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Soft Storey Effects on Plastic Hinge Propagation of Moment Resisting Reinforced Concrete Building Subjected to Ranau Earthquake

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Abstract. On 5th June 2015, a moderate earthquake with Mw 5.9 hit Ranau, resulted in damages of the existing non-seismically designed buildings, such that 61 buildings, including mosques, schools, hospitals and Ranau police headquarters were suffered from different level structural damages. Soft storey irregularity is one of the main reasons of the building damage. This study is to investigate the soft-story effect on the propagation path of plastic hinges RC building under seismic excitation. The plastic hinges formation and seismic performance of five moment resisting RC frames with different infill configurations are studied. The seismic performance of building is evaluated by Incremental Dynamic Analysis (IDA). Open ground soft storey structure shows the lowest seismic resistance, collapses at 0.55g pga. The maximum interstorey drift ratio (IDR_{max}) in soft storey buildings ranging from 0.53% to 2.96% which are far greater than bare frame ranging from 0.095% to 0.69%. The presence of infill walls creates stiffer upper stories causing moments concentrate at the soft storey, resulting the path of plastic hinge propagation is dominant at the soft storey columns. Hence, the buildings with soft storey are very susceptible under earthquake load.

INTRODUCTION

Malaysia lies on a largely seismically stable, whereby it is situated entirely on the Sunda tectonic plate, and bounded between Australian Plate and Eurasian Plate in the west of Peninsular Malaysia, and the Philippine Sea Plate and Eurasian Plate at Borneo Although Malaysia is not located at seismic prone area, Peninsular Malaysia is accustomed to light seismic movement caused by earthquakes along the Sumatran islands of Indonesia, generated mainly by the Great Sumatran fault and Sunda megathrust. The Borneo Malaysia states, especially Sabah, which is situated in the north part of Borneo, is more prone to moderate interplate and intraplate earthquakes due to its location nearer to the Ring of Fire. Sabah receives compression forces from the interaction of three main tectonic

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plates [1]. The Philippine Plate and Pacific Plate are running westwards at a rate of about 10cm per year, colliding with the Eurasian Plate, as shown in Fig. 1.

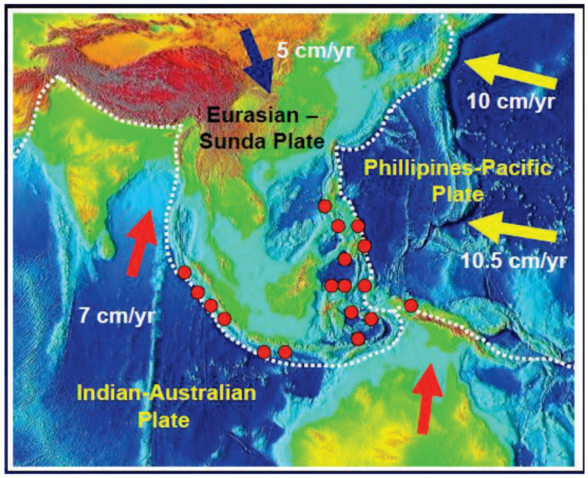


FIGURE 1. The interaction between the three tectonic plates nearby Malaysia. [2]

Ranau is one of the famous attractions in Sabah as it is the place where the highest mountain of south East Asia, Mount Kinabalu stands. There are at least two active regional fault zones intersect each other in the area between Ranau and Mount Kinabalu such as the Mensaban fault and Lobou-lobou fault. Figure 2 shows active faults in Ranau. These fault zones are active and past earthquakes have resulted in extensive damage to infrastructures in the area, specifically to schools and teachers' quarters. Most of the epicenters are concentrated on the east coast of Sabah, around Lahad Datu and Ranau area. These epicenters are mainly shallow depth (<70km) whereas those offshore tend to be intermediate (70-200km) in depth.

