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Rectification of Sabah Stilt House Using Shear Wall Subjected to Earthquake

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Abstract: A moderate earthquake with 6.0-magnitude hit Sabah in 2015 especially in Ranau, Sabah has been labelled as one of the most powerful earthquakes ever in Malaysia. Numerous buildings in Sabah have become defective with the severity level of damages as absolute (non-repairable) in the RC beam-column joints and soft-storey structures. Seismic design and construction requirements were not considered in most buildings in Sabah. Hence, this research is to investigate how to mitigate the effect of earthquake on the low-rise building using a more practical and economical method. A stilt house model is developed using ABAQUS software to determine the behaviour of the stilt, low-rise building subjected to earthquake by constructing shear wall at the short columns support. There are 4 models constructed namely, frame model without shear wall (W1), with shear wall of 100mm (W2), 300mm (W3) and 500mm (W4). The results of seismic response are evaluated and compared. Different length of shear wall affects the displacement and stress of the frame model. As shear wall length increases, the displacement, stress at columns and stress at walls decreases. Thus, adding a shear wall can be used to retrofit stilt houses and a credible way to mitigate damage due to earthquake load for new houses along hill slopes.

Keywords: Sabah earthquake, stilt house, short column, shear wall

1. Introduction

In 2015, a medium 6.0-magnitude earthquake hit Ranau, Sabah and was labelled as one of the most powerful earthquakes ever in Malaysia. Earthquakes hardly occur in Malaysia because of its position quite far from major plate boundary faults. Thus, such medium intensity earthquake occurrence in Ranau can result to substantial damages to the affected areas [1]. No seismic design code was employed to the Malaysian buildings until 2017, after which the Malaysian Annex for Eurocode 8 has been applied for local seismic design. Hence, most of the present structures have not been designed and constructed without considering the seismic loads. Ductile detailing had not been considered and implemented in their construction [1], [2]. Consequently, numerous buildings in Ranau have become defective with the severity level of damage as absolute (non-repairable) in the structural RC beam-column joints and soft-storey buildings [2]. Fig. 1 shows the time history of Ranau earthquake in 2015.

Damage observed in the surveyed RC buildings of Ranau due to the poor quality of construction elements and loose infill walls were 25% and 15% respectively [1], [2]. Due to the inadequate design and construction of RC frame components, these buildings essentially behaved like masonry shear wall structures with a shear-dominant failure mechanism [7]. The vulnerability of the buildings is due to obsolete design codes, poor design practices and enforcement of the code [4]. Most of these buildings are currently in operation but need further evaluation and

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upgrading to minimize seismic damage and improve the safety of life. Most of the buildings with damage level grade 3 and grade 2 are residential houses built with wood and positions near or on the hill [4], [9]. The main causes of the seismic induced damage of the surveyed structures in Ranau are the short column effect (20%) and the plan and elevation irregularity of buildings (30%) [4]. Most of the short column failures that have occurred in the buildings were constructed on inclined slopes where these buildings at the hill slope are built with different heights of columns.

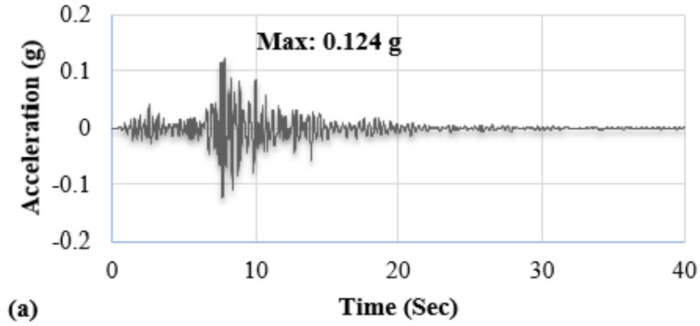


Fig. 1 - Time history of Ranau earthquake [2]

Short columns usually suffer more damage compared to the others. Short column phenomenon normally occurs to structures built on inclined slope that have different heights of first story columns [1]-[3], [8], [12]. It is found that structures with short columns are very vulnerable to seismic action because the short column would be stiffer, has limited flexibility and thus draws a higher bending moment in an earthquake. This type of column also results in more shear force demand since their bending moment arm is short [1], [5].

