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Comparative study of strengthening strategies for reinforced concrete frame with soft ground story

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ABSTRACT

One of the common forms of reinforced concrete (RC) framed building is to provide parking facility at ground level which is created by not providing any infill masonry at parking floor level. Due to the presence of infill walls in the entire upper story except for the ground story makes the upper stories much stiffer than the open ground story resulting in their poor performance during earthquakes. So strengthening of such reinforced concrete (RC) frame buildings with an open ground story is indispensable. In the present study several Strengthening options were evaluated for their effectiveness in improving the performance of such building without disturbing the parking facility of ground story based on linear and nonlinear analysis. The strengthening techniques studied were changing column dimension, providing diagonal bracing, lateral buttresses, shear wall, and providing chevron. The Strengthened building results were compared with the results of the original structure to deduce the structural performance improvement and cost associated to each solution were determined to develop cost efficiency relation for different strengthening technique. Providing lateral buttresses in the open first story was found to be more feasible in both case of increase ground story strength and economic point of view among all strengthening options.

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1. Introduction

One of the common form of residential and commercial building in several countries is masonry-infilled reinforced concrete framed building with parking facility at ground level which is created by not providing any infill masonry at parking floor level .It introduces sudden discontinuities in the lateral strength and stiffness along its height .If the story stiffness is less than 70% of the floor immediately above it or less than 80% of the three floors above it, then the story is called soft story . The columns at such a floor, have a good possibility to get damaged to collapse under horizontal vibration due to earthquake. In considering the structural effect of infill in building design various national codes can be broadly grouped into two categories – those that consider the role of masonry infill (MI) wall while designing RC frames and those do not consider. A very few codes specifically recommend isolating the MI from the RC frames such that the stiffness of MI does not play any role on the overall stiffness of the frame (standards New Zealand NZS -3101, Russian SNIP -II -7-8D). Some national codes of a few countries: India-IS 1893(BIS 2002), Israel—SI 413 (SII 1995) and Bulgaria (Bulgarian Seismic Code 1987) recommend that the open-story beams and columns to be designed for higher forces obtained by multiplying the design seismic forces with predetermined factors varying from 2.1 to 3.0. In some past researches several strengthening techniques were recommended for open first story buildings. Sahoo and Rai (2013) recommend two techniques, first technique termed as column retrofit and the later technique termed as full retrofit. Kaushik et al. (2009) developed a rational method for the calculation of the required increase in strength of open – first story column. Furtado et al. (2015) studied four strengthening mechanisms,

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namely: (a) RC column Jacketing, (b) introduction of RC shear wall, (c) introduction of steel bracing, (d) additional of steel bracing with energy dissipation device. This paper presents the analytical investigation of several strengthening mechanisms to improve the seismic performance of open first story RC frames. The parking facilities or other facilities for which the ground story was keep open were not be hampered by those strengthening mechanisms. All the strengthening strategies are applied to the outer side of building to make the ground story usable. Equivalent static analysis and nonlinear static analysis were carried out using ETABS 9.7.0.

2. Description of RC Building

For this study, 6-story building with twenty meter height, regular in plan was modeled. The building was fairly symmetric in plan and in elevation. The plan and elevation view of the building frame was studied as shown in Fig 1. In modeling plane frame the following material properties and geometrical properties was used for beam, columns, masonry infill. Columns were assumed to be fixed at the base. M-20 grade concrete and Fe-415 grade of reinforcing steel were used for all the frame models used in the study. Modulus of elasticity of concrete and masonry was 22361 MPa and 700 MPa respectively. Poison's ratio was 0.2 and 0.3 respectively for concrete and masonry. The unit weight of concrete and masonry was taken as 23.56 KN/m^3 and 20 KN/m^3. The floor finish and random wall on the floors were 1 KN/m^2. The live load on floor was taken as 2 KN/m^2. All beams and columns had cross sectional area e.g. 45cm X 30 cm and 45cm X 45 cm respectively. Infill walls and slabs were modeled as 20 cm and 15 cm thick respectively.

