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SEISMIC PERFORMANCE OF REINFORCED CONCRETE SCHOOL BUILDINGS IN SABAH

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A R T I C L E I N F O

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A B S T R A C T

One of the methods to evaluate the seismic performance is the nonlinear time history analysis where the structural models are imposed to the real or artificial earthquake ground motion records. Current practice only considers single earthquake in the analysis. However, in reality the earthquake tremors are always occur multiply. Ranau earthquake which occurred on 5th June 2015 was also not a single earthquake, but followed by several number of aftershock. This project investigated the performance of reinforced concrete school buildings in Sabah when subjected to multiple earthquakes. A total number of 3 models of school building which have 2, 3 and 4 storeys has been used for the project. . All models have been designed based on BS8110 to represent the existing reinforced concrete school buildings. A total of 7 ground motions for both single and multiple earthquake has been considered in nonlinear time history analysis conducted on all models. All models are assumed to be located in moderate seismic region in Sabah, Malaysia. Based on a series of nonlinear time history analyses, this study concludes that the action of multiple earthquake has contributed around 55% to 107% higher interstorey drift ratio compared to the single earthquake. Thus, multiple earthquake should be considered in order to design new buildings as well as the evaluation for maintenance and rehabilitation for existing buildings.

1. Introduction

A study related to seismotectonic setting of Malaysia conducted by Jabatan Mineral and Geoscience Malaysia (JMGM) has found that Malaysia is considered as a country with low seismicity except for Sabah state (MOSTI, 2009). The Ranau earthquake on 5th June 2015 with a magnitude of M_w5.9 has been recorded as the strongest tremors to affect Malaysia for the last 45 years. The damages occurred on reinforced concrete (RC) buildings due to that event are presented in previous publication (Adiyanto, 2016; Adiyanto et al., 2017). This tragedy has given a very big challenge to the nation especially in construction industry to come out with analysis and design of structure against seismic loading.

Occasionally, analysis of seismic performance based on Eurocode 8 (2004) and FEMA 368 (2000) only considered single earthquake for every single structure. Nevertheless, the nature of earthquake events shows that most of the earthquake events are occurred multiply. It is always seen that there will be certain number of tremors after the first one. This nature is called as multiple earthquake (Amadio et al., 2003; Hatzigeorgiou and Liolios, 2010).

The structures might experience minor to major damage after the main earthquake event. Any maintenance or rehabilitation work on the structure is impractical due to time constrain. Thus, it is important to take attention that the not yet repaired structure may experience greater damage which can leads to collapse when subjected to the aftershock earthquake event. According to Hatzigeorgiou and Liolios (2010), the interstorey drift ratio (IDR) of frame is higher when subjected to multiple earthquake compared to the single

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one. The 2015 Ranau earthquake also demonstrated that more than hundreds tremor was occurred after the first tremor (MMD, 2015). Table 1 shows the list of selected tremors during the 2015 Ranau earthquake.

Table 1: List of selected tremors during 2015 Ranau earthquake (MMD, 2015)

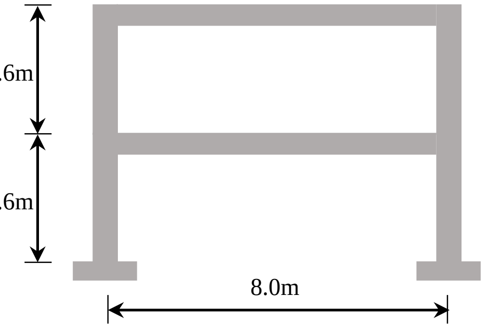
Date	Time	Location	M_w
5/6/2015	7.15am	Ranau	6.0
5/6/2015	7.28am	Ranau	3.6
5/6/2015	9.51am	Ranau	3.9
5/6/2015	12.05pm	Ranau	4.0
5/6/2015	2.40pm	Ranau	3.0
5/6/2015	1.45pm	Ranau	4.5
5/6/2015	6.58pm	Ranau	3.2
5/6/2015	10.36pm	Ranau	3.3
6/6/2015	1.32am	Ranau	3.7
6/6/2015	2.19pm	Ranau	3.4

In this paper, the seismic performance in term of IDR of multi-storey single bay frame is presented. A total of three typical RC school model which has two, three and four storeys have been designed based on BS8110 (1997) to represent the existing RC school buildings. All models are assumed to be built in Sabah which is loacted in the moderate seismic region as depicted in the Malaysia earthquake hazard map presented by Adnan et al., (2009).