Several strengthening/retrofitting methods had been carried out. These methods are needed to extend the span in column area, create high strength and ductility in the joints and effectively improve the joint shear strength capacity. The strengthening methods executed have enhanced the energy capacity dissipation and lessened stiffness degradation of beam-column joints. Methods associated to non-seismic design of structural beam-column joints such as the steel dissipation jacket and steel cages have visibly been implemented in the strong column weak-beam concept. Applying external post tension rods and fiber reinforced polymer as one of the retrofitting methods had considerably improved the strength of non-seismic design to 40 %, thus avoiding major brittle shear failure at joints [2]. However, particular care is needed especially for the welded section; wherein the brittle/corrosion failure under elevated number of cycles may occur [2]

In this study, the influence of shear-wall to a low rise building on stilt subjected to earthquake is investigated. Different lengths of shear walls are provided at the shorter lengths of the column to the low-rise building on stilt. The significance of using shear walls can be an alternative to a more practical and economical method to rectify the effect of earthquake on the existing low-rise building on stilt as well as to mitigate new low rise building constructed along slopes [5].

2. Short Column Phenomenon in Ranau Houses

Fig. 2 shows a building on sloping ground which has suffered severe damage due to the short column failure during the Ranau earthquake. It can be observed that all the supporting columns of the building which were about 1 m long failed through shear [1], [4].

Fig. 2 - Stilt house damaged due to short column effect

The side and plan view of this building are shown in Fig. 3(a) and Fig. 3(b) [1]. The wall and roof were made from wood while reinforced concrete was used for the floor beams and columns. Referring to Fig. 3(b), the columns with lengths of 2.7m along gridline 5 were the longest but gradually reduced towards gridline 1 where the shortest column's height was about 1 m. All the columns had a square 200 mm cross-section, reinforced by four 12 mm diameter longitudinal bars and 10 mm diameter transverse stirrups at 250 mm apart [1].

