Experimental study on a traditional house in Sabah, Malaysia using shake table

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Abstract. Due to destructive earthquake seldom happen in Malaysia, Malaysian have lack of awareness and knowledge towards earthquake disaster. Hence, most of the buildings constructed in Malaysia do not consider lateral loads in the building design. This includes traditional houses in Lahad Datu that located in Sabah state of East Malaysia where moderate earthquakes had occurred in past decades. These houses may be vulnerable towards earthquake due to lack of appropriate lateral resisting system in place. In this paper, the seismic hazard in Sabah is first reviewed. It is followed by an experimental study on a 1/4 scale model of a traditional house. The building is a hybrid structure with the combination of timber main frame and small portion of concrete beam and slab which is a common construction in local community. The model was constructed and tested on uni-directional shake table using the ground motion recorded at KKM seismic station and scaled to 80gal. Seven Linear Variable Differential Transducers (LVDTs) and nine accelerometers were installed to record displacements and accelerations of the model, respectively. The displacements and accelerations at various parts of the model were analyzed and discussed.

1. Introduction

Due to Malaysia was located away from seismically active region, buildings constructed decades ago in Malaysia especially traditional houses do not consider seismic design. Many researches and incidents show that Malaysia is under seismic threat, especially Sabah. Sabah seats on Sunda plate which is near to seismically active tectonic plate, Philippines Sea plate and Indo-Australia plate [¹] as shown in Figure 1. Malaysia is considered low seismicity group, expect for Sabah that is categorized as moderate seismicity [²]. There are few major earthquakes happened in Sabah, for instance, the 2015 Ranau earthquake with the moment magnitude of 6.0 and the 1976 Lahad Datu earthquake with the moment magnitude of 6.2. Lahad Datu has been chosen to be the research location because it is one of the several places in Sabah that is predicted for earthquake happens from year 2015 to year 2022 [³]. Therefore, Lahad Datu might have high potential of earthquake occurrence in near future.

A few decades ago, most of Malaysian engineers did not have any awareness toward earthquake, therefore, the design code for seismic did not fully develop and design of building did not considered earthquake as well. Hence, evaluation of the structure especially traditional building is necessary to be carried out to minimise fatality rate in the next major earthquake. The hybrid structure which is a combination of timber and concrete in Lahad Datu is very common in construction practice. This type of structure might suffer severe damages during earthquake and it was typically built in Lahad Datu.
To evaluate the performance of the structure, shake table test is one of the analysis approaches that could be used. Shake table test can accurately demonstrate the behaviour of the structure however it is more time and cost consumption. Shake table test carried out with various scale specimens have been conducted all over the world to study the performance and behaviour of the timber structure as presented in past studies [4] to [11].

![Figure 1. Regional tectonic setting of NW Boneo and earthquake events near Malaysia [1]](image)

**2. Research Background**

**2.1. Tectonic setting of Sabah**

Sabah is the most seismically active region in Malaysia. It shows the earliest earthquake activities since 1897 [12]. Thousands of earthquakes happened around these plate due to the continuous movement of the India-Australian plate and Philippine-Pacific plate against Eurasian plate [13]. Several faults in Sabah that have been identified as active or potential faults and now have been confirmed that these faults are considering earthquake-generating faults. Some of the faults are found in Ranau-Kundasang area such as Mensaban Fault and Lahad Datu fault.

Sabah sits on South China Sea Basin which is near to the active region of mobile belts in Sulawesi and Philippines. The mobile belts are an oblique westward convergence of the Philippines sea plate against the Sundaland and Indo-Australia plate namely Philippines-Sulawesi-Irian Jaya Mobile Belts as shown in Figure 2. In this region, the moving Philippines sea plate bends the Sunda Trench westward along the Sorong-Matano-Palu-Koro sintral strike-slip faults [14].

**2.2. Historical earthquake events in Sabah**

According to the database of USGS [15], 55 earthquake events were recorded in Sabah starting from 1923 until April 2016 as demonstrated in Figure 3. Most of the past events did not cause any damage because the magnitude of the event was small or the earthquake did not happen at town area. A few recorded disastrous earthquakes happened in Sabah, including the 1951 Kudat earthquake, the 1976 Lahad Datu earthquake, the 2015 Ranau earthquake and so on. The 1976 Lahad Datu earthquake, is by far the strongest earthquake happened in Malaysia, with the recorded magnitude of 6.2, there was
reported that the four storey police complex which was under construction suffered severe structural damages, and was reported that some of the road have visible crack.