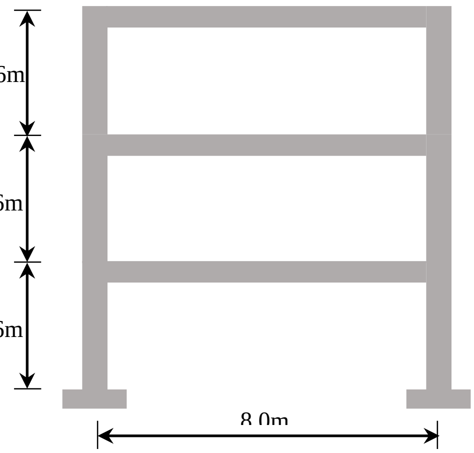
2. Methodology

In this study, the method used to investigate the effect of multiple earthquake on seismic performance is the nonlinear time history analysis (NTHA) by using SAP2000 software. Three set of multi-storey and single bay models had been adopted from the typical RC school building in Sabah, Malaysia. The frame is regular in plan where the storey height and beam span is equal to 3.6m and 8.0m, respectively as shown in Figure 1.

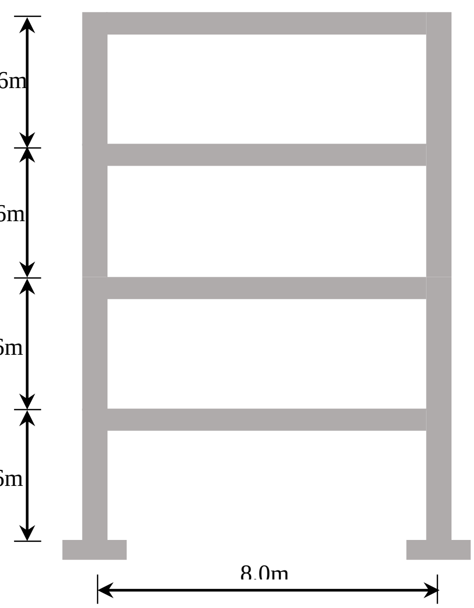
The school buildings have been used as model in this study because school building is an important structure to survive during the earthquake event. During such disaster, the RC school building will be very important for evacuation and temporary shelter purpose. The structure must survive with no or minor damage which is not affecting its function. The RC design for all models has been performed based on BS8110 (1997) which is currently used for design the RC buildings in Malaysia. The concrete compressive strength, f_{cu}=30 N/mm^2 and yield strength of steel, f_y= 460 N/mm^2.



(a) Two storey single bay RC school frame



(b) Three storey single bay RC school frame



(c) Four storey single bay RC school frame

Figure 1: Elevation view of multi-storey single bay RC school models

This study consider the Type 1 elastic response spectrum recommended by Eurocode 8 (2004) which compatible for Soil Type D for seismic hazard in Sabah. To represent the moderate seismic region in Sabah, the reference peak ground acceleration, a_{gR} equal to 0.12g had been used to develop the elastic response spectrum as proposed by Adnan et al., (2009).

In order to perform the NTHA, two set of ground motions has been prepared namely single and multiple ground motion. Each cases consist of 7 number of ground motions as listed in Table 2. All ground motions has been scaled by using CUMBIA program (2007) to match the elastic response spectrum in Sabah, Malaysia. Then, 3 single earthquake ground motions has been randomly combined to generate 1 artificial multiple earthquake ground motion. A total of 7 artificial multiple earthquake ground motions has been generated. Every artificial multiple earthquake ground motion generally consist of fore-shock, main-shock and after-shock as used in previous studies (Hatzigeorgiou, 2010; Ade Faisal et al., 2013; Adiyanto and Majid; 2014). Figure 2 and Figure 3 present the typical profile of both single and multiple ground motions, respectively.