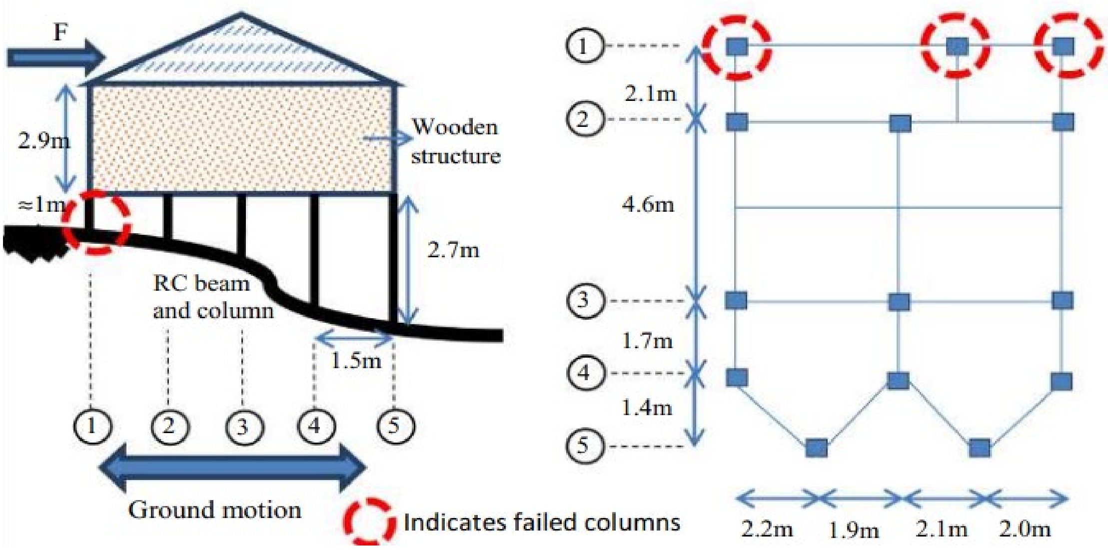
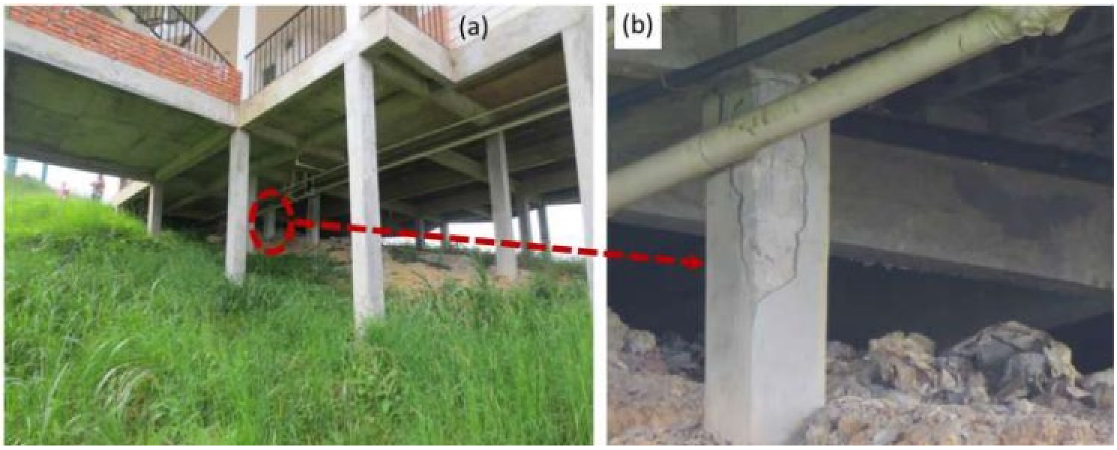


Fig. 3 - Building configuration measured onsite and columns grid as referenc (a) side elevation, and; (b) building plan [1]

Fig. 4(a) shows a short column failure for a three-storey RC building constructed on a slope in Ranau. According to the site measurement, all the columns in this building had a square cross section of 250 mm but with varied lengths from 1.2 m to 3.4 m. It was observed that shear cracks occur at the shortest columns of this building, as shown in Fig. 4(b).



(a) (b)

Fig. 4 - A three-story RC building on sloping ground (a) short column phenomenon with short and long columns, and; (b) shear crack damage at shortest column

3. Methodology

The main objective of this paper is to study how to mitigate the effect of earthquake on the low-rise building with short columns; and possibly rectify the damages caused. Hence, the Sabah stilt house in Fig. 3(a) and Fig. 3(b), based on dimensions from Alih [1] such as height, width, length, beam and column size and size of rebar, is selected to generate a simplified building model as shown in Fig. 5. The two front, long columns supporting the structure are modelled as `long column' and two rear short columns, as 'short column'. The model has 4.1m length, 3.1m width, 2.9m height of wall, 2.7m height of long column, 1m height of short support column. The columns are 200mm by 200mm cross-section with four 12mm Ø longitudinal reinforced bar.

