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Preventing soft storey irregularity in RC buildings by pushover analysis

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Abstract

The soft storey is the one in all that the rigidity is lesser than the other storeys due to the very fact that it's not got the walls with an equivalent property the other ones have. If the vertical load-bearing structural component and additionally the partitioning wall continue all storeys, then that structure is no soft storey. The soft storey is usually present entrance (below) floors of buildings. Because the entrances to the building used as a bank branch, store, restaurant, office, car parking and above stores are used as accommodation. Soft stories have a devastating effect during earthquakes and increase construction cost. Such features are extremely undesirable in buildings made in seismically active areas; This has been verified by various experiences of robust tremors throughout past earthquakes. The soft storey is an irregularity that affects the building during the earthquake and decreasing of lateral rigidity. For this cause, the soft storey should be avoided as much as possible. In case it is necessary, irregularities can be eliminated by increasing the lateral rigidity of this storey by increasing beam-column size, putting up additional walls and shear wall etc. To fulfil the above objectives, a 7 storied RC building increasing beam-column size and putting up additional walls modelled with ETABS and SAP2000 software by pushover analysed in this study.

Keywords: Soft storey, pushover analysis, irregularities, additional walls, beam-column size, lateral rigidity.

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1. Introduction

Many urban multi-storey buildings in Bangladesh today have the first storey open as an inevitable feature. It is being taken to connect the first-floor parking or reception lobby. The upper floor is filled with bricks wall panel. BNBC (2006) classifies that soft-storey may be a storey within which the lateral stiffness is a less than 70% of that in the storey above or less than 80% of the mean stiffness of the three stores above. Interestingly, this classification renders most Bangladeshi buildings, with no masonry infill walls on the first floor, to be “buildings with the soft first storey.” Whereas the total seismic base shear as adept by a building during an earthquake is dependent on its natural period, the earthquake force distribution is dependent on the distribution of stiffness and mass along with the height.

According to ATC-40 (1996), a weak or soft storey is considered a deficiency if it can lead to a loss of vertical stability at the seismic hazard level associated with the target performance objectives. In buildings with soft first floors, the upper floors are stiff so that smaller inter-storey drifts. However, the inter-storey drift in the soft first storey is more. The strength demand on the columns in the first storey is also more as the shear in the first storey is large. For the upper floor, the force of the columns is effectively decreasing due to the presence of the buildings with sudden changes in storey stiffnesses have uneven lateral force distribution along with the height, which probably induces stress concentration locally.