3. Masonry Infill in RC Structure

To understand the behavior of infilled frame many experimental and analytical research has been carried out in the past. Several analytical model has been developed for featuring infill characteristics in RC frame. Those models are mainly two categories: macro-model and micro model. Macro-model is based on equivalent strut method and most widely used for its simplicity. Thus masonry infilled RC frames can be modeled as equivalent braced frames with infill walls replaced by equivalent diagonal strut which can be used in nonlinear pushover analysis. The basic parameter of these struts is their equivalent width, which affects their stiffness and strength. Extensive research has been carried out to find out the width of equivalent strut, for example Holmes(1961), Stafford Smith and Carter (1969), Mainstone (1971), Paulay and Preistley (1992), Liauw and Kwan (1984), Hendry (1998). In the comparative study by K. H. Abdelkareem et al. (2013), of different expressions for the width of equivalent strut shows that the Paulay and Priestley equation is the most suitable, due to its simplicity and because it gives an approximate average value among those studied in that paper. Consequently, this method of modeling is being used in this study. The width of compressive struts is considered as one fourth of the diagonal length of the infill.

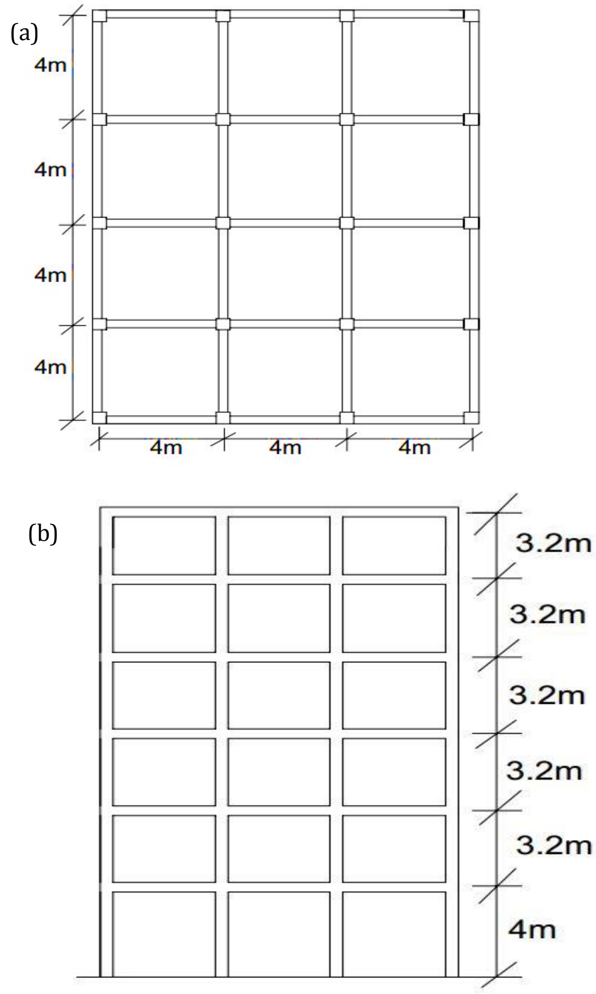

Fig. 1. General view of the building under analyses: (a) Building plan; (b) Building elevation.

4. Nonlinear Static Analysis

Nonlinear static analysis has become preferred analysis procedure for design and seismic performance evaluation purposes. It is an incremental static analysis used to determine the force displacement relationship. The most convenient way to plot the load deformation curve is by tracking the base shear and the roof displacement. The capacity of structure is represented by pushover curve. Pushover analysis was carried out for all the study frame to estimate seismic structural deformations. Default hinge properties were assigned to beams, columns and strut for pushover analysis. The built-in default hinge properties were typically based on FEMA-273 and ATC-40 criteria. Usually moment hinge properties (Default-M3) were assigned to beams and interacting hinge properties (Default-P-M-M) were assigned to columns and axial hinge properties (Default-P) were assigned to diagonal strut. The overall capacity of a structure depends on the strength and deformation capacities of the individual components of the structure. The building performance level can be determined by target displacement using the Capacity Spectrum method.