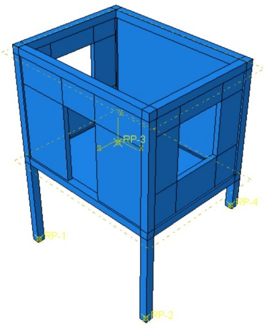


Fig. 5 - Assembling part instances

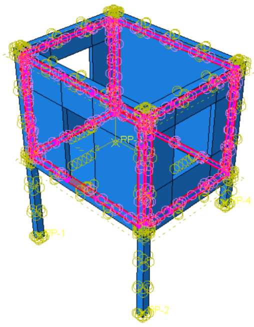


Fig. 6 - Applying tie constraints for all surface that were in contact

The stilt house model is developed and verified [10] by using finite element modelling software, ABAQUS. The wall, slab and columns use solid elements and the rebars are from wire elements. Five parts are created consisting of concrete beam, concrete column, concrete slab, brick wall and rebar. Referring to Fig. 5, all parts are assembled using translate and rotate commands, and tie constraints will be used to bind together two different surfaces in the interaction module as shown in Fig. 6. Boundary conditions are made as fixed supports as in Fig. 8. All the parts are assigned as dependent, and the structure model are meshed part by part. For this study, shear walls are introduced at the two ‘short’ columns of the model to study the seismic response to the stilt house model as shown in Fig. 9 and Fig. 11 (in red circle). A 6.0-magnitude time-history of Ranau earthquake is applied in the `z-direction’ to the bases of the four supports of the model as shown in Fig. 7. The earthquake in this direction will give maximum rotation-translation effect to the building.

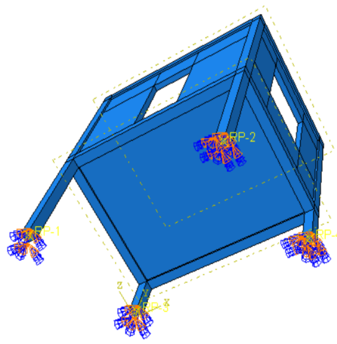


Fig. 7 - Applying boundary condition

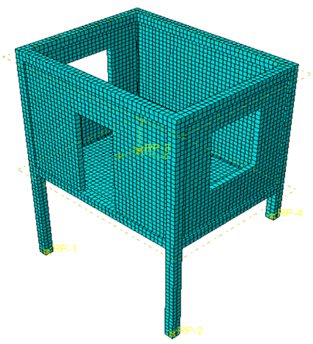


Fig. 8 - Meshing of model

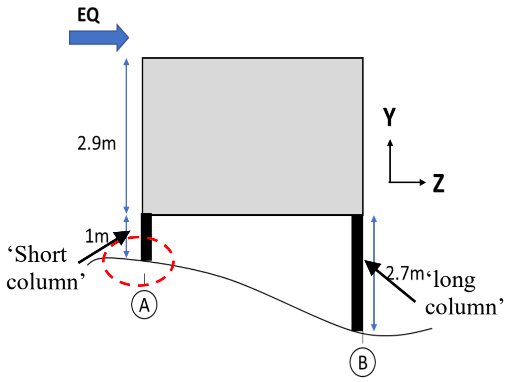


Fig. 9 - Side view of stilt house model

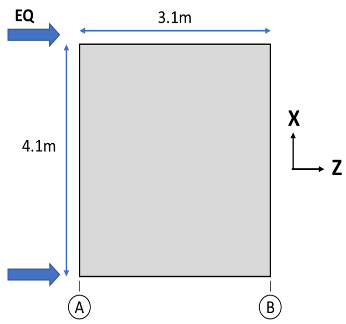


Fig. 10 - Plan view of stilt house model

3.1 Models with Different Length of Shear Wall

Models constructed namely, frame model without shear wall (W1), shear wall of 1m height with lengths of 100mm (W2), 300mm (W3) and 500mm (W4) in the z-direction are as shown in Fig. 11 respectively.