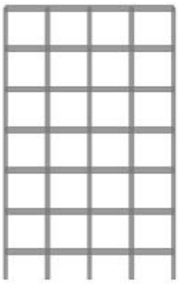


Fig. 1. Model 1 Elevation View

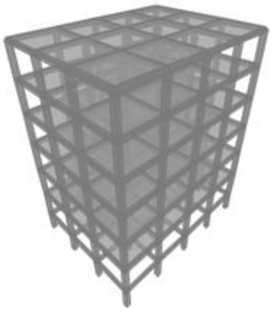


Fig. 2. Model 1 3D View

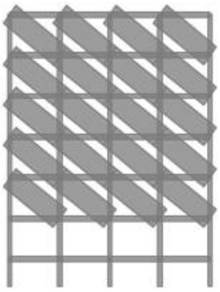


Fig. 3. Model 2 Elevation View

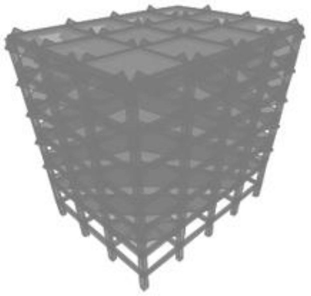


Fig. 4. Model 2 3D View

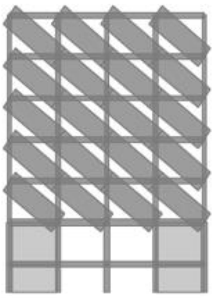


Fig. 5. Model 3 Elevation View

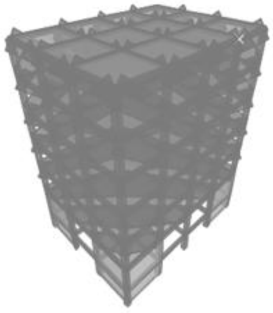


Fig. 6. Model 3 3D View

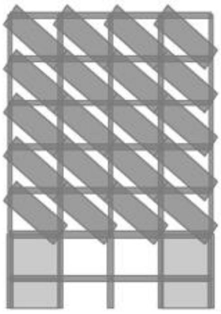


Fig. 7. Model 4 Elevation View

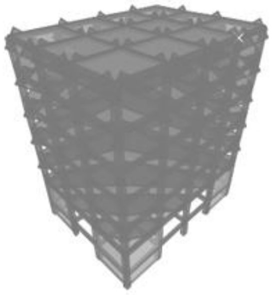


Fig. 8. Model 4 3D View

This adversely affects the functionality of the building when the ground shakes. Such buildings are required to be analyzed by the nonlinear analysis and designed carefully. There have been several studies on the soft storey, pushover analysis and irregularities of various structures as expressed below. They investigated that response of mass irregular structure need to be studied for the earthquake scenario. In that paper, researchers restricted RC framed structures in each regular and mass irregular buildings with totally different analysis ways (Khan and Dhamge, 2016). Reviewed existing works relating to set up irregularities and even the preference of single-storey building models over high-rise building models (Fetene, 2016). The studied pushover analysis of RC building with the effect of the thickness of the shear wall. He concluded that shear walls are more effective in resisting lateral load in the RC structure (Islam, 2018). Focused his study of pushover analysis on the effect of the soft storey and infill wall on different floors in RC buildings. He concluded that the brick infill enhances the seismic performance of the RC buildings. He also found that building with a soft storey shows poor seismic responses and therefore soft-storey should be avoided in the seismic region (Nath, 2015). The roof diaphragm is modeled as rigid and semi-rigid, focusing on its study in buildings with vertical irregularities such as mass irregularities and mass and stiffness irregularities (Prakash et al., 2017). As demonstrated by this paper deals with Geometric vertical irregularity in buildings. A Nonlinear static analysis (Pushover analysis) is performed on all six models. From the analysis results, it has been observed that the increase in the irregularity of the building with a decrease in structural performance (Kazi and Shaikh 2016). This paper is to hold out the pushover analysis of two (regular and vertical irregular) G+7 RC buildings by using design and analysis software ETABSv9.5.0. From the analysis results, it has been observed that the vertical irregular structure has less seismic performance as compared to the regular structure (Sadhana and Shinde, 2016). Studied concentrating on finding the best place for soft stories in high rise buildings (Khan et al., 2013). In this study, soft-storey effects on 3-storey and 8-storey earthquake behavior were observed isolated buildings were investigated under near and far fault earthquakes (Erdem and Saifullah, 2016). This paper highlights the importance of taking immediate action to clearly recognize the presence of open first floors in building analysis and to prevent the arbitrary use of soft first floors in buildings. They find out from this analysis that the pushover demand, spectrum capacity and plastic hinges the real behavior of structures (Akshay et al., 2014).

Table 1
Common parameters and material properties of models

Model Parameter	Value/Dimension
Span length	4 m
Number of span × bay	4×3
Bay width	4 m
Base height	2m
Floor height	3 m
Number of storey	7
Slab thickness	150 mm
Floor finish load	1 KN/m^2
Partition wall load	1 KN/m^2
Live load	2 KN/m^2
Beam Width	250mm
Beam depth for model 1-2	400 mm
Beam depth for model 3	400 mm storey 3-7 and storey 1-2, 440 mm (10% area increased)
Beam depth for model 4	400 mm storey 3-7 and storey 1-2, 480 mm (20% area increased)
Column dimension for model 1-2	400×400 mm
Column dimension for model 3	400×400 mm storey 3-7 and storey 1-2, 419.53×419.53 mm (10% area increased)
Column dimension for model 4	400×400 mm storey 3-7 and storey 1-2, 438.18×438.18 mm (20% area increased)
Modulus of elasticity	24855.576 MPa
Crushing strength of concrete (f ′c)	27.579 MPa
Strut thickness	125mm
Strut depth	1670 mm (one-third of the diagonal length)
Additional wall thickness (model 3)	125mm (model 3)
Additional wall thickness (model 4)	250 mm (model 4)
Seismic zone	II (Dhaka)
Importance factor	1
Response reduction factor	8
Seismic zone factor	0.15
Yield strength of steel (f y)	413.685 MPa