5. The Building Models Studied

Model 1 - This frame represents the most currently used common practice of not including the strength and stiffness of masonry infills in the analysis and design procedure. Effects of infills were not considered in all stories.

Model 2 - In this frame the effects of infills were considered in the upper stories; however, the first story of the frame was kept open.

Model 3 - In this frame for strengthening ground story, sectional area of all column of ground story increased by 1.5 times.

Model 4 - Diagonal bracings were provided in all external bays to improve lateral load performance of the frame. The size of section of bracings were same as to beam and plastic hinge properties of bracings were kept identical to that of the already existing first-story columns.

Model 5 - Lateral buttresses were provided in the open ground-story to ameliorate lateral strength. Inclination of buttresses with ground was 60^0. Sectional property and plastic hinge properties of the buttresses were kept identical to that of the columns in the first story.

Model 6 – In this frame shear walls were provided in ground story only in external four corner and wall thickness was provided as 25 cm.

Model 7 - Chevron were provided in all external bays. Sectional dimension was same as to beam and plastic hinge properties were kept identical to ground-story columns.

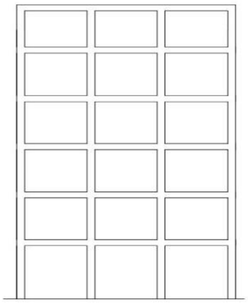

Fig. 2. Model 1

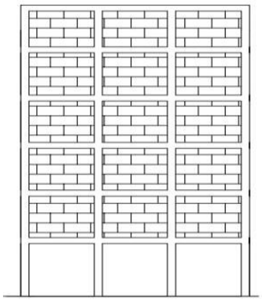

Fig. 3. Model 2

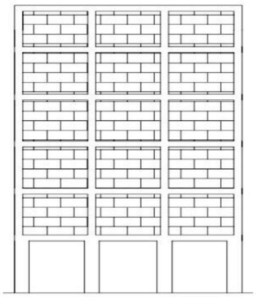

Fig. 4. Model 3

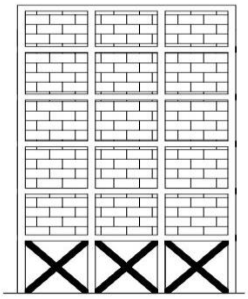

Fig. 5. Model 4

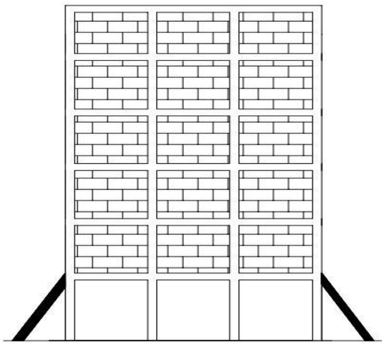

Fig. 6. Model 5

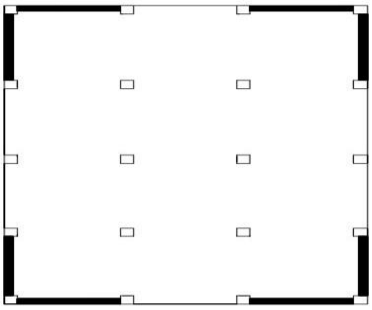

Fig. 7. Model 6 (Plan view)

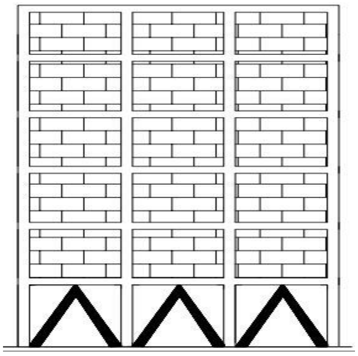

Fig. 8. Model 7

6. Results and Discussion

Linear and nonlinear analysis of different frames were carried out using ETABS software. The obtained results were represented graphically. Performance point of the building were obtained form of the results of pushover analysis.