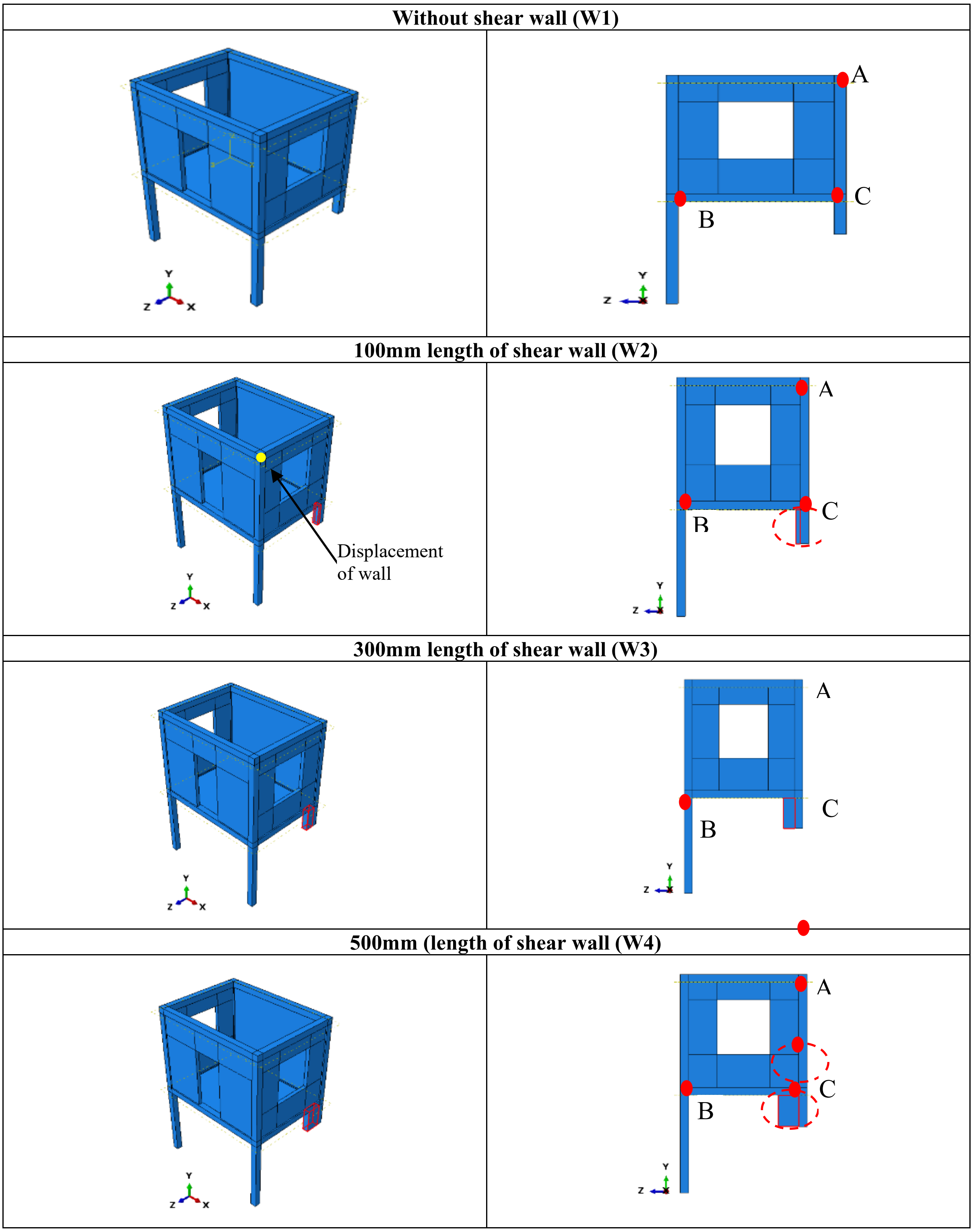


Fig. 11 - Different shear wall lengths at the short column

4. Results and Discussion

Maximum displacement of wall and maximum stress at the short column are compared to distinguish the effect of adding shear wall in the short column phenomenon.

4.1 Maximum Displacement of Wall at Point A

Fig.12 shows the lateral displacement of the frame with different shear wall length due to the Ranau earthquake load. From Fig. 12, it is found that the displacement at A decreases as the shear wall length increases. The displacement value is very small because of the presence of short columns. A short column is usually stiffer and resist deformation as compared to a tall column [5]. The percentage difference of maximum displacement between frame without shear wall (W1) and frame with shear wall 500mm (W4) is about 56.7%. This proves that shear wall can improve the stiffness of the model and at the same time shear wall can limit the displacement of the frame from swaying too much.