In Ranau district, an earthquake was triggered on 5th June 2015. This earthquake affected people in Ranau who felt moderate to strong shake and some structural damage for buildings. Buildings in Ranau obviously did not considered seismic load during design, many structural damages can be observed after the shock. More than 268 structures were affected with mild to moderate damage by this earthquake [16]. Figure 4 presents the damage of a building in a hospital in Ranau area.

![Figure 2. Earthquake data extracted from USGS database [14]](image1)

![Figure 3. Historical earthquake event in Sabah [17]](image2)
3. Research Methodology

3.1. Description of the test model
In this study a model which downscaled into a ratio of 1:4 was constructed and undergone shake table test. The footprint of the model was 2330mm x 2890mm. The total height of the model excluded roof was 1075mm. The model was seated on 18 concrete posts with the size of 50mm in length, 50mm in width and 275mm in height. The total area of the model was 5.18m$^2$, while the concrete section has the area of 1.27m$^2$. Timber used to construct the model consists of the size of 25.4mm x 25.4mm and 50.8mm x 25.4mm. The concrete beam and concrete posts were reinforced by using 7mm steel and 2mm galvanized iron wire, while the concrete slab was reinforced by 50mm spaced wire mesh. Figure 5 shows the plan view of the model and the constructed model. The connections were made by 25.4mm and 38.1mm flat head screws and 38.1mm plain shank nails.

![Figure 4](image_url1)  
**Figure 4.** Structural damage in a hospital building during the 2015 Ranau earthquake [18]

![Figure 5](image_url2)  
**Figure 5.** Plan view of model (left) and the constructed model (right)
3.2. Experimental apparatus
A 3m x 3m uni-directional shake table was used to simulate the ground motion at Heavy Structural Laboratory of the School of Civil Engineering, Universiti Sains Malaysia. It powered by Shimadzu dynamic actuator with the horizontal load capacity of 30 tonnes and strokes of +/-50mm. Seven Linear Variable Differential Transducers (LVDTs) and nine accelerometers were installed to record the displacement and acceleration of the model. Figure 6 illustrates the locations of the instruments in the test.

![Figure 6. Locations of LVDTs (left) and accelerometers (right)](image)

3.3. Important parameters used
Due to the model was downscaled into ratio of 1:4, therefore, some of the parameters have to scale it according to the similitude law. Table 1 shows the scale factors used for test. Ground motion used in this experiment was ground motion recorded at KKM station in Sabah during the 2015 Ranau earthquake. In this paper, the ground motion downscaled into 0.08gal was used for shake table test as displayed in Figure 7.

| Parameters         | Relationship | Model/Prototype |
|--------------------|--------------|-----------------|
| Length             | S₁           | 1/4             |
| Stress             | S            | 1               |
| Elastic Modulus    | Sₑ = S       | 1               |
| Mass               | Sₘ = S * S₁²/S₀ | 1/16           |
| Acceleration       | Sₐ           | 1               |
| Force              | S₉ = S*S₁²   | 1/16            |
| Time               | S₁ = S₁⁰.₅*S₀¹⁰.₅ | 1/√4         |

![Figure 7. Input ground motion for shake table test](image)
4. Results and Discussion

The experimental results are discussed in three subsections, they are comparison of acceleration in different locations, comparison of displacements in different locations and roof drifts as in the following.

4.1. Comparison of accelerations

Figure 7 gives the acceleration recorded at locations A3, A4, A6, A7, A8 and A9. The comparison of acceleration among locations A3, A4 and A7 is displayed in Figure 8. For clearer view, combine plots of the highest acceleration recorded at floor and roof are shown. Location A3 is the acceleration on shake table and it is plotted together with locations A4 and A7. This is to access the degree of amplification of the model at floor and roof level. It can be seen that location A4 has the highest acceleration due to the accelerometers was place on concrete slab which has high rigidity as compared to acceleration at timber decking whereas location A7 has highest acceleration among other roof locations because of the rigidity at location A7 is the highest.

Figure 9 presents the graph of comparison of accelerations among locations A6, A7, A8 and A9. From the graph clearly shows that acceleration at location A7 has the highest magnitude of 5.88m/s² at second 5.52. Other than that, the figure also shows that the acceleration at location A8 was not having the same trend with others locations, this might due to the irregularity in plan of the model.

![Figure 7. Accelerations time histories for locations A3, A4, A6, A7, A8 and A9](image-url)
Figure 8. Comparison of accelerations among locations A3, A4 and A7

Figure 9. Comparison of accelerations among location A6, A7, A8 and A9

4.2. Comparison of displacements

Focus of this study is placed at the roof part where large displacement is observed. Figures 10 and 11 show different displacements are recorded at the same side of the model. Figure 10 shows the comparison of displacement between LVDT4 and LVDT6 while Figure 11 shows the comparison of displacement between LVDT5 and LVDT7. The graphs show that the behaviour of both sides of the model having the same behaviour. Although the behavior is the same, the displacements are still different due to the model is irregularity in plan.

