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Assessment of building vulnerability by integrating rapid visual screening and geographic information system: A case study of Ranau township

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Assessment of building vulnerability by integrating rapid visual screening and geographic information system: A case study of Ranau township

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Abstract. The earthquake may cause many deaths and injuries and extensive property damage and dramatically change the geographic structure of the impacted area. Vulnerability in the context of building structure can be defined as inability to resist the earthquake loadings and unfortunately the majority of existing buildings in Ranau Township were built consequently without seismic consideration. The rapid development had increased the probability of building damages due to the earthquake activities that appeared around the area since. This study aims to identify, evaluate buildings and calculated vulnerability using the Rapid Visual Screening (RVS) method through the framework of Geographic Information System (GIS). The results of this study revealed that from 245 buildings, the damage level for 21 buildings were in grade 3, 11 buildings under grade 2 and other buildings in grade 1 i.e. heavy, moderate and little damages, respectively. After knowing the vulnerability level of buildings, the developer may do an early prevention to avoid further damages due to earthquakes in the future. This method can be used in moderate seismicity region such as Sabah as an early detection for building vulnerabilities.

1. Introduction

The vibration from seismic activity will cause the ground to shake in a way that might affect densely urbanized regions and can cause damages and loss of life. An earthquake itself might not kill people but the buildings and structures collapsing due to it will. Hence, there is a need to find the best solution to reduce a catastrophic effect by the earthquakes. Vulnerability is a degree of buildings being exposed to the destruction or damage risk. Generally, there are two ways to measure building vulnerability; quick survey and meticulous inspection. Quick Survey in Rapid Visual Screening (RVS) requires only a small survey time, no need for expertise, even cheaper than meticulous inspection where equipment is more expensive, requires longer time and specialist participation requirements related to building structures. The disadvantage of using meticulous inspection is the need to inspect the building individually while the RVS method can be effectively used to evaluate the vulnerability of a large number of buildings [1]. The main of the RVS method used in this study is to determine whether a building needs a more detailed investigation. The vulnerability score will be presented in form of map produced using GIS showing buildings of different vulnerable categories. GIS is a powerful tool that have the ability to store, analyse and display large information. Hence, in this study GIS has been used and consists of two phases; at the beginning of RVS and at the end of displaying RVS results in the form of interactive maps.

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2. Study area

Ranau Township is located in the Central North Zone as shown in Figure 1 where other major seismic zone of Sabah are also shown including–Labuk Bay-Sandakan Basin and Dent-Semporna Peninsula zones[2]. In the history of earthquake events of Ranau Township, only two incidences have caused considerable damages to buildings that occurred between 1991 and 2015. On May 1991, an earthquake swarm with a magnitude of M_W 5.1 produced substantial damage to properties. The 4-storey teacher's quarters suffered structural damage with brick walls collapsed and cracks also appeared in several other buildings. In June 2015, a M_W 6.0 earthquake struck the area again and resulted in the loss of lives. Some infrastructure, 23 schools and a mosque was reported damaged due to the tremor. Serious damage also occurred onto the hostels and rest house near the summit of Mount Kinabalu. The recent event, occurred on March 2018, more than 100 climbers rushed down to the safety point at Laban Rata in Mount Kinabalu after a M_W 5.2 magnitude earthquake hit the area. Fortunately, there were neither reports of any casualties nor damages from the incident. However, the shaking was felt by approximately within 200 km from the epicentre.

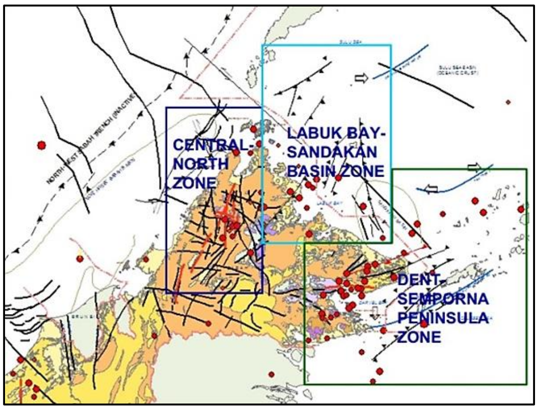

Figure 1. Three main seismic zones of Sabah i.e. Central North Zone, Labuk Bay-Sandakan Basin Zone and Dent-Semporna Peninsula Zone [2]