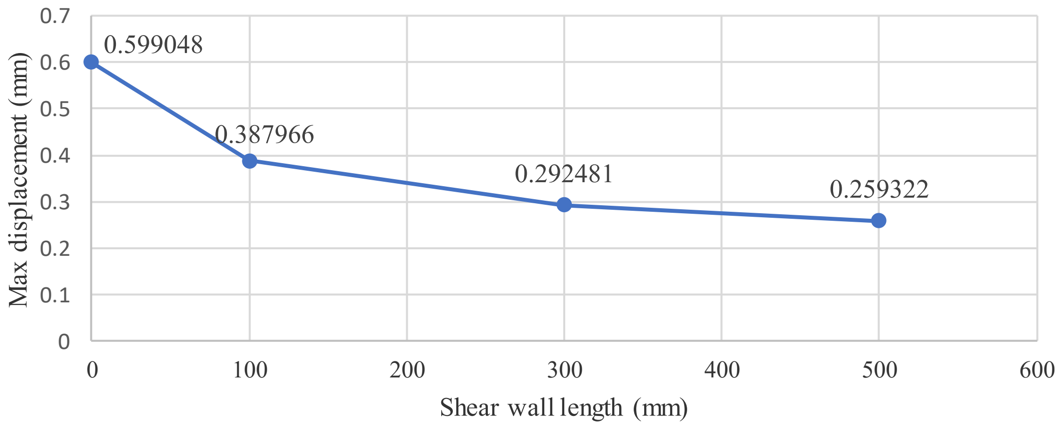


Fig. 12 - Maximum displacement of frame with different shear wall length

4.2 Maximum Stress of Columns at Points B and C

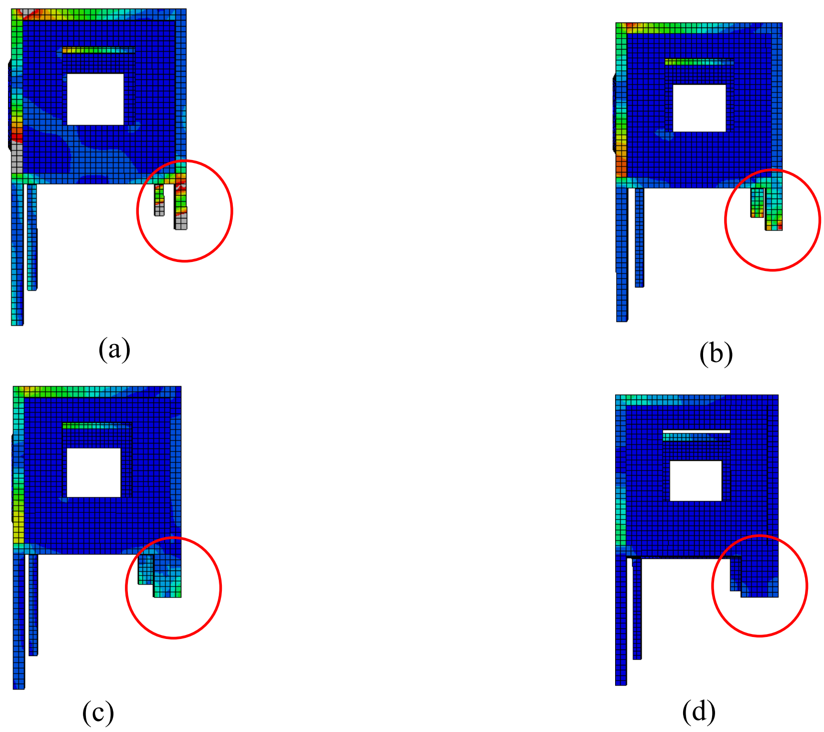


Fig. 13 - Stress contour at short column from right view (a) W1; (b) W2; (c) W3, and; (d) W4

Fig. 13 shows the stress contour at point C of the short column as indicated by the red circle. From the figure, it can be observed that the stress at the short column slowly disappears as the length of shear wall increases. As the short column has more stress value than the tall column, a 'shear wall' was constructed by increasing the length at the short column to increase its strength and stiffness. Fig.14 showed the comparison of maximum stress at the long column (at point B) and short column (at point C) respectively indicating that adding 'shear wall' has improved the behaviour of the short column. Thus, the short column becomes stronger and reduces the stress which may lead to shear failure of column.

