Seismic vulnerability assessment in Kota Kinabalu, Sabah

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Abstract. Sabah has witnessed an increasingly low to moderate number of seismic activities throughout the years due to active Mensaban and Lobou-Lobou faults lines. Vulnerability level of older buildings in Sabah, designed and built on the basis of older codes of practice poses a significant threat to life safety and structural capacities of the existing buildings. This paper presents a framework of preliminary seismic vulnerability assessment of existing buildings in Kota Kinabalu. Building stocks include major government buildings and facilities, residential, educational, institutional, business as well as public buildings. The objective of this study is to evaluate and determine the vulnerability of existing buildings in seven major areas near Kota Kinabalu district using Rapid Visual Screening (RVS) scoring method based on FEMA154 (2002). The rapid visual score indicates that from the total two-hundredth-fifty (250) buildings assessed, (60.4%) are categorized as unsafe buildings and are strongly recommended for further evaluation and detailed analysis whereby modelling of structure is necessary.

1. Introduction

East Malaysia, namely Sabah and Sarawak have been categorized under low to moderate seismicity areas [1],[2],[3],[4],[5] according to previous records of local ground motion intensity data. Sabah is especially prone to earthquake activities compared to other state in Malaysia. Previous earthquake data in Sabah showed the earliest seismic activities since 1897 [5-6] generated by intra-plate active faults. Other earthquake events that have caused considerable damages to buildings are the three incidences that occurred in 1976, 1991 and 2015. June 5th, 2015 marked the highest earthquakes magnitudes ever recorded in Malaysia, with moment magnitude of 6.0 on Richter scale that originates from Ranau, Sabah as shown in Figure 1 [7]. The epicenter was said to be located 14km away from northwest Ranau at 10km beneath the ground [7] and were felt as far as 400 km from the epicentre. The earthquake claimed eighteen (18) lives of locals and foreigners and caused much structural and infrastructures damage which extended to Kota Kinabalu area such as public buildings, residential buildings, shoplots, roads and bridges [8].
After the catastrophic event in June 2015, Malaysian Meteorological Department (MMD) has recorded a series of low magnitude earthquakes ranging from 2.3 to 4.0 on Richter scale in Kundasang area. Apart from the local earthquakes, East Malaysia were also affected by large earthquakes originated from Southern Philippine, Makassar Strait, Sulu Sea and Celebes Sea with maximum intensity as high as VII on Modified Mercalli scale [9].

In terms of its relative proximity to major plate boundary faults in the Philippines and Sulawesi active subduction zones, Sabah is considered one of the most tectonically active areas throughout Malaysia, with Mensaban and Lobou-Lobou fault zones in Kundasang, Ranau classified as active faults according to the Ministry of Science, Technology and Innovation (MOSTI). Figure 2 illustrates the location of Sabah being closely situated between some of the most seismically active plate boundaries; the Indian-Australian Plate, Eurasian Plate in the west and Philippine Plate in the East [10].
Figure 2. Tectonic setting of Sabah with major plate movements [1].

These continuous accumulations of tectonic stress are noted to have significant impact on the possibility of earthquakes greater than moment magnitude of 5.0 on Richter scale to hit Sabah in the future. Continental drifts resulted from land movement due to plate tectonics will generates hazards such as soil liquefaction and landslide that are also significantly destructive to the existing sub-standard structures in Sabah. The nearest active fault lines to Kota Kinabalu is about 58km away from Ranau and Kundasang area [11], whereby redlines in Figure 3 denote the active fault lines near the region.

Figure 3. Active fault lines in Sabah [11].
Since most of the buildings in Kota Kinabalu were design and built with non-seismic compliance, it is safe to presume that the seismic vulnerability of these building stocks is primarily responsible for possible large number of human casualties in the future. Due to limited availability of local building seismic vulnerability assessment data, Rapid Visual Screening (RVS) is proven to be a suitable rapid data collection methods for buildings inventory with a fieldwork-based procedure whereby process of screening involves site inspection, data collection and decision-making processes. This work aims to investigate the building inventory data in Kota Kinabalu town needed for vulnerability assessment and to estimate the seismic risk in Kota Kinabalu, Sabah.

2. Methodology

2.1. Soil Information
Existing soil investigation (SI) information for building stock locations was collected from a recent soil classification contour map as readied information as illustrated using Geographical Information System (GIS) in Figure 4 [12] and were entered in the RVS screening form during the pre-field phase. Table 1 shows the total numbers of buildings involved under each area of Kota Kinabalu district and their respective soil classification [12].

