu, the district of Sabah

Key	Soil types	Bedrock
1	Tidal swamps	Sulphidic alluvium, sulphidic peat and alluvium
3	Beaches	Alluvium
5	Floodplains	Alluvium
6	Swamps	Alluvium and peat
30	Moderate hills: slope $>25^\circ$	Mudstone and sandstone
31	Moderate hills and minor valley floors: slope $0-20^\circ$	Sandstone, mudstone and alluvium
32	Moderate hills and minor valley floors: slope $0-20^\circ$	Sandstone, mudstone and alluvium
33	Moderate hills: slope $0-20^\circ$	Mudstone, sandstone and miscellaneous rocks
34	High hills: slope $15-25^\circ$	Basic igneous rocks
35	Moderate hills: slope $10-20^\circ$	Tuffaceous rocks, mudstone and sandstone
36	High hills: slope $>25^\circ$	Sandstone, mudstone and igneous rocks
37	Very high hills: slope $>25^\circ$	Basic igneous rocks
38	Very high hills: slope $>25^\circ$	Limestone
39	Very high hills: slope $>25^\circ$	Sandstone and mudstone

Source: ESDAC, (2017)

The table shows that the region of Kota Kinabalu mainly consists of sandstone and mudstone. In coastal area of Kota Kinabalu, the region is composed of alluvium and peat while hilly areas are basically composed of basic igneous rocks. These soil types in Kota Kinabalu had also been studied by Tating (2015). Although Malaysia is located in a safe zone from tectonic plate, it is still subjected to the risk of earthquake at any time as it is near to Sumatra and the Philippines's subzones (Adnan, et al., 2006). In the early year 2015, an earthquake with the magnitude M_w 6.0 was recorded in the areas of Ranau and Kundasang, Sabah. There were more than 100 evidences showing the aftermath of the earthquake in which 61 buildings such as school, hospital, mosque and 44 infrastructures were affected (Lee, 2015). On January 10^{th} 2017, it was reported that some mid-rise buildings in Kota Kinabalu city had experienced shaking of earthquake-induced long-period ground motions with hypocentres distance R_{epi} of about 900 km away from Celebes Sea, Philippines with the magnitude of M_W 7.3 (Sario, 2017).

There are several methods of seismic study, for instance, macroseismic intensity and seismic hazard assessment. The term "macroseismic intensity" is used entirely for classification of the severity of ground shaking or motion on the basis of observed effects in a limited area (Grünthal, 1998). This approach is different from the preceding methods that are mostly in empirical form. This method can be used with a probabilistic probability matrix (DPM) or properly analyzed data and feasible to assess vulnerability of individual buildings and municipalities. It also offers a quick and low cost solution for risk assessment, prevention and management. Moreover, it has been widely used in the European building typologies for their vulnerability characterisation of traditional constructions (especially for masonry type). Examples of vulnerability evaluations from the European research can be found in the research of seismic assessments from Faccioli et al. (2010); Giovinazzi et al. (2004); and Pierre et al. (2006).

Seismic Hazard Assessment is used to indicate the probability of specific earthquake effects in terms of acceleration and intensity given the time length (Datta, 2010a; Stefánsson, 2011). It is also used to describe the character of a regional area regardless of when and which earthquake effects happened. According to Bolt (1994), seismic hazards are the foundation of study in regards to pre and post of earthquake hazards. The four expression types of seismic hazards are ground shaking, fault rupture, secondary hazards and time-dependent hazard.

1.1.1 Fault Rupture

Surface rupture and movement along the fault lines are physically visible. Fault line is a break or fracture on the ground that occurs when the Earth's tectonic plates move or shift and the areas where earthquakes are likely to occur. The movement is associated with shaking and occurs in such a large scale that in severe cases can cause damage to major structure such as power lines, pipelines, buildings, roads, bridges, and other large structures at its proximity. The offset between rocks on the surface rupture, or on the opposite sides of the fault can be seen in Figure 1.3 (Datta, 2010).