6.1. Linear static analysis

Linear elastic analysis of the building were carried out using the equivalent static method. In the present investigation, earthquake load was chosen as a source of lateral loading on the building frame as set forth by the provision of Bangladesh National Building Code (BNBC, 1993). The total share force due to the seismic load was applied in the center of mass of all diaphragms with additional eccentricity ratio of all diaphragms. Earthquake load was applied at every story level of individual models. Drift pattern at different story level for different model are shown in Fig. 9.

6.2. Nonlinear static analysis

Pushover analysis were carried out for all the building models. First pushover analysis was done for the gravity loads (DL+0.25LL) incrementally under load control. The lateral pushover analysis was followed after the gravity pushover, under displacement control. The building was pushed in lateral directions until the formation of collapse mechanism. The capacity curve (base shear versus roof displacement) for different frames are presented in Figs. 10 and 11.

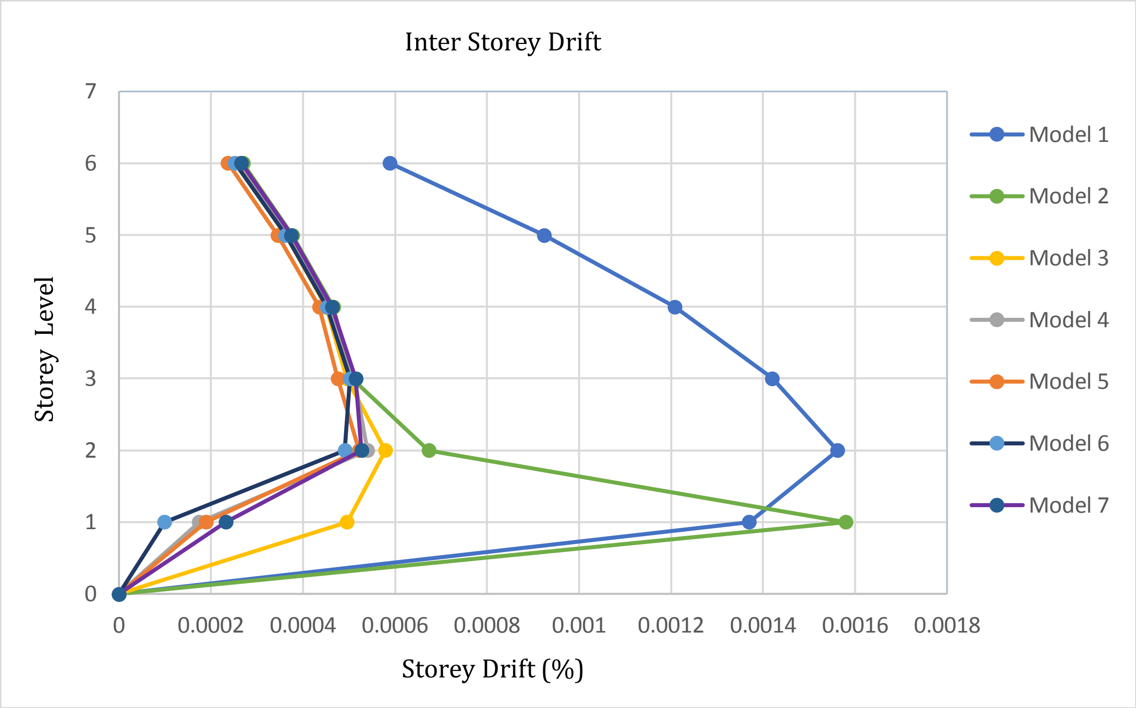

Fig. 9. Inter story drift of different model.