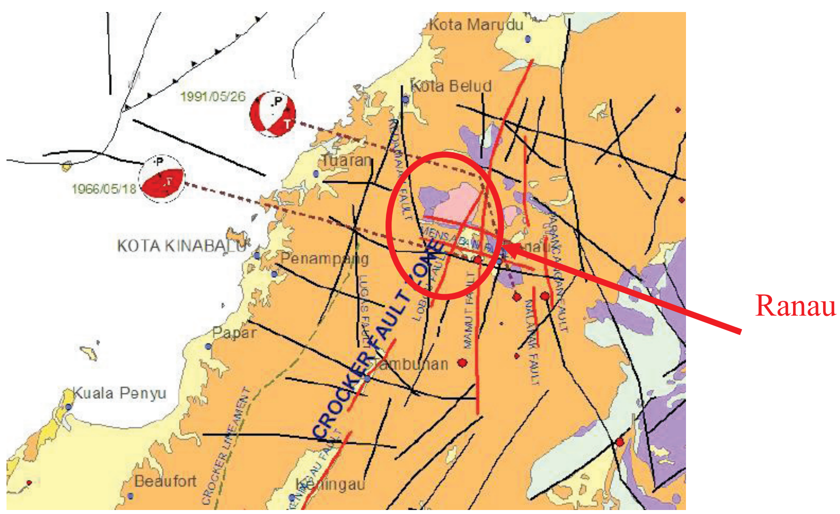


FIGURE 2. Active fault systems in Ranau area. (MOSTI, 2009)

Earthquakes in Sabah's Ranau district that exceed magnitude M_w 5.0 occur on an average of once every 24 to 25 years [3]. Earthquakes between magnitude 5.0 and 5.9 are classified as "moderate" quakes. On 5th of June 2015, an earthquake of magnitude M_w 5.9 rattled Ranau, Sabah at 7:15am, Malaysia Meteorological Department reported. According to the Malaysia Meteorological Department, the quake's epicenter was located 16 km northwest of Ranau, Sabah. The earthquake epicenter is located 6.1° N, 116.6° E, depth of 10 km under Mount Kinabalu. The hazard has resulted in some damages on structures such that 61 buildings, including mosques, schools, hospitals and

Ranau police headquarters were damaged according to Public Works Department. When a soft storey building is subjected to seismic load, the effect concentrates on the weakest level of the building, whereby the level experiences the total displacement, which results in higher damage to the building. The effect induces a critical number of plastic hinges which appear on certain elements, which may lead the structure to failure.

The study focuses the analysis of soft storey effect on building structure subjected to seismic load. The selected building is a 4-storey RC school quarter soft-story with open ground floor at Ranau and only 2-D framings were considered in structural analysis.

MODELING

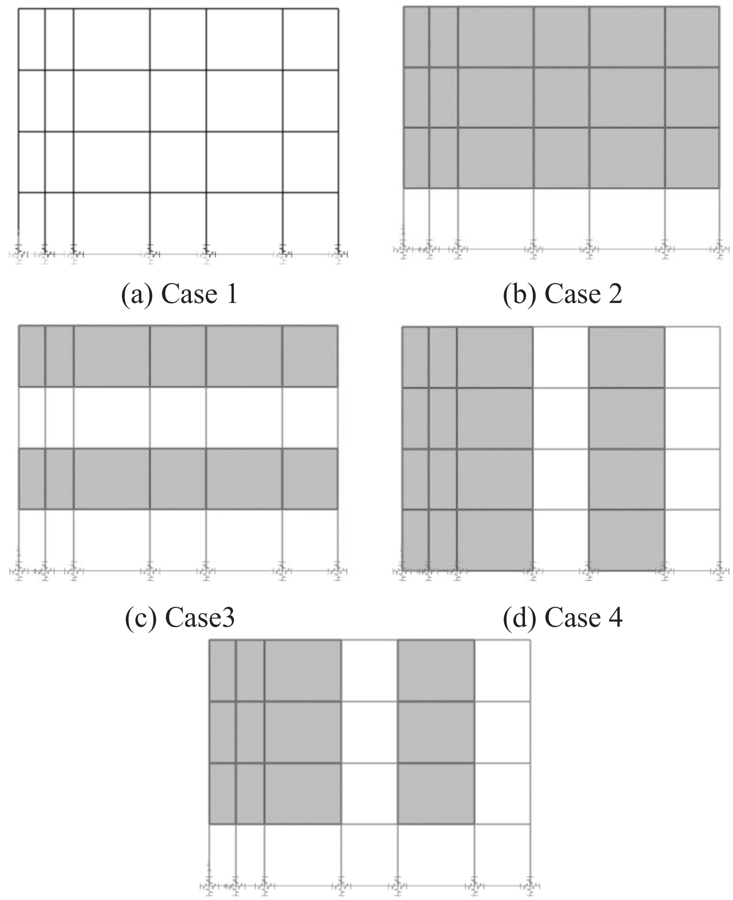
Nonlinear dynamic time history analysis is a powerful method for the study of structural seismic response. It provides the dynamic response of a structure with respect to a particular ground motion time history record by analysing the scaled seismic load according to current building codes. The time history is a series of ground motion data, generally is expressed in unit of acceleration (g), with equal time intervals and the analysis is performed using a stepwise procedure usually referred as direct integration [4-6]. As this study focuses on the soft storey effect in non-seismic building, the structure selected is a 4-storey RC building, which is the quarter of SMK Ranau. The soft storey building consists of an open ground storey. Besides, the existing structure was designed according to BS8110 [7] as it is located in Malaysia. A typical two-dimensional frame was selected as the building model and the configuration and dimension of the frame were set accordingly. Five models with different infill configurations used in the analysis as shown in Fig. 3.