![Contour map for site classification in Kota Kinabalu, Sabah](image)

**Figure 4.** Contour map for site classification in Kota Kinabalu, Sabah [12].
Table 1. Number of buildings involved and their respective soil type.

| Number | District         | Number of Buildings | Soil Type |
|--------|------------------|---------------------|-----------|
| 1      | Damai            | 26                  | C         |
| 2      | Sepanggar        | 46                  | D         |
| 3      | Kota Kinabalu    | 93                  | D         |
| 4      | Lintas           | 13                  | C         |
| 5      | Menggatal        | 36                  | D         |
| 6      | Putatan          | 23                  | D         |
| 7      | Tanjung Aru      | 13                  | D         |
|        | **Total**        | **250**             |           |

2.2. Building evaluation by rapid visual screening (RVS)

Rapid Visual Screening (RVS) is proven to be a suitable rapid data collection method for building inventory with a fieldwork-based procedure whereby process of screening involves site inspection, data collection and decision-making processes. It is a preliminary screening phase of a multi-phase procedure for identifying earthquake-hazardous buildings [13]. During the sidewalk survey, building inventory was conducted and all building features that might influence their seismic performance were visually examined and identified. According to the local seismicity condition in Sabah, only one type of FEMA 154 (2002) modified data collection forms was used in this exercise which is Moderate Seismicity criteria. Figure 5 illustrates how the RVS Basic Score Modifier was done.

Figure 5. Complete level 1 data collection form used by screener.
At the beginning of the survey, the number of stories was confirmed by inspection, and the year built was noted. The occupancy or use of the building was also identified and circled in the form. The scoring process involves the identification of each building irregularities in both categories; vertical irregularities and plan irregularities. Any visible exterior falling hazards or pounding were also noted in the evaluation form.

The individual performance score is then calculated using suitable Basic Score and Score Modifiers provided (red dotted lines) corresponding to the features of the building until the final structural score, $S_{L1}$. The final score represents the probability of building collapse when an earthquake occurs [14], with higher score indicating acceptable seismic performance while below basic score warns potential hazardous structure. Parameters such as the soil type, architectural design, current visible building condition, and earthquake resistance features are all taken into consideration while performing the survey.

3. Results and discussion
Most of the buildings in Kota Kinabalu region are Reinforced Concrete (RC) structures as shown in Figure 6. Majority (64.26%) of the building stock are categorized as type C1, Concrete Moment Resisting Frame, (19.68%) are type C3, Concrete Frame with Unreinforced Masonry Infill Walls while type C2, Concrete Shear Wall made up of (8.03%) of the building stock. 11 (4.42%) type PC2, Precast Concrete Frame, 5 (2.01%) type S1, Steel Moment Resisting Frame and 4 (1.61%) type S4, Steel Frame with Unreinforced Masonry Infill Walls are mostly situated in central Kota Kinabalu city.

![Figure 6. Building types and their respective percentage.](image)

The state capital of Sabah, Kota Kinabalu is densely populated with locals as well as foreigners. Type of buildings such as C1 is mainly comprised of government and public buildings, while shoplots, school and residential buildings were categorized as type C3. Steel structures are still limited in Sabah due to the construction source and cost factor.
Figure 7 illustrates the number of buildings and their respective type based on the number of storey. The field survey indicates that 65 (26%) number of buildings in Kota Kinabalu are categorized as low-rise buildings which mainly comprise of schools, residential buildings and shoplots. About 90 (36%) buildings are middle rise whereby number of storey ranges in between four (4) to six (6). The 95 buildings which exceed 6-storey are considered high rise and are made up of (38%) of the building stock.

![Building Distribution based on Number of Storey](image)

**Figure 7.** Distribution of buildings based on number of storeys.

Mass building disruption may become an issue when earthquake hit the city area as high rise buildings tend to be subjected to greater motion especially on the upper storey. Additionally, pounding and falling hazards from adjacent buildings are also most likely to happen.

![Building Benchmark](image)

**Figure 8.** Building benchmark.
Figure 8 shows building benchmark consisting of plan irregularity and vertical irregularity. Vertical irregularity shows a higher percentage with (54.83%), while plan irregularity was found in (45.17%) of the building stock. This figure indicates that vertical irregularity will most likely be the prominent factor that contributes to the potential building failure.

![Percentage of Hazardous and Non-Hazardous Buildings Respectively](image)

**Figure 9.** Status of buildings in terms of potential seismic hazards.

Based on the field survey, Figure 9 illustrates 151 (60.40%) buildings scored lower than its specified minimum score and are categorized as hazardous buildings with high probability of collapse; the need for further detailed building evaluation is essential. The other 99 (39.60%) buildings are categorized as non-hazardous, whereby they are less likely to collapse under the local seismic activity. The identified hazardous buildings are mostly influenced by vertical irregularities found in the design of the building itself such as weak/soft story, out-of-plane setback and short column/pier. Plan irregularities like non-parallel systems and re-entrant corner are also the typical reason for the lower final score. The overall results obtained from RVS suggest that buildings in Kota Kinabalu are in danger of collapse under local seismic activity with predicted ground motion excitation.

4. Conclusion

This study has shown that most of the buildings around Kota Kinabalu district are highly vulnerable to seismic activity with (60.40%) of building stock categorized as unsafe/hazardous with high probability of collapse. The Rapid Visual Screening (RVS) method is proven to be an effective seismic evaluation tools due its cost-effective manner and ability to evaluate large building stock quickly in a limited available time and access. However, this method of assessment has limitations such as the non-feasibility of interior inspections. Therefore, some hazardous details may not always be visible to the screeners and results in missed potentially seismically hazardous buildings. Hence, detailed structural evaluation is recommended for each individual buildings using structural analysis software to predict the actual building performance level under assigned local earthquake excitation.

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