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SEISMIC ASSESSMENT OF STAFF QUARTERS HOSPITAL RANAU SUBJECTED TO 2015 RANAU EARTHQUAKE USING FRAGILITY CURVE

T. Mohd Azuan[1], A.G. Kay Dora[1*], R. Norazila[1]

[1]Faculty of Civil Engineering, Universiti Teknologi MARA, Pulau Pinang, Malaysia

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A B S T R A C T

The 2015 Ranau Earthquake had caused damage on 23 schools in six different districts in Sabah. Most of structures which has been damaged during the tremors such as staff quarters of government buildings and school buildings were designed to have the soft-storey mechanism, where the design of soft–storey is intended as parking space and hall for assembly. Those structures that were affected by the earthquake also been designed by referring to British Standard design code of practice where there is no consideration been made on earthquake loading. The objective of this paper is to assess the seismic performance of staff quarters Hospital Ranau when subjected to the 2015 Ranau Earthquake using fragility curve. The maximum lateral strength, maximum lateral displacement, stiffness and displacement ductility of the building were also discussed in this paper.

1. Introduction

Soft-storey mechanism is commonly known to have significant difference between the stiffness and the resistance of one floor to other floor of building. These conditions could be present when the first story of a frame structure, also known in some countries as "ground floor" is free of walls, while stiff non-structural walls are present in the upper ones, or when shear walls are located in the upper stories and they do not follow down to the foundations, but they interrupt at the second floor. These architectural features are not easy to be eliminate from architects design criteria where it is function to accommodate parking or hall at open floor area. Although the design gives a series of functional and aesthetic advantages, however, in structural engineering this type of architectural configuration when not treated in a special way could produce severe structural damage and even the collapse of buildings when an earthquake occurs (Teresa, 2012).

2. Problem Statement

Seismic hazard assessment for Malaysia never been done previously due to fact that Malaysian earthquake event in history is not so profound and the nearest distance of earthquake epicenter from Malaysia is approximately 350 km. Generally, earthquake can cause significant damage within 100-200 km radius from the epicenter (Adnan. A et. al, 2005). Before this, East Malaysia has experienced several local earthquakes with low magnitude. The 2015 Sabah Earthquake was latest earthquake that struck East Malaysia (Ranau). The earthquake that occurred on 5th June 2015 at a depth of approximately 10 km with its epicenter approximately 15 km north of Ranau. The earthquake was initially reported Mw 6.0 Scale Richter by the United States Geological Survey (USGS) while the Malaysian Meteorological Department (MetMalaysia) reported the earthquake's magnitude to be 5.9 Scale Richter. The earthquake was the strongest to affect Malaysia since 1976. Tremors were also felt in Tambunan, Tuaran, Kota Kinabalu, Inanam, Kota Belud, Kota Marudu, Kudat, Likas, Penampang, Putatan, Kinarut, Papar, Beaufort, Keningau, Beluran, Sandakan, Kunak, Tawau in Sabah and as far afield as Federal Territory of Labuan, Lawas, Limbang and Miri in Sarawak as well as Bandar Seri Begawan in Brunei.
The 2015 Sabah Earthquake had caused damages on 23 schools in six different districts. Most of structural

*Corresponding author. Tel: 6019-5708781; Fax:604-3822818
*Email address: kaydora@ppinang.uitm.edu.my

damages such as staff quarters and school buildings affected were designed as soft-storey structure, where the design of soft–storey is intended as parking space and hall for assembly. The structure affected by earthquake also been design by referring to British Standard code of Practice (BS8110) where there is no consideration been made on earthquake loading.

Thus, the objective of this paper is to assess seismic performance of staff quarters Hospital Ranau as the prototype building when subjected to the 2015 Ranau earthquake using fragility curve. The maximum lateral displacement, strength, stiffness and displacement ductility were analysed using Ruaumoko2D modeling and also presented in this paper.

3. Research Methodolgy

3.1 Seismic Performance Analysis using Ruaumoko2D

In this study, the building analysis of staff quarters Hospital Ranau was carried out using Orion R18 software program. The analysis was carried out to get static load analysis such as mass node, element and other parameter. These parameters were used as an input data in Ruaumoko 2D program. Figure 1 shows the model of prototype building.