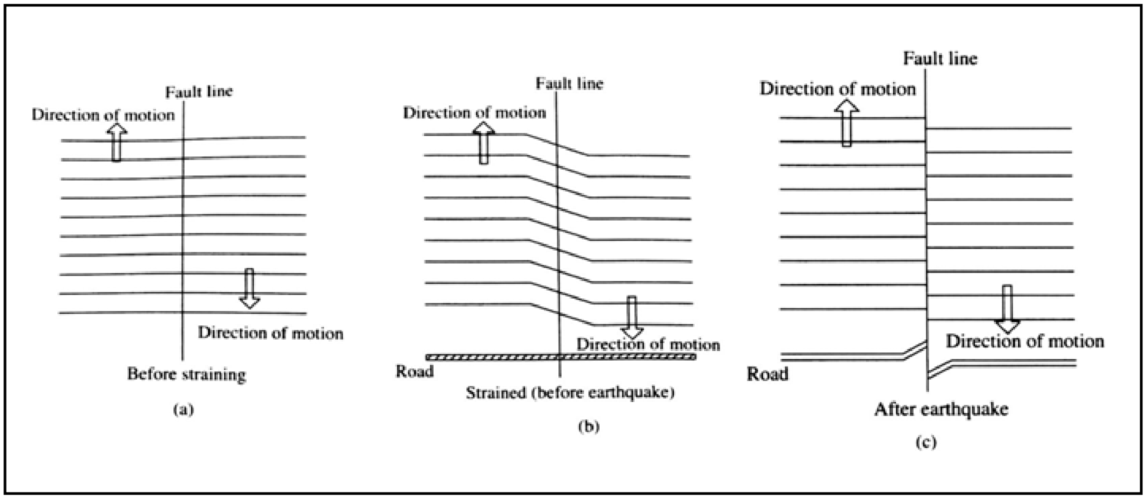

Figure 1.3: Fault rupture theory from stage (a) to stage (c)

Source: Datta (2010)

Stage (a) shows that there is an occurrence of strike-slip fault before its soil is strained in which the directions for strike-slip fault are opposed to each other along the fault line. From stage (b), the strike-slip fault occurs after the straining as the infrastructure of road is constructed. The line of soil layers become strained before the earthquake strikes. Then stage (c) shows the infrastructure of road strained together along the strike-slip fault. This fault is shown to cause destruction of infrastructure after the straining of soil.

The boundaries of large rock masses are tens to hundreds of kilometres beneath the earth's surface which can cause rise of crustal movement as a result of ground shaking as shown in Figure 1.4 (Buchholdt & Edin, 2011). When the underlying soils or sediments are weak and poorly consolidated, its ground displacement is often worsened. In urban areas where land is susceptible to earthquake risk, many cities decided to expand into wetlands and shallow coastal regions by using artificial fill to increase the land area after an earthquake incident (Juan and Yong, 2011).

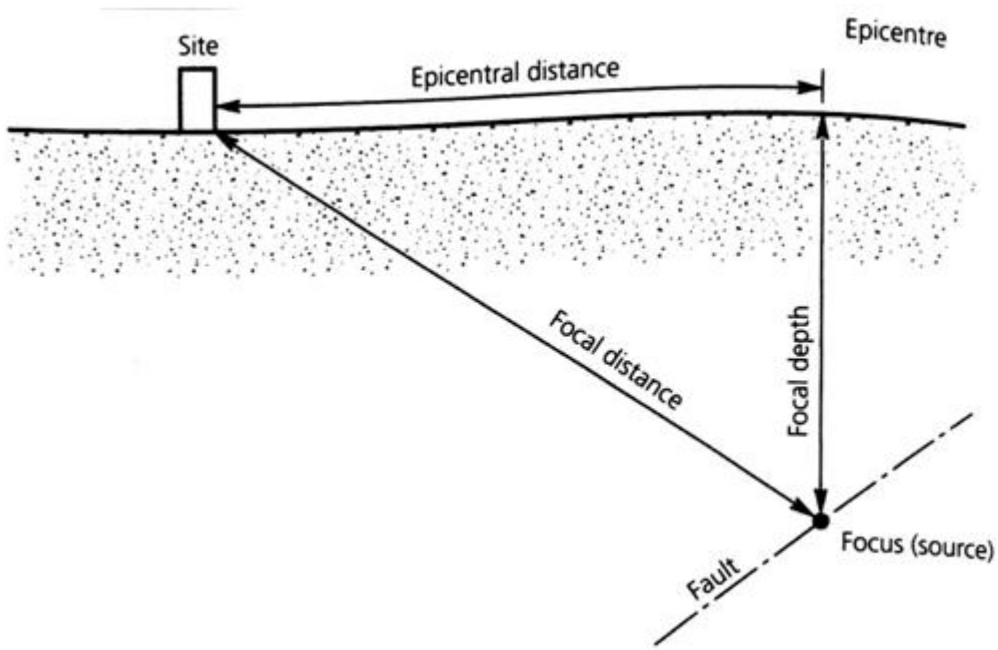

Figure 1.4: The principle of geometrical earthquake with fault line rupture

Source: Buchholdt & Edin (2011)

1.1.2 Fault Rupture in Sabah

The earthquake of Mt. Kinabalu in 2015 with M_W 6.0had caused a deadly impact. It happened from the limit of the nearest plates in a very low historical seismicity. Earthquake signifies a fragmentation of a rupture northwest mist that does not reach the surface. Its unilateral rupture was almost directly beneath 4 kilometres high of Mt. Kinabalu and activated widespread slope failures on steep mountainous slopes, where there are dangerous rockfalls. Seismological analysis showed that the rupture occurred on a common area that had spread since the previously identified at Marakau fault, where it was marked in the eastern part of Ranau (Wang Yu and Wei, 2017). Figure 1.5 shows the map of Geomorphic expressions of normal faults near the southeast flank of Mountain Kinabalu and the Ranau Basin.