4.3. Drifts at roof level

In this research, the model has plan irregularity, therefore the structure does not move as one, for each particular point, even the points are on same grid of the structure. In this study, the roof displaces more as compared to the ground. Hence, the roof displacement becomes one of the main concerns. Each of the point at roof does not reach maximum displacement at the same time. At second 5.38, LVDT 4 displaces a maximum of -5.94mm. For LVDT 5, it displaces maximum of -5.84mm at second 6.53. While LVDT 6 and LVDT 7 displaces maximum of -6.60 mm and 6.39 mm at second 5.06 and second 5.90, respectively. Table 2 is a summary table for maximum displacement for each LVDT at different
times. From the result obtained, the maximum relative displacements at roof for all locations had exceeded the allowable limits stipulated Eurocode 8 [19] which is 5.375mm.

![Figure 10](image1.png)

**Figure 10.** Comparison of displacement between LVDT4 and LVDT6

![Figure 11](image2.png)

**Figure 11.** Comparison of displacement between LVDT5 and LVDT7

| LVDT | Time (s) | Maximum Displacement (mm) |
|------|---------|---------------------------|
| 4    | 5.38    | -5.94                     |
| 5    | 6.53    | -5.84                     |
| 6    | 5.06    | -6.60                     |
| 7    | 5.90    | 6.39                      |

**Table 2.** Maximum displacement for each LVDT at different time

5. **Conclusion**

Malaysia especially Sabah state is subjected to future earthquake threats. Past moderate earthquakes happened in Ranau and Lahad Datu have demonstrated the structural damage of building. Hence, it is crucial to carry out seismic hazard assessment and performance evaluation to existing structures in
those areas. An experimental study using shake table on a 1:4 scale model has been conducted for the first of its kind in Malaysia. The model comprises a timber-concrete hybrid structure which is a common construction practice in the past in Malaysia. The ground motion of 80gal scaled from the recorded earthquake in the 2015 Ranau earthquake has been used to simulate earthquake scenario. Accelerations and displacements obtained from experimental analysis show that the structure did amplified the lateral load due to low lateral stiffness. Amplification at roof was significant which displacement of joints at corner exceed the allowable displacement according to Eurocode 8. The study has provided useful information of the structural performance for an existing traditional house in Lahad Datu, Sabah under the earthquake excitation.

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References
[1] Shah AA 2015 Scientific Malaysian 11 7–10.
[2] Department of Mineral and Geoscience Malaysia, Study on the seismic and tsunami hazards and risks in Malaysia: Report on the geological and seismotectonic information of Malaysia, 2006.
[3] Cheng K-H 2016 Transactions on Science and Technology 3 (1) 48-58.
[4] Popovski M, Prion HGL, Karacabeyli E 2003 Canadian Journal of Civil Engineering 30 (6) 1089–1100.
[5] Yamada M, Yoshiyuki S, Gotou M 2004 Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, British Columbia, Canada.
[6] Cheng H, Lu X, Lu W, Ni C 2007 Tumu Gongcheng Xuebao/China Civil Engineering Journal 10 41-49.
[7] Christovasilis IP, Filiatrault A, Wanitkorkul A 2008 Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China.
[8] Vieux-Champagne F, Sieffert Y, Grange S, Polasti A, Ceccotti A, Daudeville L 2014 Engineering Structures 69 102–115.
[9] Tomasi R, Sartori T, Casagrande D, Piazza M 2015 Journal of Earthquake Engineering 19 (3) 505–534.
[10] Huang H, Sun Z, Guo T, Li P 2017 Structural Engineering International 27 (2) 246–254.
[11] Meng X, Li T, Yang Q 2019 Engineering Structures 180 (79) 484–493.
[12] Willford GE 1967 Sabah Society Journal 3 136–138.
[13] Tongkul F 1992 Sabah Society Journal 9 (4) 315–322.
[14] Tongkul F 2017 Bulletin of the Geological Society of Malaysia 64 (December) 27–36.
[15] United States Geological Survey, Search earthquake archive, 2016.
[16] New Straits Times 2015.
[17] Tan JP 2016 Universiti Sains Malaysia Undergraduate Dissertation.
[18] Lim YS, Tan JP, Chiw LQ, Chang WH, Lau TL 2017 AIP Conference Proceedings 1892 120015.
[19] European Committee for Standardization, Eurocode 8: Design of Structures for earthquake resistance, 1998.