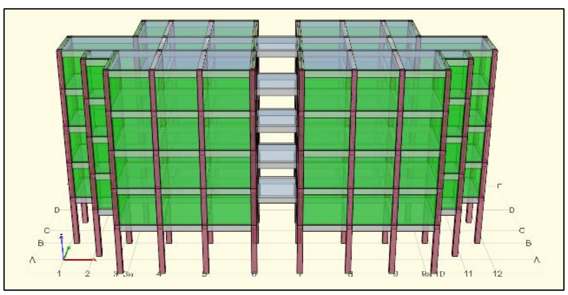

Figure 1: 3D Modeling of the Prototype Building

Table 1 shows earthquake data of 2015 Ranau Earthquake that has been used for model of the prototype building. By considering earthquake record from 2015 Ranau earthquake, seismic performance of the prototype is assessed. The maximum lateral displacement, ductility and stiffness of the building is evaluated using Dynaplot command which incorporated in Ruaumoko 2D programming.

Table 1: Data for 2015 Ranau Earthquake

Magnitude (Scale Richter)	PGA (g)	Depth (km)
6.0	0.12	10

3.2 The Development of Fragility Curve for Staff Quarters Hospital Ranau

The fragility function is used in performance-based design and use to predict the damage state of a structure following an earthquake (Lowes. L. and Li. J., 2009). The conditional probabilities of reaching or exceeding that damage state at various levels of ground motion can be computed to generate a fragility curve for a particular damage state (Hamid. et al, 2010). FEMA 273 (1997) has outlined the probabilistic hazard levels which are frequently used by corresponding with mean return periods. Four performance levels of limit states were identified as Operational, Immediate Occupancy, Life Safety and Collapse Prevention as shown in Table 2.

Table 2: Probabilistic Hazard Levels (FEMA 273, 1997)

Performance level	Earthquake having probability of exceedance	Mean return period (years)
Operational	50% / 50 year	75
Immediate occupancy	20% / 50 year	225
Life safety	10% / 50 year	500
Collapse prevention	2% / 50 year	2500

Some theoretical equations are derived in order to plot the fragility curve for precast beam-column joints for this study. Equation 1 provides the formula of the cumulative probability function to generate the fragility curve (Hamid, 2006) as follow:

$$F(SA) = \Phi\left[\frac{1}{\beta_{C/D}} \ln\left(\frac{S_a}{A_i}\right)\right] \quad (1)$$

where, Φ is standard log-normal cumulative distribution function; S_a is the spectral amplitude (for a period of T=1 sec); A_i is the median spectral acceleration necessary to cause the i^{th} damage state to occur; and $\beta_{(C/D)}$ is the normalized composite log-normal standard deviation which incorporates aspects of uncertainty and randomness for both capacity and demand.

Next, the normalized composite log-normal standard deviation was incorporated with a central limit theorem. This theorem involves the composite performance outcome of log-normal standard deviation and should be distributed equally. Later, the coefficient of variation for log-normal distribution is obtained by deriving this theorem. Kennedy et al. (1980) gives the formula for the coefficient of variation for log-normal distribution as shown in Equation 2 as follow:

$$\beta_{C/D} = \sqrt{\beta_C^2 + \beta_D^2 + \beta_U^2} \quad (2)$$

where, β_C is the randomness of the structural capacity based on the analysis and represented with the value of 0.2 (Duta and Mander, 1998) and β_D is the coefficient of the variable for the seismic demand. An analysis has been carried out by many researchers in New Zealand and has identified that the value for the coefficient of the variable of β_D is taken as 0.52 (Matthew, 2008). While, β_U is the uncertainty associated with the strength reduction factor and the global modeling process, ranging from 0.2 to 0.4 (Hamid and Mohamad, 2013). Based on the site data obtained from the 1994 Northridge Earthquake and the 1989 Loma Prieta Earthquake, the value of $\beta_{(C/D)}$ is recommended to be 0.6 (Duta and Mander, 1998). Finally, after acquiring all the parameters of the Cumulative Probability Function (CPF), the fragility curves of the soft-storey Staff Quarters Hospital Ranau was plotted and analyzed.

4. Result and Discussion

4.1 Excitation versus Time of the Prototype Building

Modeling of staff quarters Hospital Ranau using Ruaumoko 2D program gives out the excitation versus time graph for the structure that shows acceleration of the structure subjected to peak ground acceleration of 0.12g. As shown in Figure 2, the acceleration is high around 6 second to 11 second excitation. The maximum value of acceleration is 7.6 second with excitation 0.12 m/s^2.