Sabah lies at the intersection of three major tectonic plates, the Eurasian Plate to the North, the Indian-Australian plate to the West and South and Pacific-Philippine Sea Plate to the East. Other than the three local seismic zones, Sabah also being affected by tremors from large earthquakes located over Southern Philippines and Northern Sulawesi[3]. The Eurasian Plate, that includes Sundaland and South China Sea Basin is moving southeastward at a rate of about 5 cm/yr. The Indian- Australian Plate is moving northerly at a rate of about 7 cm/yr whereas the Philippine Sea-Pacific Plate at about 10 cm/yr. The interactions of the three tectonic plates are associated with active subduction zones and strike-slip faults. Although Sabah is 1,000 km away from the collision of the plates, it still can experience the compression force[4]. Since the earthquake is an unpredictable and unstable natural phenomenon, it is necessary to see the resilience and weaknesses of buildings especially in Sabah as a precautionary measure of greater destruction and harm to the lives of property and population. Table 1 shows a series of earthquakes in Ranau Township from May 1991 until March 2018 [3], [5], [6]. Through this information indicates that detailed study need to be done based on vulnerability priorities on the area [7].

Table 1. Series of earthquakes in Ranau[3], [5], [6]

Date	Magnitude (M_W)
1991-05-26	5.1
1995-08-11	4.1
2006-09-28	4.5
2014-02-01	4.7
2015-06-05	6.0
2016-03-17	2.7
2016-04-16	3.0
2016-05-14	3.6
2016-08-26	4.0
2018-03-08	5.2

3. Methodology

In seismic vulnerability evaluation, it requires a number of buildings in a brief period using a simple and robust method. The analysis will be able to quantify the overall building seismic performance and the use of vulnerability as an input parameter. Rapid visual screening (RVS) is one of recommended strategies for seismic vulnerability evaluation since it can be carried out without any structural calculations. RVS is a sidewalk visible survey of a building and filling up their information by using a collection form during surveying[8]. It is based on the system calibrated which, allow for the quantification of structural vulnerabilities. This process is easier than the analytical approach because it does not require a detailed calculations with multiple scenarios [9]. This method can help the authorities to strengthen the highly vulnerable buildings to lower the risk of damage. This can be done by gathering the information about the state of the building stock and expected damage. In this study, a pre-survey based on Geographic Information System (GIS) is used to identify and get information of the involved buildings in Ranau Township.

In this study, FEMA 154 data collection form has been used as a main tool in RVS. This is the standard form used for RVS method. There are three types of forms categorized based on the relative intensity of risk affects the area, i.e, low, moderate and high seismicity. In this study standard moderate seismicity forms were used as shown in Figure 2. Based on the form, there are several criteria reviewed in each building to get the final score. Criteria include; occupancy, soil types, falling hazards, building types, vertical irregularity, plan irregularity, pre-code and post benchmark. The data collection form has a clear structure and is easy to fill in while surveying the buildings in the field. There are 15 types of building listed in the form and the building scores will be based on the type of building as shown in Table 2.

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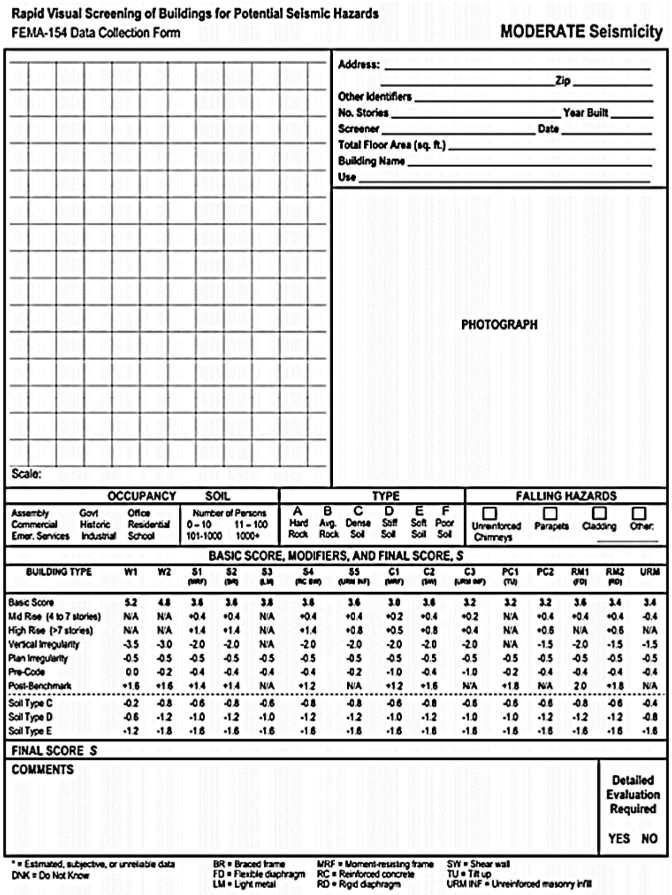

Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA-154 Data Collection Form

MODERATE Seismicity

Address: ______________________ Zip ______
Other Identifiers ______________________
No. Stories ______________ Year Built ______
Screener ______________ Date ______
Total Floor Area (sq. ft.) ______________
Building Name ______________________
Use ______________________

Scale:

PHOTOGRAPH

OCCUPANCY			SOIL		TYPE						FALLING HAZARDS			
Assembly Commercial Emer. Services	Govt Historic Industrial	Office Residential School	Number of Persons 0 – 10 101-1000	11 – 100 1000+	A Hard Rock	B Avg. Rock	C Dense Soil	D Stiff Soil	E Soft Soil	F Poor Soil	☐ Unreinforced Chimneys	☐ Parapets	☐ Cladding	☐ Other: ______

BASIC SCORE, MODIFIERS, AND FINAL SCORE, S

BUILDING TYPE	W1	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM
Basic Score	5.2	4.8	3.6	3.6	3.8	3.6	3.6	3.0	3.6	3.2	3.2	3.2	3.6	3.4	3.4
Mid Rise (4 to 7 stories)	N/A	N/A	+0.4	+0.4	N/A	+0.4	+0.4	+0.2	+0.4	+0.2	N/A	+0.4	+0.4	+0.4	-0.4
High Rise (>7 stories)	N/A	N/A	+1.4	+1.4	N/A	+1.4	+0.8	+0.5	+0.8	+0.4	N/A	+0.6	N/A	+0.6	N/A
Vertical Irregularity	-3.5	-3.0	-2.0	-2.0	N/A	-2.0	-2.0	-2.0	-2.0	-2.0	N/A	-1.5	-2.0	-1.5	-1.5
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Pre-Code	0.0	-0.2	-0.4	-0.4	-0.4	-0.4	-0.2	-1.0	-0.4	-1.0	-0.2	-0.4	-0.4	-0.4	-0.4
Post-Benchmark	+1.6	+1.6	+1.4	+1.4	N/A	+1.2	N/A	+1.2	+1.6	N/A	+1.8	N/A	2.0	+1.8	N/A
Soil Type C	-0.2	-0.8	-0.6	-0.8	-0.6	-0.8	-0.8	-0.6	-0.8	-0.6	-0.6	-0.6	-0.8	-0.6	-0.4
Soil Type D	-0.6	-1.2	-1.0	-1.2	-1.0	-1.2	-1.2	-1.0	-1.2	-1.0	-1.0	-1.2	-1.2	-1.2	-0.8
Soil Type E	-1.2	-1.8	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6

FINAL SCORE *S*

COMMENTS

Detailed Evaluation Required
YES NO

* = Estimated, subjective, or unreliable data
DNK = Do Not Know
BR = Braced frame
FD = Flexible diaphragm
LM = Light metal
MRF = Moment-resisting frame
RC = Reinforced concrete
RD = Rigid diaphragm
SW = Shear wall
TU = Tilt up
URM INF = Unreinforced masonry infill

Figure 2. Sample of standard form by FEMA 154 for data collection

Table 2. Classification of building types

Structural types	Description
W1	Light wood frame, residential or commercial, <5000 square feet
W2	Wood frame buildings, > 5000 square feet
S1	Steel moment-resisting frame
S2	Steel braced frame
S3	Light metal frame
S4	Steel frame with cast-in-place concrete shear walls
S5	Steel frame with unreinforced masonry infill
C1	Concrete moment-resisting frame
C2	Concrete shear wall
C3	Concrete frame with unreinforced masonry infill
PC1	Tilt-up construction
PC2	Precast concrete frame
RM1	Reinforced masonry with a flexible floor and roof diaphragms
RM2	Reinforced masonry with rigid diaphragms
URM	Unreinforced masonry bearing-wall buildings

The formula used to calculate the final score of the RVS is as shown in equation (1).

$$\text{Final Score (S)} = \text{Basic Score (BS)} + \text{Score Modifiers (SM)} \quad (1)$$

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The final score calculated is then grouped according to the five grade damage as shown in Table 3. Grade 1 indicates that the building can be neglected with little damage. Grade 2 is moderately damage where there was a slight structural damage, such as cracks on column frame and wall. Grade 3 suffers heavy damage with cracks in column and beam-column joints of frames at the base and joints of coupled walls. Grade 4 is very heavy damage where a few columns or a single upper floor may collapse. Grade 5 means destructive where the ground floor parts of the building may collapse.