2. Parameters of reference models

In this present study, a 3D building structures of 7 storeys have been modelled and analyzed using CSi SAP2000 and etabs software. The number of four buildings modelled has been considered in this study. The first model was not considered an infill wall but other models were considered as an infill wall diagonal strut. The second model did not consider any infill wall in the bottom storey and ground storey and beam and column area seams on all storey. In the third model, 125 mm additional walls have been added at the four corners and the bean and column area has been increased by 10% in the bottom storey and ground storey. The fourth model 250 mm additional walls have been added at the four corners and the beam and column area has been increased by 20% in the bottom storey and ground storey.

3. Result

Seismic performance has been explained and compared by analyzing ATC-40 code in all models. Model 1 is a regular model and Model 2-3 is an irregular model. Here, model 2 to 4 bottoms floor and ground floor soft storey so the result is compared to model 2 with model 3 and 4.

3.1 Comparison of storey stiffness

A comparison of storey stiffness curves for all of the building model is shown in Figure 9 and also comparison model 2-4 shown in Table 2 below. Storey stiffness is obtained from the X direction earthquake force (EQX) and ETABS software.

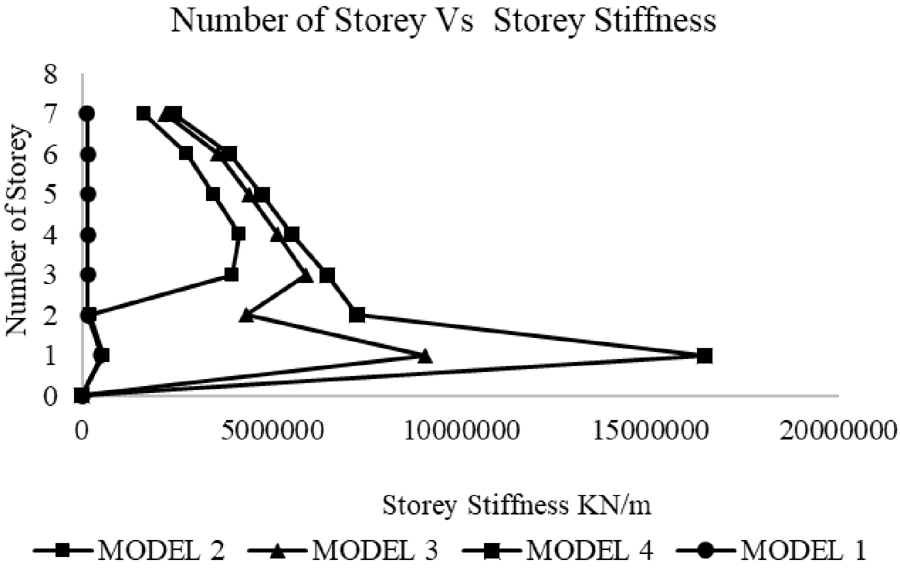


Fig. 9. Comparison of Number of Storey Vs Storey Stiffness.

Table 2
Comparison of the number of models and maximum storey stiffness

Model No.	Maximum Storey Stiffness (KN/m)	Change of Storey stiffness with respect to Model-2
Model-2	4139608	---
Model-3	9080093	+119%
Model-4	16448918	+ 297%

3.2 Comparison of storey drift ratio

A comparison of storey drift ratio curves for all of the building models is shown in Figure 10 and also comparison model 2-4 shown in Table 3 below. Storey drift ratio is obtained from the X direction performing a nonlinear static pushover analysis (PUSHX) and ETABS software.