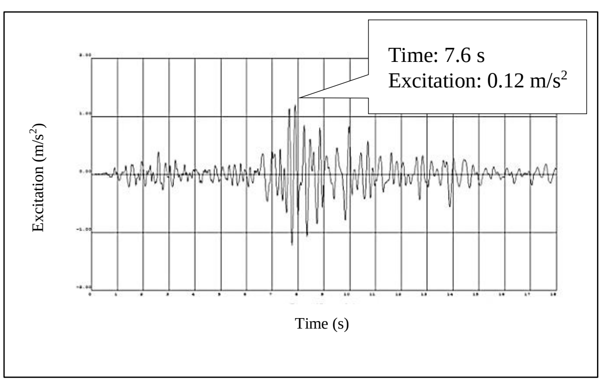

Figure 2: Excitation versus Time for 2015 Ranau Earthquake

4.2 Maximum Lateral Strength and Displacement

The Dynaplot program used to plot hysteresis loops for every node in each level. From hysteresis loops maximum and minimum force, maximum and minimum displacement in pulling and pushing direction of each node was determined. As seen in Table 3, lower floor is carrying more axial load than upper floor. However, the lateral displacement is higher when floor level of a building is increase. Deformation capacity is reasonably high where axial force or strength is low, while at lower floor, deformation is hard to occur because of the present high axial load.

Table 3: Maximum Load and Displacement on Each Floor Level

Floor level	Load (kN)	Displacement (mm)
Level 1	70.85	66.24
Level 2	56.68	74.44
Level 3	40.64	80.80
Level 4	25.19	87.02
Roof	9.482	93.25

4.3 Stiffness and Ductility

Table 4 summarized the stiffness values of each node on each floor of the building. Effective stiffness of the building at pushing direction is higher at lower floor and reduces as floor level of the building increase with difference between 20% to 30%. However, effective stiffness at Roof level is almost twice the effective stiffness of Level 4. Meanwhile, at pulling direction, the effective stiffness of the building is much higher with difference about 30% to 40% between floor level. This is because, the lower floor carried more axial load than upper floor as at upper floor only few floor weight need to be carried, thus created sudden increase in lateral displacement at Roof Level.

Table 4: Lateral Stiffness of Building

Floor Level	Stiffness, K (kN/mm)	
	Push (+ve)	Pull (-ve)
Level 1	1.275	1.057
Level 2	1.009	0.753
Level 3	0.748	0.497
Level 4	0.493	0.286
Roof	0.204	0.101

In addition, relationship of load and displacement used to determine displacement ductility of the structure. Displacement ductility is influenced by peak ground acceleration which is 0.12g and the structural system of the building. As shown in Table 5, the displacement ductility at positive direction is higher compared to the negative direction with difference about 15% to 20%. Eurocode 8 has specified value of ductility should be within 3 to 6 to sustain seismic loading. However, all value of displacement ductility is less than 2 with damping ratio of 5%. This indicated that the building has experienced severe damage at beam-column joint when subjected to moderate or high ground motion.

Table 5: Displacement Ductility of Prototype Building

Floor Level	Displacement Ductility (μΔ)	
	Push (+ve)	Pull (-ve)
Level 1	1.38	1.30
Level 2	1.41	1.19
Level 3	1.46	1.26
Level 4	1.51	1.25
Roof	1.61	1.23

4.4 Fragility Curve for Staff Quarters Hospital Ranau

The first step in developing the fragility curve was the characterization of the damage state of the building based on visual observation of the damage after the 2015 Ranau Earthquake stroke. Damage measurements need to be carried out to categorize the damage state and estimate loss after the earthquakes. For this study, HAZUS®99 (1999) which has been developed by the Federal Emergency Management Agency (FEMA) and the National Institute of Building Science (NIBS) and were used to categorize the damage, characterization of damage state and estimation of losses after an earthquake.

Table 6 shows the visual observation of damage of the soft-storey building after the earthquake. More cracks were observed at the upper part of the columns at the ground floor of the soft-storey building and the area of the beam-column joint. The joint experienced moderate damage but still remains functional after the earthquake. The joint needs to be repaired and strengthened before the building can be occupied. The building could lose its elastic stiffness if the same tremor happened. The displacement ductility analyzed from Ruaumoko 2D was taken as 1.38 for the beam-column joint at the Ground Floor.

Table 7 outlines the relation of damage states with HAZUS descriptor used for seismic assessment purposes as recommended by HAZUS®99 (1999) for the building. Damage State 1 (DS1) was described as "none" by HAZUS and refers to no damage on the specimen, with displacement ductility 0.08. Damage State 2 (DS2) described as "slight" by HAZUS which proved by minor cracking at the specimen, with displacement ductility 0.35. Large cracks, cover spalled and gap openings with displacement ductility 1.38, was indicated as Damage State 3 (DS3) which was described as "moderate" by HAZUS and the damage is repairable. Meanwhile, Damage State 4 (DS4) with ductility 1.80 and Damage State 5 (DS5) with ductility 2.20 were described as "extensive" and "complete", where both of them are categorized as irreparable damage. The DS1, DS2, DS4 and DS5 damage state levels were assigned according to the displacement ductility ratio estimated from the experimental results (Kay Dora, 2014).