According to EC8 [8], moment-rotation relationship has to be established by a bi-linear or tri-linear relationship before deterioration of strength in order to prepare a simple yet adequate structural model. It is preferred to apply tri-linear relation to get more accurate results although bilinear is accepted and it is the minimum requirement in EC8. CONSEC was used to determine the bi-linear moment-curvature hinge properties of the structural members. The bi-linear moment-curvature was converted to tri-linear moment- rotations by applying equations suggested by Dolsek [10]. The infill wall property is defined as brick wall with the density of 23 kN/m^3 and elastic modulus of 14 MPa. The spring stiffness for each pile group was determined based on FEMA-356 [11]. The spring stiffness in this case is governed by size of pile caps, depth of pile cap and number of piles in a pile group.

The ground motion used in this study is Ranau earthquake that happened at 7:15am local time on 5^{th} of June, 2015. The ground motion record was obtained from Malaysia Meteorological Malaysia (MMD). Table 1 shows the summary of Ranau earthquake ground motion.

NONLINEAR AND TIME HISTORY

The configuration of masonry infill has significant effect on global stiffness of a building. The stiffness of a building strongly influences dynamic response of the building to ground shaking. The stiffness of a building is strongly related to the period of the structure, the distribution of loads within the structure, and the deformation demands. From TABLE 2, it can be observed that infill configuration of a frame has large impact on the fundamental period of the structure.



(e) Case 5

FIGURE 3. Five storey RC frames to be considered in SAP2000: (a) Case 1, (b) Case 2, (c) Case 3, (d) Case 4 and (e) Case 5

TABLE 1. Summary parameters of the Ranau ground motion record for nonlinear time history analysis

Earthquake	Year	Magnitude (M_w)	PGA (g)	Focal Depth (km)	Time Step	No of Time Step	Epicenter Coordinate
Ranau	2015	5.9	0.124	10.0	0.01	4000	5.987, 116.541

TABLE 2. Fundamental period of each case study at the PGA it collapses.

Case	Fundamental Period, T_1 (s)	Structure fails at PGA (g)
Case 1	0.374	0.78
Case 2	0.486	0.55
Case 3	0.417	0.62
Case 4	0.123	1.42
Case 5	0.388	0.52

It is noted that the configuration of infill walls influences stiffness of a building significantly. The infill distribution in soft storey frames (Case 2, Case 3 ad Case 5) results in variation in stiffness due to irregularities in vertical direction; thus reducing global stiffness in these frames. As a result, the fundamental periods of these frames are higher than Case 1 and Case 4. Bare frame (Case 1) and frame with filled vertical panel (Case 4) has a uniform vertical global stiffness. Case 4 shows the integrity of infill wall in vertical direction plays a significant role in increasing stiffness of a building. From Fig. 4, it is noted that the building consists of soft open ground storey (Case 2, Case 3 and Case 5) exhibits torsionally-unbalanced behaviour which rotates about y-axis significantly. For building which has fully filled vertical panel, the frame deforms in a more uniform shape as a result of the vertical local stiffness is consistent in each storey.