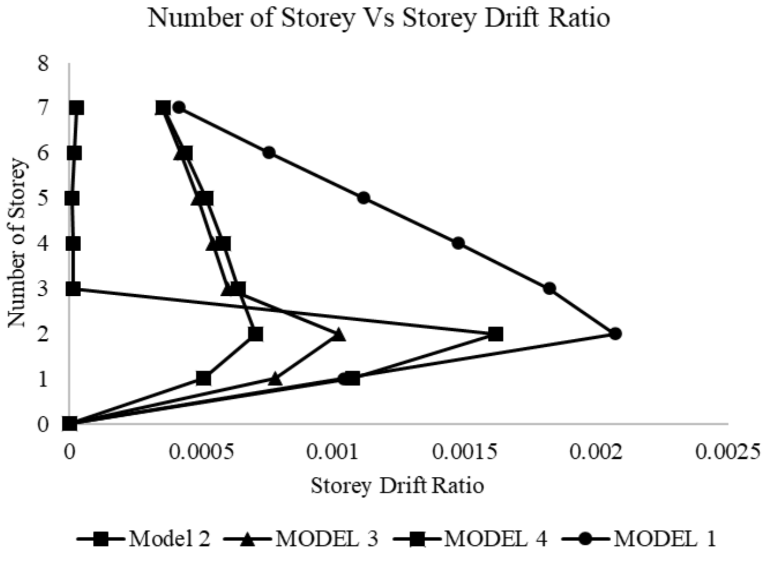


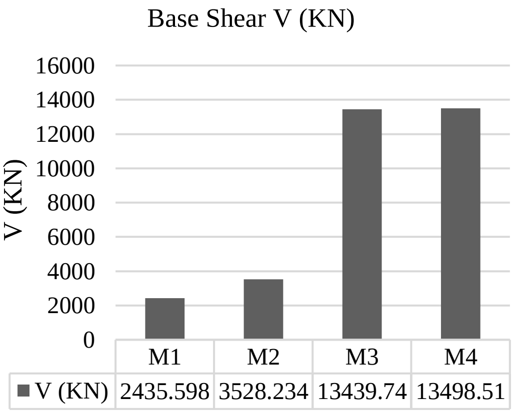
Fig. 10. Comparison of Number of Storey Vs Storey Drift Ratio.

Table 3
Comparison of the number of models and maximum storey drift ratio

Model No.	Maximum storey Drift ratio	Change of storey drift with respect to Model-2
Model-2	0.001617	---
Model-3	0.001021	-37%
Model-4	0.000705	-56%

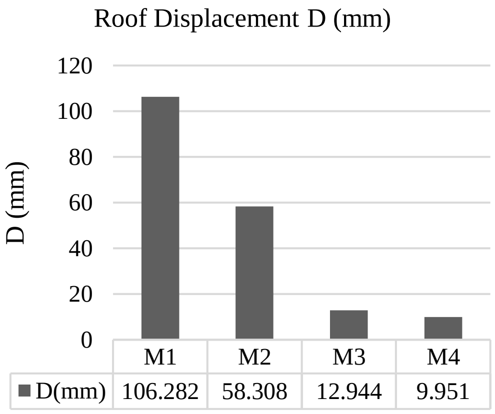
3.3 *Comparison of base shear, roof displacement, spectral acceleration, spectral displacement and effective time period*

A comparison of base shear, roof displacement, spectral acceleration, spectral displacement and effective time period at performance point from the pushover analysis for all of the buildings model is shown in Figures 11-15 and also comparison model 2-4 shown in Tables 4-6 below. Performance point is obtained from the X direction performing a nonlinear static pushover analysis (PUSHX), ATC 40 (1996) and SAP2000 software.



	M1	M2	M3	M4
■ V (KN)	2435.598	3528.234	13439.74	13498.51

Fig. 11. Comparison of base shear at performance point.



	M1	M2	M3	M4
■ D(mm)	106.282	58.308	12.944	9.951

Fig. 12. Comparison of roof displacement at performance point.