Table 6: Damages on Prototype Building Based on Visual Observation

Visual observation	Damage State	Ductility (μΔ)
	3	1.38

Table 7: Damage States and Ductility Ratios according to HAZUS®99

Damage State	HAZUS descriptor	Evidence / Utility	Ductility (μΔ)
1	None	None (pre-yield)	0.08*
2	Slight	Minor cracking	0.35*
3	Moderate	Large cracks, cover spalled, gap openings	1.38**
4	Extensive	Failure of components, fracture of reinforcement	1.80*
5	Complete	Partial / Total collapse	2.20*

*predicted
**modeling result

The combination of Tables 6 and 7 were used to generate Table 8. Based on the ductility factors, Table 8 was created by tagging the color-coding. Green color-coding indicates an operational performance level which was described as none and with slight damage to the specimen (DS1). The green color-coding was tagged with displacement ductility of

0.08. Meanwhile, yellow color-coding was tagged with displacement ductility of 0.35, which means an immediate occupancy performance level (DS2). Yellow color-coding describes slight structural damage with small cracks in columns and beams; hence the building can be entered to remove belongings. The orange (DS4) and red (DS5) color-codings were categorized as life safety and collapse prevention, respectively. Orange color-coding describes moderate structural damage which leads to buckling of reinforcement; meanwhile red color-coding describes large cracks in structural elements leading to near-collapse of the building. For the building, both orange and red color-codings were expected to have displacement ductility values of 1.38 and 1.80, respectively. Table 9 was used to produce the fragility curve for the building. Figure 3 shows the fragility curve which was developed for the Staff Quarters Hospital Ranau using Equations 1 and Equation 2. The fragility curves were shown by the black continuous lines. In the fragility curve, the excitation was based on the PGA 0.12g which happened during the 2015 Ranau Earthquake. It is denoted as the dotted vertical lines which predicted the confidence interval (CI) percentage. Under PGA of 0.12g, the percentage of CI was 26% under the green color-tag and 69% chance of slight damage (yellow color-tag) to the structure. However, the joint has 5% CI under orange color-tag and would suffer moderate structural damages and also buckling of reinforcement bars. The CI values exhibited that the Staff Quarters Hospital Ranau would still have higher chances to sustain under immediate occupancy (yellow color-tag) when subjected to PGA = 0.12 g. The building would still safe for occupancy and suffers slight damage.

Table 8: Color-coding and Performance Levels

Damage State	Tag color	Performance level	Description of damage level	Displacement Ductility (μ_Δ)
DS1	Green	Operational	Fine cracks in plaster; building occupiable.	0.08
DS2	Yellow	Immediate occupancy	Small cracks in columns and beams of frames; initial spalling of concrete cover; the building can be entered to remove belongings.	0.35
DS3	Orange	Life safety	Moderate structural damage; cracks in columns and beam-column joints; more spalling of concrete cover.	1.38
DS4, DS5	Red	Collapse prevention	Large cracks in structural elements; fracturing of the longitudinal bars; no stability of structures; the building near collapse and cannot be entered.	1.8