Table 2: List of selected ground motions (PEER, 2013)

No	Event	Component	PGA (g)	M_w
1	Imperial Valley	HE03140	0.266	6.0
2	Imperial Valley	HE03230	0.221	3.6
3	Loma Prieta	A02043	0.274	3.9
4	Loma Prieta	A02123	0.220	4.0
5	Chi-Chi	CHY026N	0.066	3.0
6	Chi-Chi	CHY026W	0.076	4.5
7	Chi-Chi	CHY032W	0.088	3.4

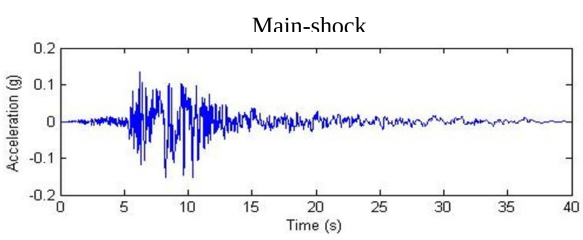


Figure 2: Typical profile of single ground motion

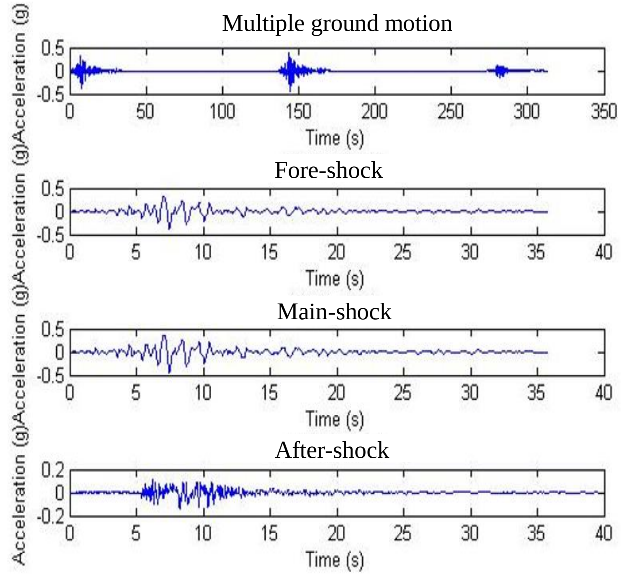


Figure 3: Typical profile of multiple ground motion

3. Result and Discussion

In this study, the seismic performance of all RC school model in presented in term of IDR. The latter can be defined as the relative displacement between two adjacent storey, divided by its height. It is presented as percentage of its column height. As explained in previous section, a total of 7 number of ground motions for each single and multiple earthquake had been used in NTHA. Therefore, the magnitude of IDR presented here is the mean value (denoted as IDR_{mean} afterward) resulted form all 7 ground motions.

Figure 4 presents the distribution of IDR_{mean} along the height of the two storey RC school model when subjected to single and multiple earthquakes. It can be clearly seen that the IDR_{mean} caused by multiple earthquake is higher compared to single earthquake. The IDR_{mean} caused by multiple earthquake is around 0.116%, which is almost double than that caused by single earthquake (0.056%). This is caused by stiffness and strength degradation which occurred on the structure when subjected to the first tremor. Then, the unrepaired structure undergo larger lateral displacement when subjected to the second and third tremors. This result in higher IDR_{mean}. For this model, the maximum IDR_{mean} occurred at the top storey.

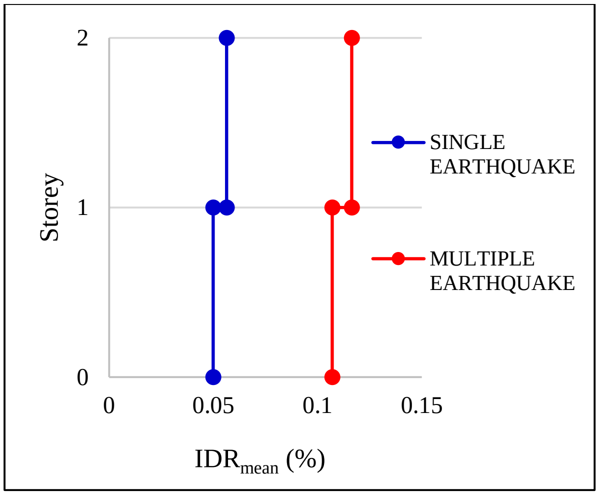


Figure 4: Distribution of IDR_{mean} for two storey RC school model

Figure 5 presents the distribution of IDR_{mean} along the height of the three storey RC school model when subjected to single and multiple earthquakes. For this model, similar pattern of result is obtained where the magnitude of IDR_{mean} caused by multiple earthquake is larger compared to single earthquake. The maximum IDR_{mean} caused by multiple and single earthquake is equal to 0.084% and 0.051%, respectively. This mean that the multiple earthquake had caused the increment around 65% to the magnitude of IDR_{mean}. This significant increment might cause greater damage on the structural system. For the three storey RC school model, the maximum IDR_{mean} occurred at the bottom storey for both cases of single and multiple earthquake. This is associated with low strength for column at bottom storey. This result will lead to soft-storey failure mechanism (Elnashai and Sarno, 2009).