Table 3. Structural score with damage potential [9]

RVS Score	Damage Potential
S < 0.3	High probability of Grade 5 damage; Very high probability of Grade 4 damage
0.3 < S < 0.7	High probability of Grade 4 damage; Very high probability of Grade 3 damage
0.7 < S < 2.0	High probability of Grade 3 damage; Very high probability of Grade 2 damage
2.0 < S < 2.5	High probability of Grade 2 damage; Very high probability of Grade 1 damage
S > 2.5	Probability of Grade 1 damage

3.1 Example of conducted RVS

In this section, an example of how the RVS is performed using information obtained from GIS will be explained. Figure 3 shows one of the building information (denoted by hatching block) using GIS software. In this system, the information such as location of building coordinates, building names and areas are displayed. Figure 4 shows a completed data collection form for moderate seismicity level.

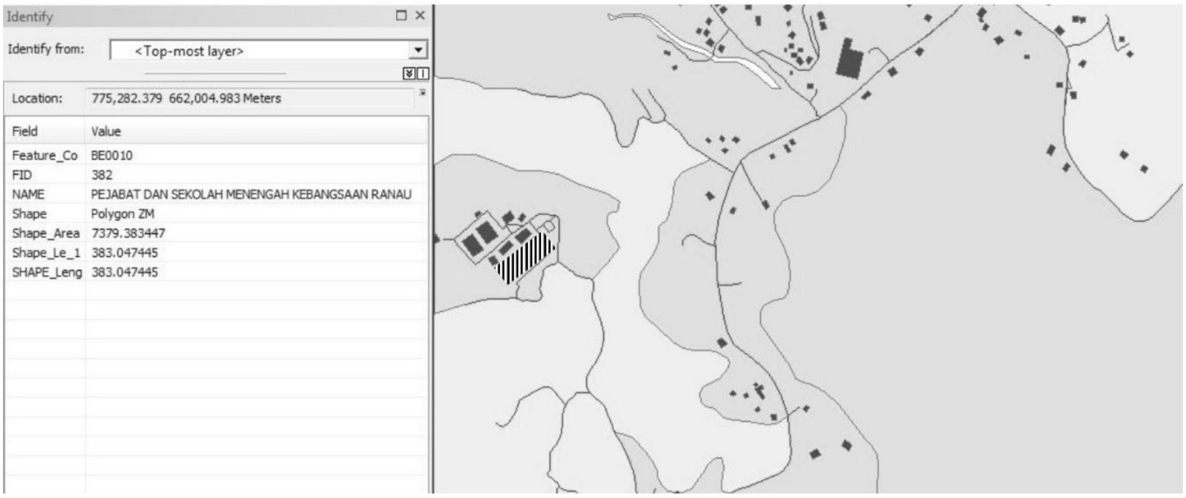

Figure 3. Building information at study area in GIS software

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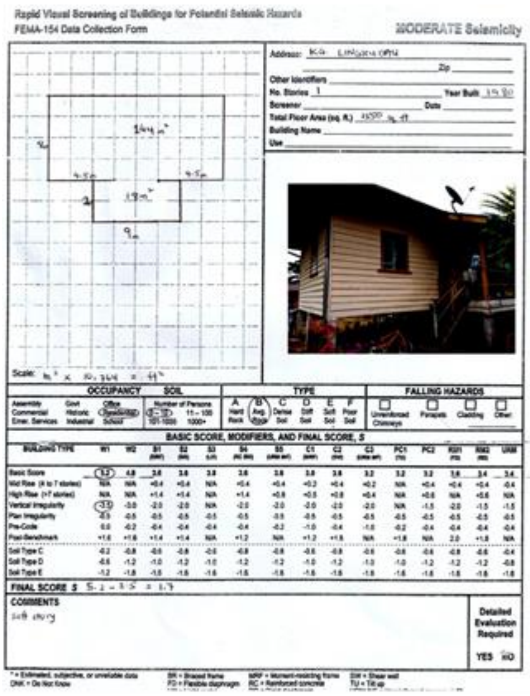

Figure 4. Example of RVS scores for a residential building situated at Kampung Lingkudau, Ranau Township

With reference to the completed form of Kampung Lingkudau, at the top right section of the form is the information of the surveyed building. Photo of the building is attached to facilitate the introduction of the building. The upper left section is the sketch area where the floor map of the building is drawn to calculate the overall floor area. The maximum occupancy load of the building depends on the total floor area. The total floor area of this building is 1550 sq. ft. Thus, this building can only accommodate up to 15 people at a time for a residence where the occupancy load per person is 100-300 sq. ft. The building is situated in an area with soil type B corresponding to average rock. At the bottom part of the form is the basic score, modifier and the final score section. Basic score depends on the type of building and modifier is a factor that will affect the final score such as the number of stories, the presence of vertical and plan irregularity, pre-code or post benchmark, and soil types (A, B, C, D and E). The final score is the sum of both basic score and modifier values. Classification of building type with reference to Table 2 shows that this type of building is in the W1 group (light wood frame with area less than 5000 sq. ft.) where the basic score is 5.2. In the modifier section, this building has a vertical irregularity because it is a soft story house (house was built over garage). In this case, the score modifier is -3.5 and the final score of this building is 1.7. Based on Table 3, this final score is categorized as high probability of Grade 3 and very high probability of Grade 2 level of damages.