From Fig. 14, the percentage difference between maximum stress at short column between W1 and W4 is 89.8%. Stress at tall column also decreases from 0.69MPa to 0.19MPa for frame without shear wall (W1) and with shear wall with width of 500mm (W4) respectively. Therefore, with bigger length of shear wall, stiffness of the column increases while lowering the shear stress.

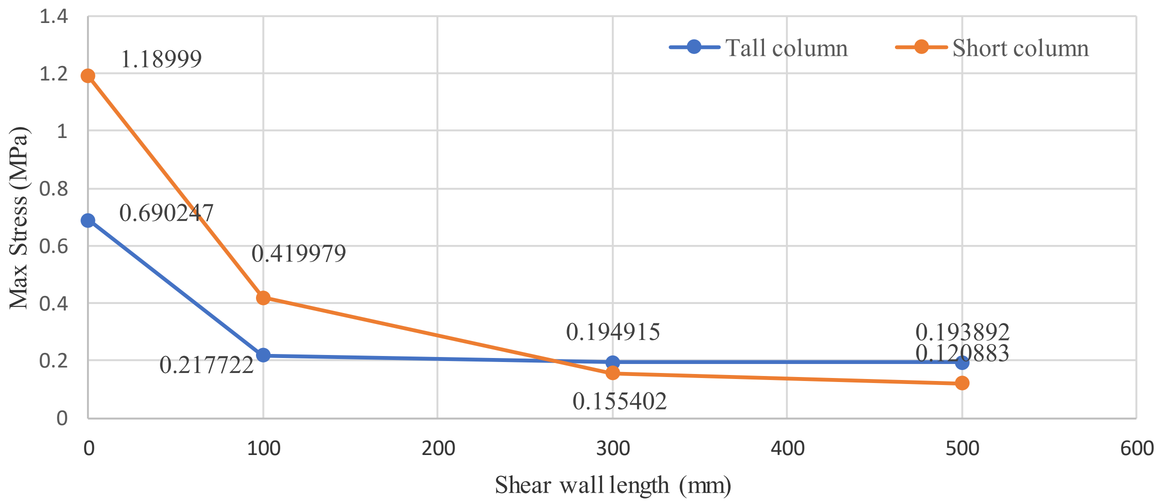


Fig. 14 - Maximum stress at tall column and short column

4.3 Maximum Stress of Wall at Point D

The horizontal earthquake force in the z-direction has induced in-plane forces in the wall, hence causing the diagonal stress in the wall as shown in Fig. 15 [7]. It can be observed that the stress contour at point D on the wall decreases as the length of shear wall increases. It indicates that the tensile stresses on the wall can be reduced and the diagonal cracks can be minimized with the addition of shear wall in the short column support.