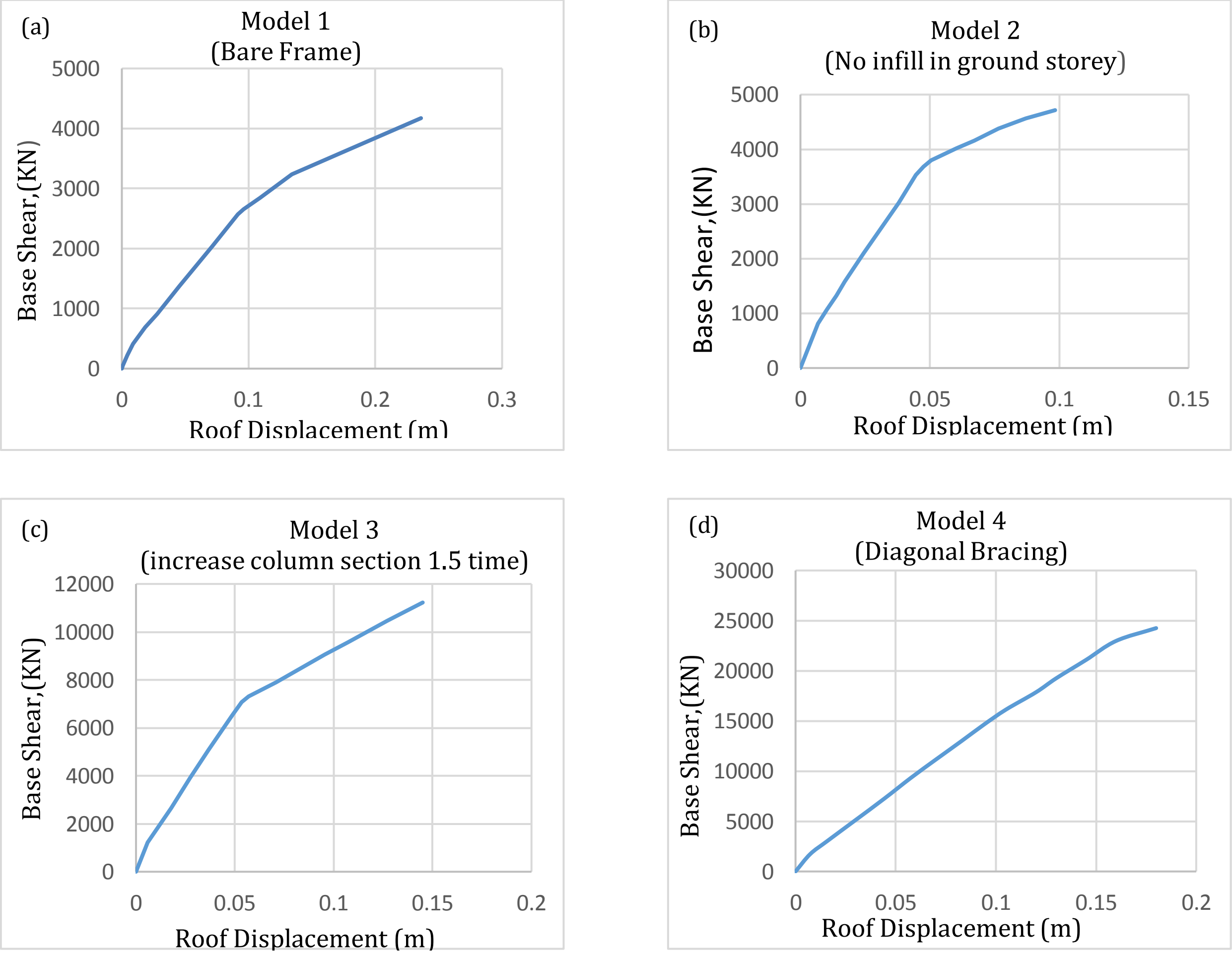

Fig. 10. Capacity curves:

(a) Model 1 (considering no infill); (b) Model 2 (no infill in ground story);
(c) Model 3 (increased column sectional area); (d) Model 4 (strengthened by x bracing).