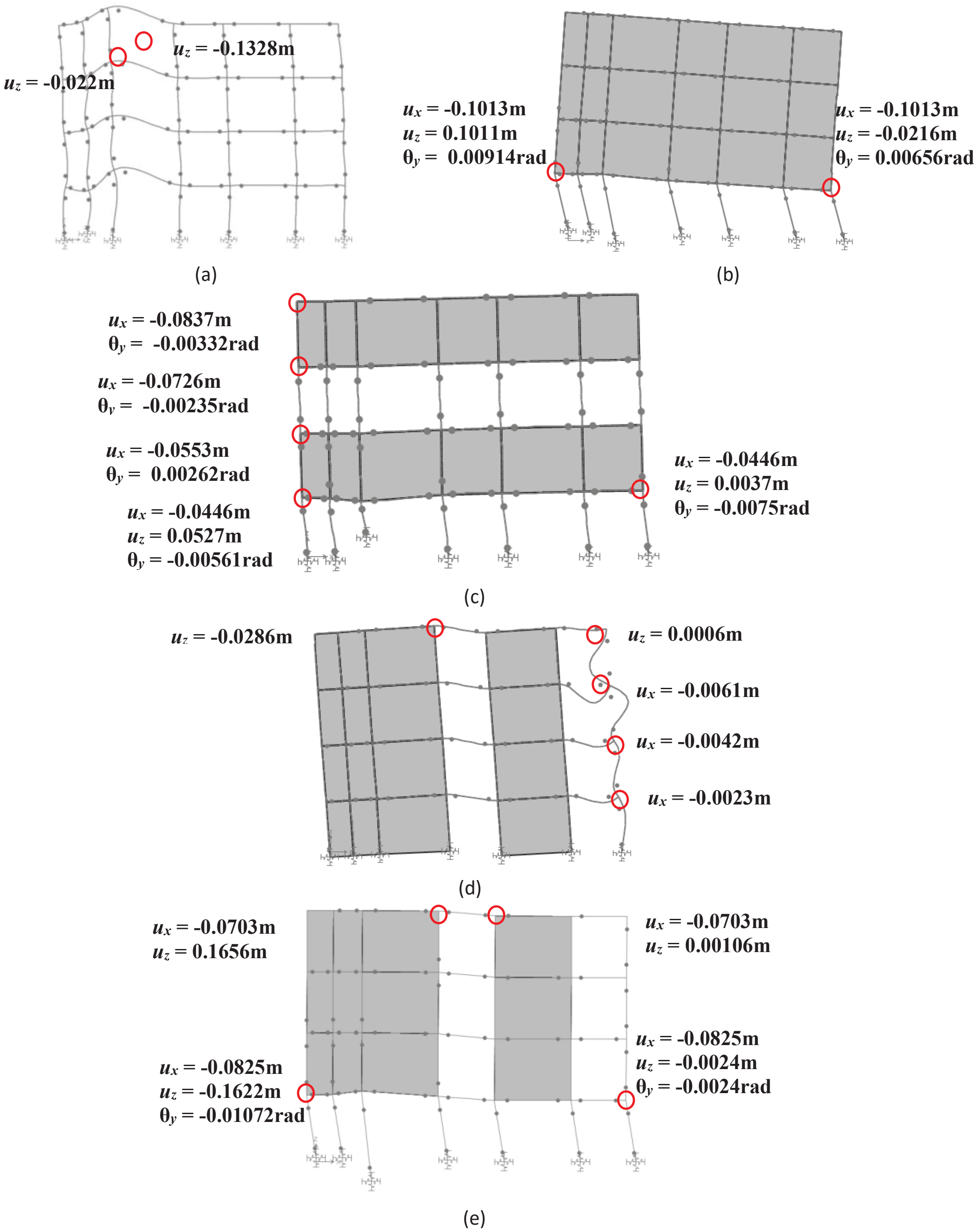


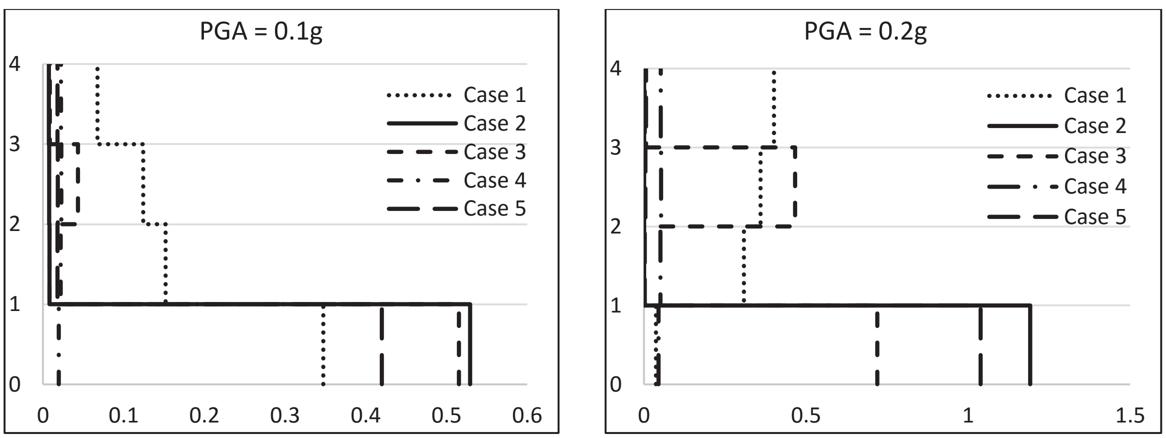
FIGURE 4. Maximum deformation of nonlinear time history analysis for (a) Case 1, (b) Case 2, (c) Case 3, (d) Case 4 and (e) Case 5

INTERSTOREY DRIFT RATIO (IDR)

The IDR of frame can be calculated using the formula as follows:

$$IDR = \frac{D_{i+1} - D_i}{H} \times 100\% \quad (1)$$

where D_i and D_{i+1} refer to the i-th and i+1-th storey horizontal displacement and H is storey height. For ordinary buildings such as residential building and working office in Ranau, the PGA for 10 % probability of exceedance (PE) for 50 years used is 0.124g. Building consists of soft storey shows maximum drift at a particular storey and its IDR is much higher than the IDR of other stories as shown in Fig. 5. For the building with soft storey, the increment of IDR_{max} is high when ground intensity increases. Hence a minor increase of ground motion intensity significantly increases the storey drift. The results from the research by Dolsek and Fajfar [8] also clearly demonstrated that soft storey mechanisms in a four storey building using 1999 Kocaeli (Turkey) earthquake data, that all damages are concentrated in the bottom storey as a result of extreme deflections at the storey. The results also deduce that global stiffness influences IDR in the frame without infill walls. But, local stiffness has greater impact on IDR if infill walls are present.



(a) (b)

FIGURE 5. IDR graph of all case studies at (a) PGA = 0.1g and (b) PGA = 0.2g.