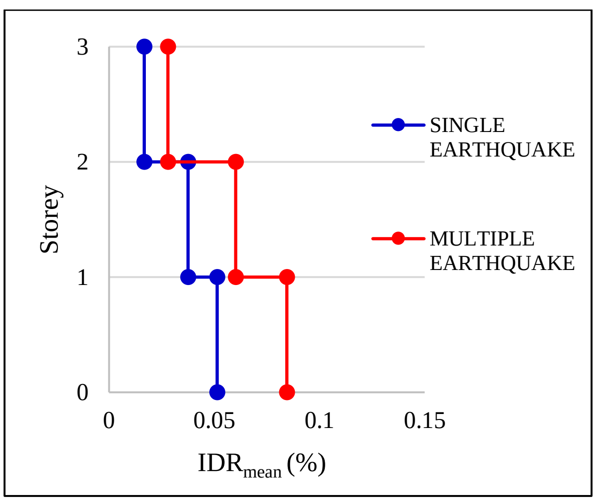


Figure 5: Distribution of IDR_{mean} for three storey RC school model

The distribution of IDR_{mean} along the height of the four storey RC school model when subjected to single and multiple earthquakes is presented in Figure 6. As what can be seen for the two and three storey RC school models, the four storey RC school model also presents similar pattern of result for the IDR_{mean}. The magnitude of IDR_{mean} caused by multiple earthquake is clearly higher than the single earthquake. For this model, the maximum IDR_{mean} caused by multiple and single earthquake is equal to 0.084% and 0.054%, respectively. Hence, the multiple earthquake had caused the increment around 55% to the magnitude of IDR_{mean}. As seen in Figure 6, the maximum IDR_{mean} occurred at the lower storey for both cases of single and multiple earthquake. This is also associated with low strength for column at that storey. As for the case of three storey RC school model, the four storey RC school model is also exposed to the soft-storey failure mechanism.

The seismic performance in term of IDRmean for all model shows that the multiple earthquake tends to induce higher IDRmean compared to single earthquake. This result is in good agreement with previous studies (Hatzigeorgiou, 2010; Ade Faisal et al., 2013; Adiyanto and Majid; 2014). Therefore, the multiple earthquake should be considered in analysis and design even for medium seismic region like in Sabah.

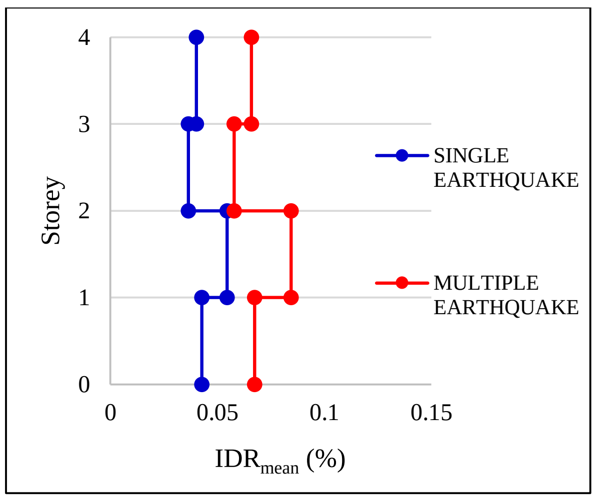


Figure 6: Distribution of IDR_{mean} for four storey RC school model

4. Conclusions

This study present the evalution of seismic performance on the two, three, and four storey RC school model in Sabah. All models has single bay as typical RC school building in that region. All models had been designed without seismic consideration by referring to BS8110

(1997) to represent the existing RC school building. The NTHA has been conducted on all model by using SAP2000 computer software. A total of 7 ground motions for each single and multiple earthquake has been used in the NTHA. Based on analysis, the multiple earthquake tends to increase the magnitude of IDRmean around 55% to 107% higher than the single earthquake. It can be concluded that the occurance of continuous tremors as the nature of earthquake cannot be ignored in process of analysis and design for safer earthquake resistance structures.

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