In the final phase of this study, the map contains a results of building vulnerability assessment will be generated using GIS [10]. GIS was used in data collection, database development and analysis. In data collection phase, all the data collected will be stored in the GIS. The collected data will be process by digitizing and corrected the incomplete information in the existing map. Digital topography map obtained will be processed accordingly by digitizing and building database. The obtained digital map needs to be digitize to make it more precise and accurate because this research focused on each buildings in town including residential, commercial building, schools, and government buildings such as hospital and government office whereas the maps obtain are more general [11]. Database was developed in GIS using information gather during survey. The analysis information from RVS was shown clearly in GIS interface to ease the community to understand current condition of their buildings.

4. Results and discussion

The Ranau Township was chosen because it has a lot of buildings and infrastructure in many areas. This situation can cause a high-risk level of damage during the earthquake. There are various types of buildings studied including residential, commercial buildings, schools, public amenities, places of worship, emergency services and hospitals. In this study, 245 buildings were screened. As a result, 21 buildings were in grade 3, 11 buildings under grade 2 and other buildings in grade 1, i.e. heavy, moderate and little damages, respectively, as shown in Table 4. Nearly buildings in Grade 2 and 3 are categorized in W1, light wood frame and located near the hill. This location of the survey is hilly where many buildings are located near the hill and this increases the risk of damage during the earthquake. Buildings with Grade 1 level of damage comprise new buildings that are more stable and sturdier reinforced concrete buildings. Since Ranau Township is earthquake prone area, therefore, the authorities have enforced strict guidelines in terms of building construction, for example, buildings to be built should not be more than 4 stories to minimize damage if the earthquake occurs in the future. Barbat et al. (2010) concluded that the vulnerability of the building was due to the old building design code, poor design practices and weak code enforcement. Most of these buildings are in operation and needed to be assessed and upgraded to minimize seismic damage and improve the safety of life [12]

Table 4. Result of RVS

Damage grade	No. of buildings
1	213
2	11
3	21
Total	245

Most of the buildings was non-engineered and suffered considerable damage during the previous earthquake. Therefore, these failure projects require the need to implement seismic vulnerability assessment and suggest possible solutions to overcome such problem. Due to the detailed assessment of the building is complex and expensive task, it cannot be implemented in all buildings in the area and by using RVS as an alternative, objectives can be achieved. S. Ajay Kumar et al. (2017) mentioned that past survey reports show that simple assessment of existing buildings such as RVS should be required [13].

The limitation in this this study includes; i) misunderstanding types of construction or the building structures; ii) limited access to certain buildings; and iii) residents not participating [14]. There are some buildings that cannot be evaluated because the permission required for the survey has been rejected by the building owner due to safety and confidentiality reasons. Improving the performance of new and existing buildings as an example replacing with a durable and sustainable material for seismic vulnerable buildings in the near future may not be a viable option as it will be prohibitively expensive especially in low-to-moderate seismicity region. The replacement cost can be imbalanced with the benefits of risk reduction. Therefore, this study has been conducted where appropriate steps can be taken by referring to the guidelines and risk levels are known to avoid an inefficient allocation of resources. Thus, interactive maps have been created using GIS to facilitate the community to gain information about the safety of their buildings. In addition, the results of this study can create awareness among the public about the safety of their buildings.

5. Conclusion

The results of this study are important to Ranau Township authorities and their community as their building safety guidelines and to reduce the risk of damage if future earthquake occur. For construction with higher risk, they can take preliminary steps on their buildings to make them safer and able to withstand the quake in the future. However, this study can be done more accurately if all buildings can be assessed since RVS is an important method to detect building vulnerabilities. Further analysis and assessment can be carried out to the buildings if the RVS results indicate that they are in high potential damage. Furthermore, this could be an early warning to the residents of the area surveyed about the safety and condition of their buildings. This research also can contribute to town planner, authorities and communities in managing and planning the development of the area in the future. The map resulting can be very useful to the community and local officials to choose suitable locations for future land-use planning and implementation of development based on predictions of seismic risk mapping.

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