INCREMENTAL DYNAMIC ANALYSIS (IDA)

Figure 6 shows the IDA curves for all case studies. In this study, PGA is used as the intensity measure of seismic action in the IDA instead of the first mode spectral acceleration, Sa (T1). The results reveal that soft storey has significant effect on seismic performance of a building. Soft storey buildings in Case 2, Case 3 and Case 5 have lower seismic capacity than bare frame in Case 1 and the vertically filled frame in Case 4. The configuration of infill is proven to have a remarkable effect on stiffness of frame. Local stiffness contributed by infill resulting in plastic hinges concentrate at the storey without infill as the columns at soft storey are overstressed compared to other structural members. This is portrayed in Fig. 6(b), Fig. 6(c) and Fig. 6(e), where plastic hinges developed in soft storey columns when ground intensity increases. The first member that exceeds ultimate state is the vertical structural members at soft storey. In the case of bare frame (Case 1), although the stiffness of building is not influenced by infill walls, the columns still less resistance to seismic load. However in Case 4, the presence of infill walls throughout the vertical panel contributes to global stiffness of frame. As a result, damages are observed in beams without infill instead of columns. Plastic hinges are observed to propagate at beams with no infill until the beams reach their capacity.

IDA curves also indicate that soft storey building has higher maximum interstorey drift ratios, IDR_{max} for the same PGA than other cases. It shows that the soft storey building has high drift capacity and fails at IDR_{max} in the range of 2.5% to 3.0% because the flexibility of soft storey results in extreme deflections. IDA curve of Case 4 shows failure at relatively lower IDR_{max} which is 0.63%, indicating the drift capacity of Case 4 is low because the horizontal displacement has been constrained by vertical infill walls which able to brace the frame at certain level from deflecting laterally.