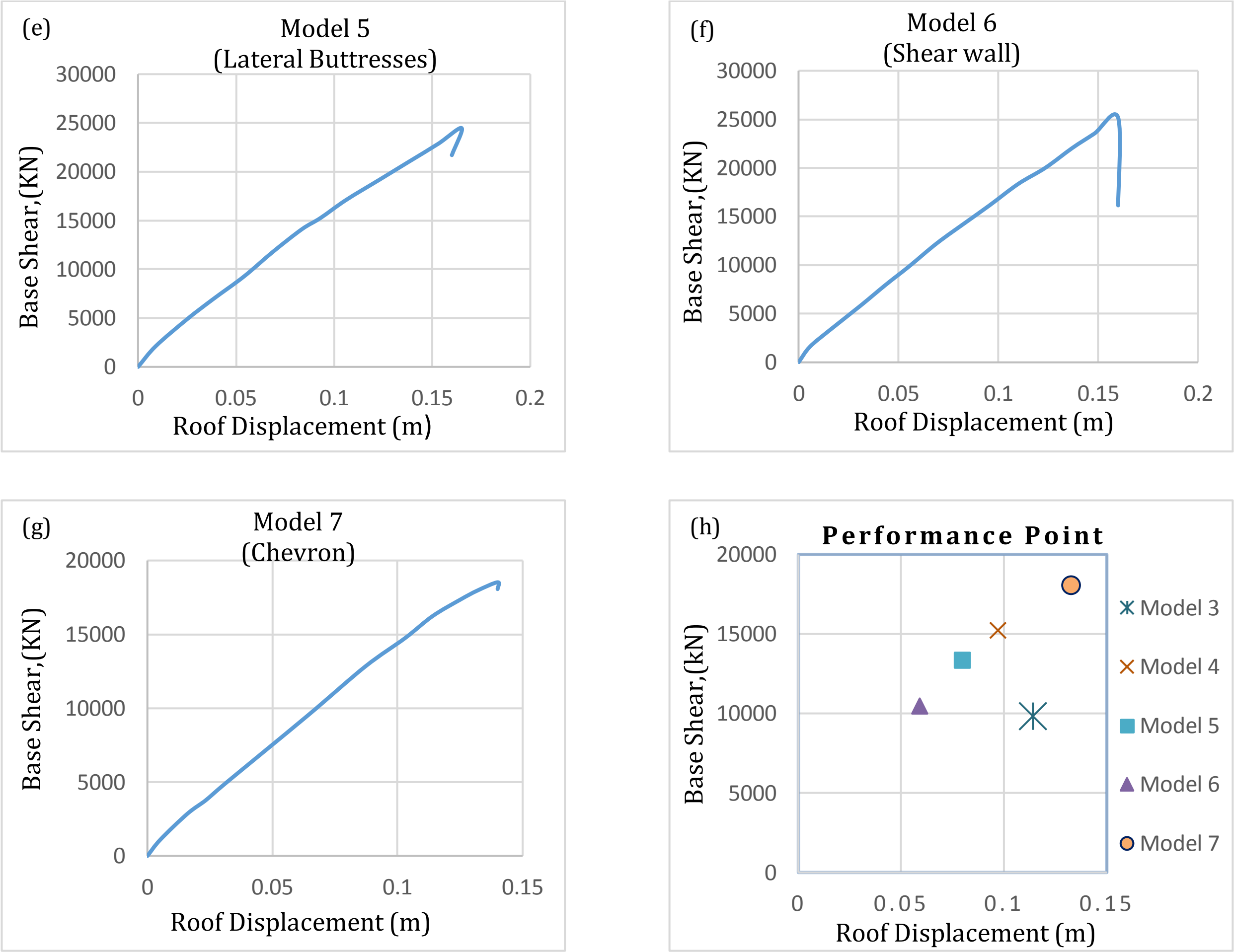

Fig. 11. Capacity curves:
(e) Model 5 (strengthened by lateral buttresses); (f) Model 6 (strengthened by shear wall);
(g) Model 7 (strengthened by chevron); (h) Performance point of different frame.