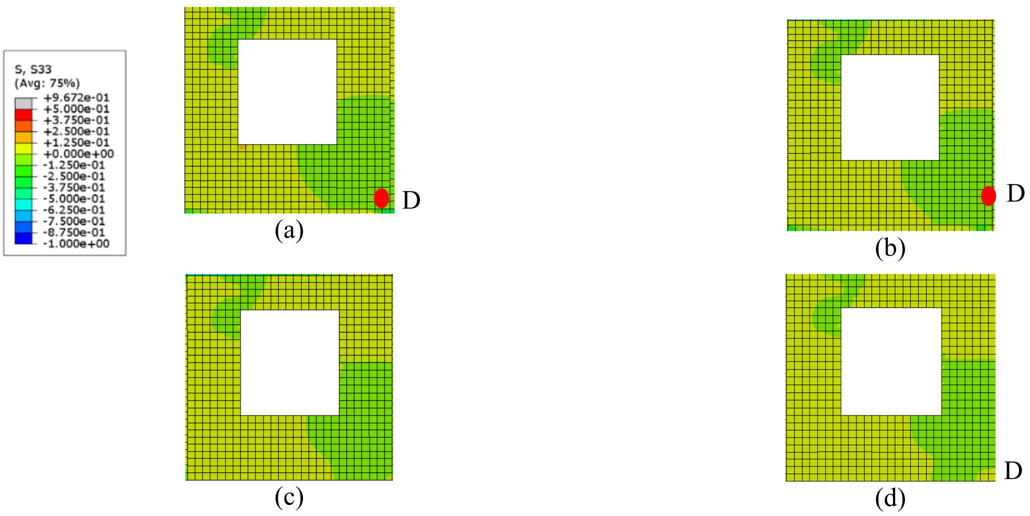


Fig. 15 - Stress contour at the wall in right view (a) W1; (b) W2; (c) W3, and; (d) W4

Fig. 16 shows the maximum stress at point D of the wall decreases gradually with the increase of length of shear wall. The percentage difference between stress on wall for W1 and W4 is about 39.4%. The stress continues to drop after adding more length to the shear wall. Adding shear wall (in the perpendicular direction of the longer span of building) helps in reducing damages of the wall and decrease the stresses on the wall due to earthquake load [7], [13].

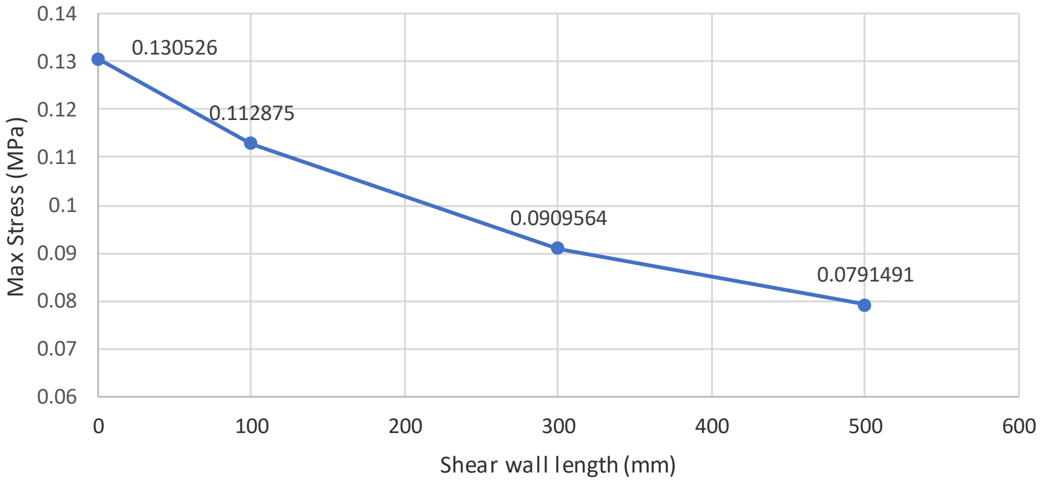


Fig. 16 - Maximum stress at point D of wall

5. Conclusion

As earthquakes have affected most stilt buildings in Ranau Sabah, it is important to understand how to rectify and mitigate the affected building using a more practicable and cost-effective way. The behaviour of a stilt house in Ranau was modelled and analysed using ABAQUS software. Rectification is made by introducing a shear wall to the short column of the stilt house model. From the displacement analysis, it is found that as the shear wall length increases, the wall displacement of the model gets smaller. For the stress analysis, short columns are found to experience greater stress than tall columns. Constructing shear wall at short column can improve the strength of column and reduces stresses; hence minimise structural damage to the column. Based on results obtained, the shear wall is extended to about 500mm to effectively reduce stress and displacement at the short columns. Hence, adding a shear wall can be used to retrofit stilt houses and a credible way to mitigate damage due to earthquake load for new houses along hill slopes.

Acknowledgement

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