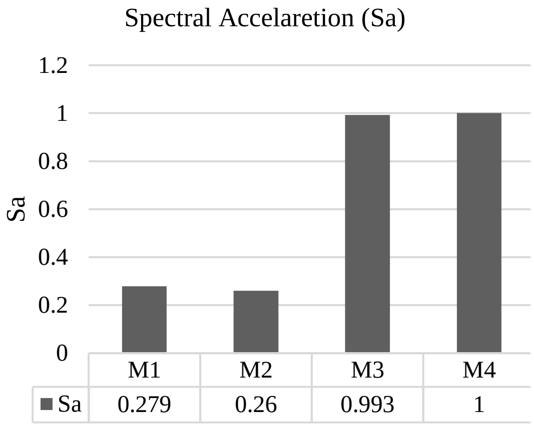


Fig. 13. Comparison of spectral acceleration at performance point.

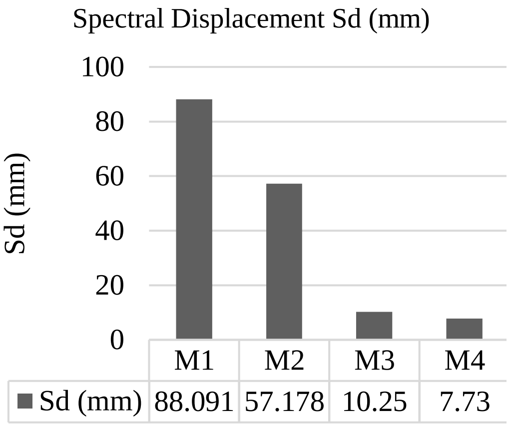


Fig. 14. Comparison of spectral displacement at performance point.

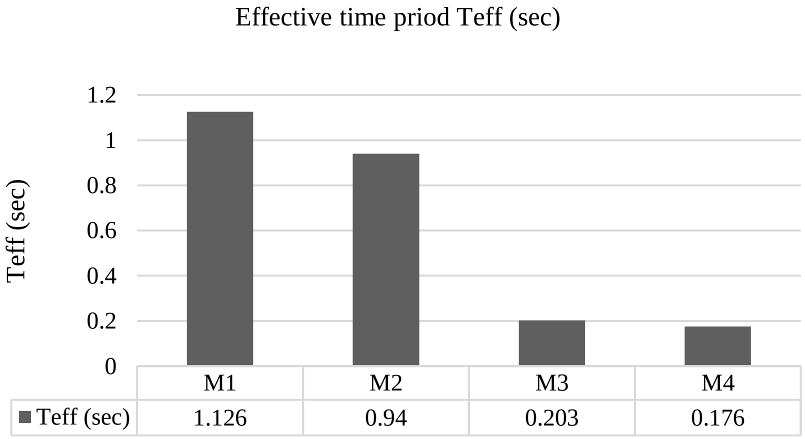


Fig. 15. Comparison of effective time period at performance point.

Table 4
Performance points were compared with base shear and roof displacement

Model No.	Base Shear, V (KN)	Change of Base Shear with respect to Model-2	Roof Displacement, D (mm)	Change of Roof Displacement with respect to Model-2
Model-2	3528.234	--	58.308	--
Model-3	13439.739	+281%	12.944	-78%
Model-4	13498.511	+ 283%	9.951	-83%

Table 5
Performance points were compared with spectral acceleration and spectral displacement

Model No.	Spectral Acceleration, Sa	Change of Sa with respect to Model-2	Spectral Displacement, Sd (mm)	Change of Sd with respect to Model-2
Model-2	0.26	---	57.178	---
Model-3	0.993	+282%	10.25	-82%
Model-4	1	+ 285%	7.73	-86%

3.4 Comparison of base shear vs. roof displacement

A comparison of pushover curves for all of the building model is shown in Figure 16 below. This curve is obtained from X direction performing a nonlinear static pushover analysis

(PUSHX), ATC 40 and SAP 2000 software. The pushover curve shows base shear Vs roof displacement obtained from pushover analysis. The white points (○) of Figure 16 indicate the performance point of all the building models respectively where capacity meets the demand.