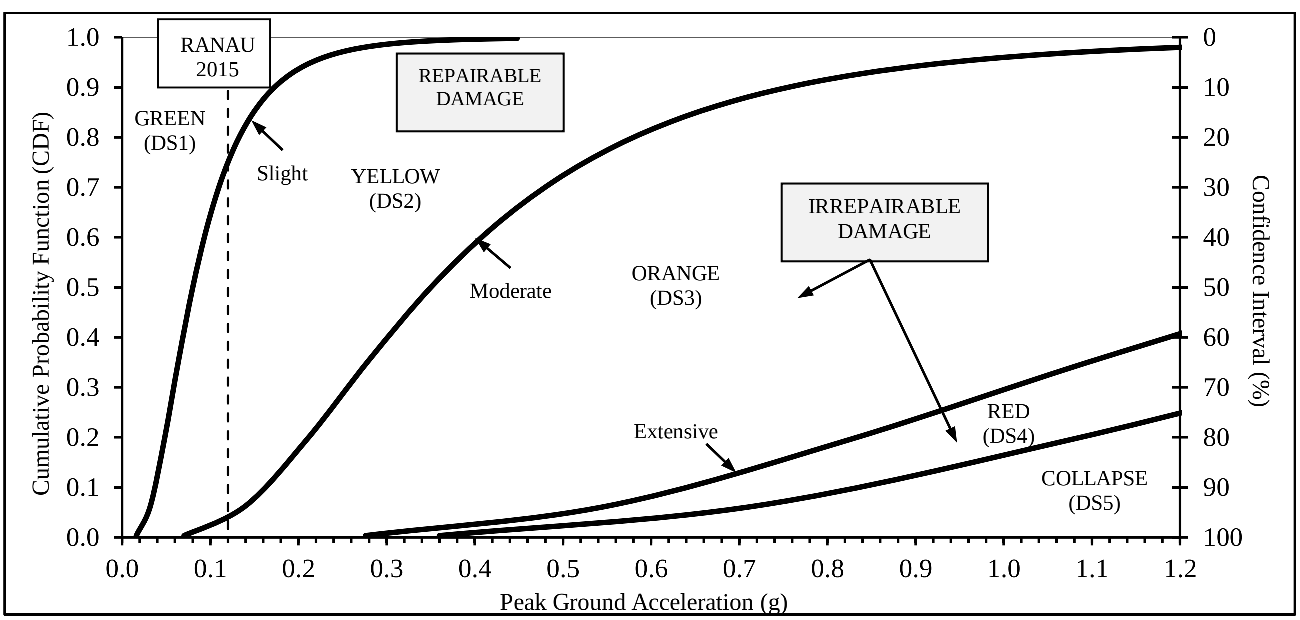

Figure 3: Fragility Curves for the Staff Quarters Hospital Ranau

5. Conclusions

From the analysis of Ruaumoko2D and Dynaplot Program, Level 1 is the most critical part of Staff Quarters Hospital Ranau when subjected to the 2015 Ranau Earthquake. This concluded that the soft-storey building would experience damage at lower floor. This is proved by on-site observation which showed moderate damages at beam-column joint area at Level 1 during the earthquake. However, based on the fragility curve analysis, the building would still safe for occupancy and suffers slight damage. In other words, the building still have chanced to be repaired and strengthened using an appropriate retrofitting method, so that it can be reoccupied after three to six months of retrofitting.

References

Adnan, A., Hendriyawan, Marto, A. & Irsyam, M. (2005).*Seismic Hazard Assessment For Peninsular Malaysia Using Gumbel Distribution Method*. JurnalTeknologi 42(B), Universiti Teknologi Malaysia, pp.57-73.

Dutta, A., & Mander, J. B. (1998).*Seismic Fragility Analysis of Highway Bridges.* Paper presented in the INCEDE-MCEER Center-to-Center Project Workshop on Earthquake Engineering Frontiers in Transportation Systems, pp. 22-23.

Hamid, N.H., Hamzah, S.H., Rosli, M.F.I. & Amin, N.M. (2010). *Seismic Performance on Multi-Storey Precast Buildings (IBS) in Malaysia Subjected to Long-Distant Earthquake Excitation.* Research Report for the Research Management Institute, UniversitiTeknologi MARA Shah Alam, Malaysia.

Hamid, N.H.A. & Mohamad, N.M. (2013). *Seismic Assessment of a Full-Scale Double-Storey Residential House using Fragility Curve.* Procedia Engineering, 54, pp. 207-221.

Hamid, N.H.A. (2006). *Seismic Damage Avoidance Design of Warehouse Buildings Constructed Using Precast Hollow Core Panel*. Doctoral Thesis, University of Canterbury.

Kay Dora A. G. *Seismic Performance of Full-Scale Precast Beam-Column Joint with Corbels under Inplane Lateral Cyclic Loading* (2014). Unpublished Doctoral Thesis, Universiti Teknologi MARA.

Kennedy, R. P., Cornell, C. A., Campbell, R. D., Kaplan, S., & Perla, H. F. (1980). *Probabilistic Seismic Safety Study of an Existing Nuclear Power Plant*. Nuclear Engineering and Design, 59(2), 315-338.

Lowes, L. & Li, J. (2009).*Fragility Curve for Reinforced Concrete Moment Frames*. Paper presented at the ATC & SEI 2009 Conference on Improving the Seismic Performance of Existing Buildings and Other Structures.

Matthews J.G. (2004). *Hollow-core Floor Slab Performance following a Severe Earthquake.*Ph.D Thesis, Christchurch, New Zealand: Department of Civil Engineering, University of Canterbury.

Teresa, L. Guevara-Perez (2012). *"Soft Story"and "Weak Story" in Earthquake Resistant Design: A Multidisciplinary Approach.* Proceedings of 15th World Conference On Earthquake Engineering.