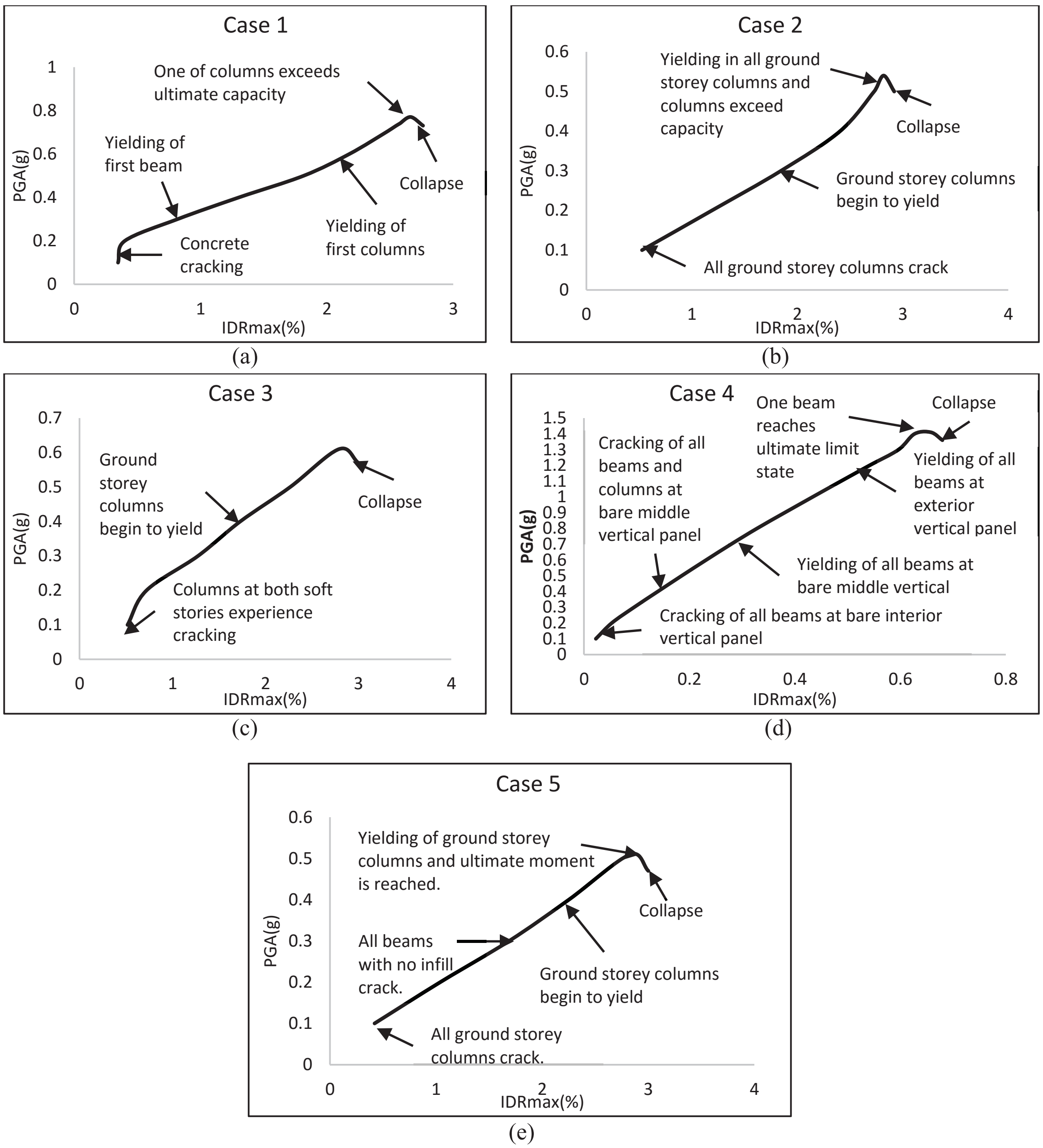


FIGURE 6. IDA curve for (a) Case 1 and (b) Case 2 (c) Case 3 (d) Case 4 (e) Case 5.

CONCLUSIONS

This research studied seismic performance and soft storey effect on plastic hinges propagation in a 4-storey RC building with different configurations of masonry infill. Soft storey frame has variation in local stiffness due to irregularities in vertical direction. Bare frame and frame with filled vertical panel has a uniform vertical global stiffness. Besides, building consists of a soft open ground storey (Case 2) behaves in torsionally-unbalanced manner which tends to rotate about y-axis. In a soft storey building, the plastic hinges propagation begins in columns at the weak storey and moment only redistributes at columns until the capacity of columns is exceeded. Yet, the development of plastic hinges in building with vertically infill walls concentrated in beams rather than in columns. Soft storey building shows maximum drift at the weak storey. The IDR of soft storey is much higher than the IDR of bare frame and vertically filled frame. Soft storey building has high drift capacity and fails at IDR_{max} in the range of 2.5% to 3.0%. IDA curve of Case 4 shows failure at relatively lower IDRmax which is 0.63%, indicating the drift capacity of Case 4 is low because the horizontal displacement has been constrained by vertical infill walls which able to brace the frame at certain level from deflecting laterally.

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REFERENCES

1. Astro Awani. *7 things you should know about the Ranau earthquake* (June, 2015).
2. MOSTI, *Seismic and tsunami hazards and risks study in Malaysia.* Final Report, 59-142 (2009).
3. Sin Chew Daily, *A moderate earthquake in Ranau every 25 years* (June, 2015).
4. A. Y. Elghazouli, *Seismic Design of Buildings to Eurocode 8*, Abingdon, Spon Press (2009).
5. A. J. Urich and J. L. Beauperthuy, *Protagonism of the Infill Walls on Seismic Performance of Venezuela Buildings,* In 15 Word Conference on Earthquake Engineering, Lisbon, (2015), Paper 4518.
6. D. Vamvatsikos and C. A. Cornell, *The incremental dynamic analysis and its application to performance-based earthquake engineering*, In Proceedings of the 12th European Conference on Earthquake Engineering (2002), Vol. 40.
7. BS8110 Code British Standard. *Structural use of Concrete. Code of Practice for Design and Construction, Part 1* (1997).
8. Eurocode 8, *Design of structures for earthquake resistance. Part 1: General rules, seismic actions and rules for buildings. Brussels* (2004).
9. M. Dolsek, *Development of computing environment for the seismic performance assessment of reinforced concrete frames by using simplified nonlinear models*. Bull Earthquake Eng, **8**, 1309-1329 (2010)
10. M. Dolsek and P. Fajfar, *The effect of masonry infill on the seismic response of a four-storey reinforced concrete frame - a deterministic assessment*. Eng Struct **30**(7), 1991–2001 (2008).
11. FEMA-356. *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*. Federal Emergency Management Agency. Washington, D. C (2000).