6.2.1. Performance points

Performance point obtained from pushover analysis shows the maximum structural displacement expected for the demand earthquake ground motion. The buildings were pushed to a displacement of 4% of height of the building to reach collapse point. Fig. 11(h) shows the comparison of the performance points obtained from pushover analysis of the different frames. Model 6(Shear Wall) exhibit minimum displacement and displacement for Model 4 and Model 5 is moderate, where in case of Model 7 high displacement occur. Model 3 exhibits displacement about 2 times of Model 6. The strengthening option Model 6 in which shear wall is provided in the open ground story, may be considered as the best strengthening solution. On the other hand, Model 5 in which additional lateral buttresses were provided in the open ground storey may be a good alternative for strengthening.

6.3. Cost–efficiency analysis

For cost efficiency comparison of each strengthening solution studied one indicator is used that would be take into account the value of the first-story maximum drift due to earthquake and the volume of concrete required for the strengthening solution (Fig. 12). The estimated volume of concrete for the strengthening solutions were taken as the percentage of volume required for beam, column and slab. It was observed that Model 3 (column section increased 1.5 times) exhibit maximum drift under earthquake but less cost among all solutions. Cost for Model 6 (shear wall) is maximum but it reduced about 93% drift of open ground story building. The cost and drift control performance of Model 4, Model 5 and Model 7 are moderate.

7. Conclusions

The seismic performance of RC frame with soft ground story was found to be very poor due to their inadequate lateral strength and drift control capacity. The effectiveness of the proposed strengthening techniques to improve the lateral load capacity of such buildings was evaluated by using pushover analyses. The strengthening schemes in which shear wall and lateral buttresses were provided in the open first story were found to be significantly more effective in improving both lateral strength and ductility of such frames. When diagonal braces were used a huge increase in lateral strength and stiffness of the frame was observed. From cost-efficiency analysis providing lateral buttresses is most effective but if it will not convenient due to lack of space to provide buttresses then diagonal bracing or shear wall may be used.

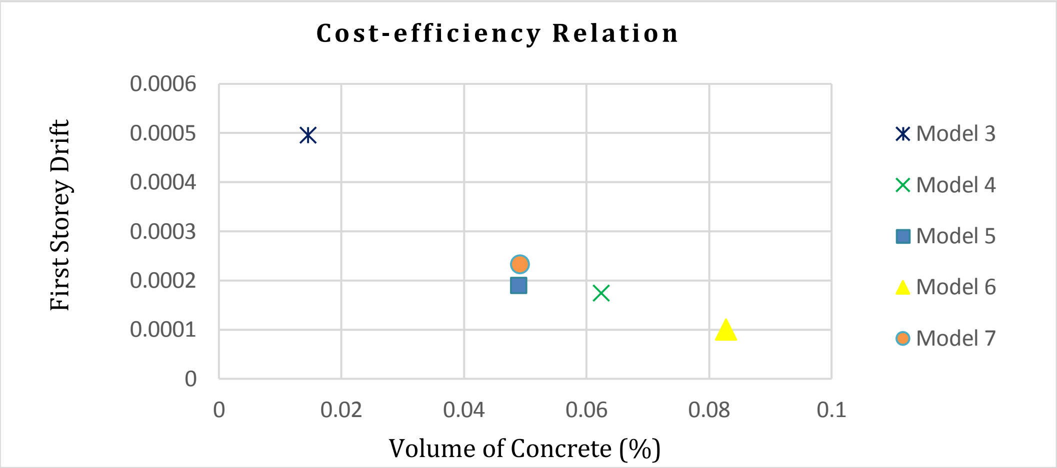

Fig. 12. Cost–efficiency comparison of strengthening solutions.

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