Table 6
Performance points were compared with the effective time period

Model No.	Effective Time Period, Teff (sec.)	Change in T_{eff} (sec.) with respect to Model-2
Model-2	0.94	--
Model-3	0.203	-78%
Model-4	0.176	-81%

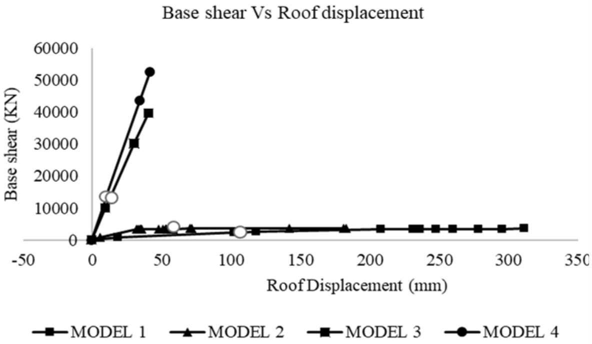


Fig. 16. Comparison of base shear vs. roof displacement.

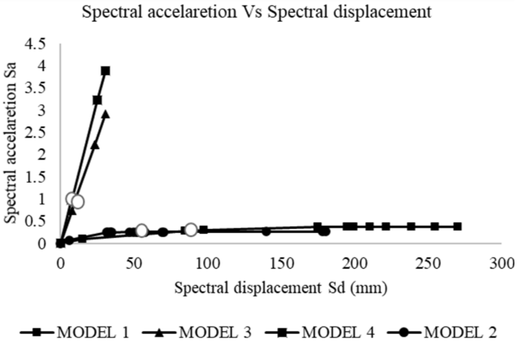


Fig. 17. Comparison of spectral acceleration vs. spectral displacement.

3.5 *Comparison of spectral acceleration vs. spectral displacement*

A comparison of spectral acceleration Vs spectral displacement for all of the building model is shown in Figure 17 below. This curve is obtained from X direction performing a nonlinear static pushover analysis (PUSHX), ATC 40 (1996) and SAP2000 software.

The white points (○) of Figure 17 indicate the performance point of all the building models respectively where capacity meets the demand. Performance point is obtained from the X direction performing a nonlinear static pushover analysis (PUSHX), ATC 40 (1996) and SAP2000 software.

3.6 *Comparison of location of plastic hinges*

A comparison of the location of plastic hinges formed for all of the building models is shown in Figures 18-21 below. These hinges formed is obtained from X direction performing a nonlinear static pushover analysis (PUSHX), ATC 40 (1996) and SAP2000 software.

Table 7
Comparison of hinges formed status for all of the models

Model No.	Hinge Formed Status: Load Case PUSH_X								
	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E	Total
Model-1	952	308	148	0	0	20	0	0	1428
Model-2	1888	16	84	0	0	60	0	0	2048
Model-3	1888	160	0	0	0	0	0	0	2048
Model-4	1858	190	0	0	0	0	0	0	2048

A: Initial Stiffness; B: End of Elastic Stiffness; IO: Immediate Occupancy; LS: Life Safety; CP: Collapse Prevention; C: Collapse; D: Damage; E: Energy Loss;

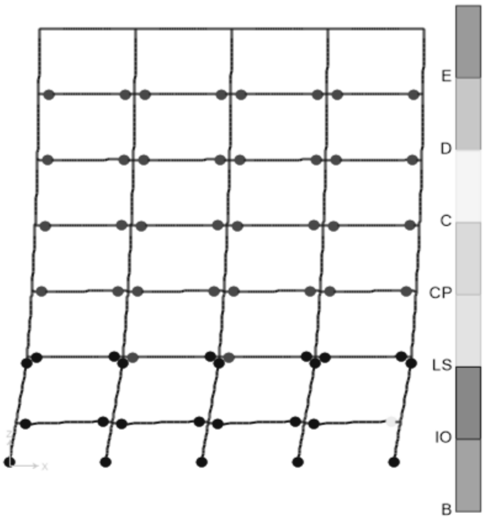


Fig. 18. Comparative location of plastic hinges at the last step of model 1 (section 1-1)

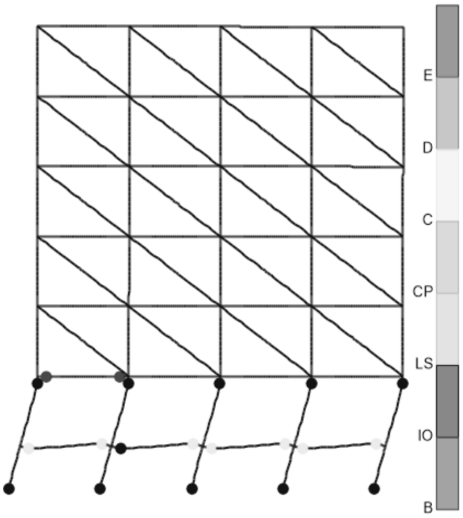


Fig. 19. Comparative location of plastic hinges at the last step of model 2 (section 1-1).

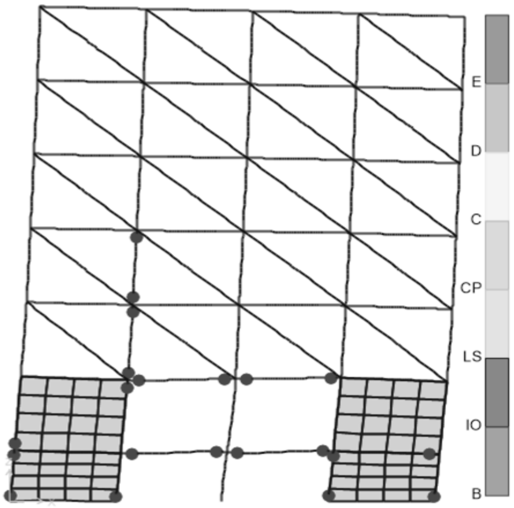


Fig. 20. Comparative location of plastic hinges at the last step of model 3 (section 1-1).

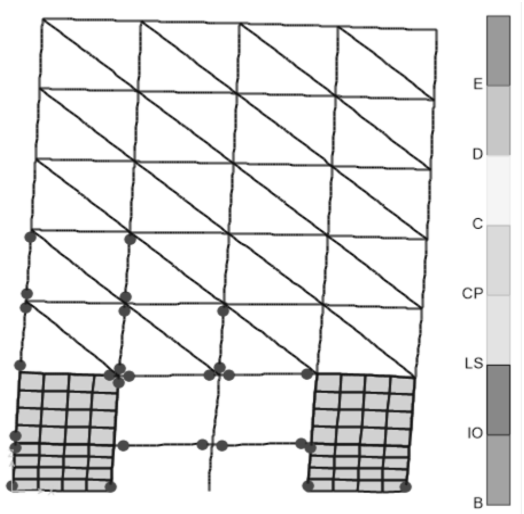


Fig. 21. Comparative location of plastic hinges at the last step of model 4 (section 1-1).

4. Conclusions

The general output of the investigation indicates a different characteristic behavior of additional wall, beam and column size RC frame with open (soft) ground floor when the structural effect of the additional wall, beam and column size is incorporated in the model and pushover analysis is performed. The results are summarized below.

- Model 3 and Model 4 have 119% and 297% more storey stiffness than Model 2.
- Model 3 and Model 4 have 37% and 56% less storey drift ratio than Model 2.
- Model 3 and Model 4 have 281% and 283% more base shear capacity than Model 2.
- Model 3 and Model 4 have 78% and 83% less roof displacement than Model 2.
- Model 3 and Model 4 have 282% and 285% more spectral acceleration capacity than Model 2.
- Model 3 and Model 4 have 82% and 86% less spectral displacement than Model 2.
- Model 3 and Model 4 have 78% and 81% less effective time period than Model 2.

- Observing the location of the plastic hinges at the last step shows that the model 3 and model 4 from the End of Elastic Stiffness (B) to the immediate occupancy level and the model 2 from the collapse to the damage level.

This is because the beam and column area on the open floor has not been increased in Model 2 and no additional wall has been added. On the other hand, the beam and column area has been increased by 10% and 20% on the open floor in Model 3 and 4 and 125 mm and 250 mm additional wall has been added by four corners. So, from the above results, we can probably infer that Model 3 and Model 4 prevented soft storey irregularity. From the location of the plastic hinges formed result, we can probably infer that Model 3 and Model 4 are earthquake-resistant buildings.

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