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SEISMIC ANALYSIS OF RCC STRUCTURES WITH SOFT STOREY AT DIFFERENT LEVEL

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Abstract: With urbanization and increasing unbalance of required space to availability, it is becoming imperative to provide open ground storey and soft storey at different level of multistory building. These provisions reduce the stiffness of the lateral load resisting system and a progressive collapse becomes unavoidable in a severe earthquake for such buildings due to soft stories. Soft storey behavior exhibit higher stresses at the columns and the columns fail as the plastic hinges are formed. Hence it is required to assess the performance level of such building for safety of the structure during earthquake. In present study G+12 storey building is considered by keeping soft storey at different level along with soft storey at ground level. They are designed according to IS 456-2000 without ductile detailing and seismic evaluation of these buildings is carried out with nonlinear static pushover analysis using SAP 2000 software. Performance points and performance levels of these buildings are determined by capacity spectrum method. In this it is found that in all the beams plastic hinges are formed and hinges are also formed at ground soft storey columns. In brick infill hinges formed are of E level. Then various retrofitting schemes viz. steel X braces, infill walls and shear walls are employed for strengthening of these building to reduce hinges from beam and remove hinges from columns. The results obtained from these retrofitting schemes are compared with without retrofitted models based on performance point, hinge formation pattern. The result shows that there is no unique solution and several different strengthening schemes can be provided to give adequate performance. Most increase in the lateral strength is related to using Steel-Bracing and shear walls.

Keywords: soft storey, plastic hinges, seismic evaluation, static pushover analysis, shear wall system, performance point.

1. INTRODUCTION

Investigations of past and recent earthquake damage have illustrated that the building structures are vulnerable to severe damage or collapse during moderate to strong ground motion. An earthquake with a magnitude of six is capable of causing severe damages of engineered buildings, bridges, industrial and port facilities as well as giving rise to great economic losses. Generally ordinary structures are built to safely carry their own weights and therefore perform poorly under large lateral forces caused by even moderate size earthquake. These lateral forces can produce the critical stresses in a structure and in addition cause lateral sway of the structure. Now a day's reinforced-concrete framed structure in recent time has a special feature i.e. the ground storey is left open for the purpose of parking. Also upper storey is left open for the purpose of communication hall etc. Such buildings are often called soft storey buildings. These soft storeys buildings are collapsed due to irregularities introduced in RC frame buildings. These irregularities are primarily due to uneven distribution of mass, strength and stiffness in both plan, elevation of the building. Discontinuities of frame member and masonry infill walls are common causes of irregularities in RC frame building which is commonly termed as open ground storey RC building. According to IS 1893 part 1: 2016, a soft storey is one in which the lateral stiffness is less than the lateral stiffness of storey above.

2. BEHAVIOR OF SOFT STOREY AND RC FRAMES UNDER LATERAL LOADS

Due to increasing population since the past few years car parking space for residential apartments in populated cities is a matter of major concern. Hence the trend has been to utilize the ground storey of the building itself for parking. Also for offices or for any other purpose such as communication hall etc. soft storeys at different levels of structure are constructed. With ground soft storey, for office space open floor is required on different levels of building. Experience in the past earthquake has shown that the buildings with simple and uniform configurations are subjected to less damage. Regularity and continuity of stiffness in the horizontal planes as well as in vertical direction is very important from earthquake safety point of view. A building with discontinuity is subjected to concentration of forces and deformations at the point of discontinuity which may leads to the failure of members at the junction and collapse of building carbon dioxide, is created when fossil fuels like oil andgas are burned to produce energy. Masonry infill walls are widely used as partitions all over the world. Evidences are that continuous infill masonry walls can reduce the vulnerability of the reinforced concrete structure. Often masonry walls are not considered in the design process because they are supposed to act as non-structural members or elements. Separately the infill walls are stiff and brittle but the frame is relatively flexible and ductile. The composite action of beam-column and infill walls provides additional strength and stiffness. But as the infill walls are not provided at the intermediate soft storey the failure of that storey takes place during earthquake due to discontinuity in stiffness distribution, mass distribution etc. As a result of failure of intermediate soft storey the above floors of multistory buildings collapse.

3.NECESSITY OF PUSHOVER ANALYSIS

The pushover is expected to provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis. The following are the examples of such response characteristics:

1. The realistic force demands on potentially brittle elements, such as axial force demands on columns, force demands on brace connections, moment demands on beam to column connections, shear force demands in reinforced concrete beams, etc.
2. Estimates of the deformations demands for elements that have to form in elastically in order to dissipate the energy imparted to the structure.
3. To understand the effect of the strength deterioration of individual elements on behavior of the structural system.
4. Identification of the critical regions in which the deformation demands are expected to be high.
5. Estimates of the inter storey drifts that account for strength or stiffness discontinuities and that may be used to control the damages and to evaluate P- Delta effects.

4. OBJECTIVES

1. To study g+12 storey building to determine seismic capacity of reinforced concrete framed buildings with soft storey at different levels by using non-linear static pushover analysis as follows:
   a. Soft storey at GL &4th floor.
   b. Soft storey at GL &8th floor.
   c. Soft storey at GL &12th floor
2. To find out performance points of above buildings and decide performance levels by using capacity spectrum method.
3. To study the plastic hinges formation pattern for G+12 storey building with soft storey at different levels.
4. To analyze the seismic performance of above buildings by using strengthening measures such as reinforced concrete shear walls, steel bracings and infill walls and to study effects of these strengthening measures on performance of buildings.
5. To suggest most efficient strengthening system out of infill walls, reinforced concrete shear walls and steel bracings.

5.RESEARCH METHODOLOGY

This chapter presents pushover analysis of G+12 storied building with soft stories at different levels, to check their performance against lateral forces. Analyses have been performed using SAP2000, which is a general- purpose structural analysis program for static analyses of structures.

5.1 Description of building

1. Size of Building: 20 m X 20 m.
2. Grade of concrete: M 25
3. Grade of steel: Fe 415
4. Floor to floor height: 3.2 m
5. Plinth height above foundation: 2 m
6. Parapet height: 1.5 m
7. Slab thickness: 150 mm
8. Wall thickness: 230 mm
9. Size of columns: 600mm X 600mm
10. Size of beam: 300mm X 700mm
11. Live load on floor: 4kN/m 2
12. Floor finishes is 1.5kN/m 2
13. roof treatment: 1.5 kN/m 2
14. Seismic zone: V
15. Soil condition: Medium
16. Importance factor: 1
17. Building frame:Special moment resting frame (SMRF)
18. Density of concrete: 25 kN/m 3
19. Density of masonry wall:20kN/m3

5.2 Description of Model

The description of the models are given as below

1. G+12 storey building with soft storey at GL & 4th floor.
2. G+12 storey building with soft storey at GL & 8th floor.
3. G+12 storey building with soft storey at GL & 12th floor.
4. G+12 storey building with soft storey at GL & 4th floor retrofitted with brick infill walls.
5. G+12 storey building with soft storey at GL & 8th floor retrofitted with brick infill walls
6. G+12 storey building with soft storey at GL & 12th floor retrofitted with brick infill walls.
7. G+12 storey building with soft storey at GL & 4th floor retrofitted with shear walls.
8. G+12 storey building with soft storey at GL & 8th floor retrofitted with shear walls.
9. G+12 storey building with soft storey at GL & 12th floor retrofitted with shear walls.
10. G+12 storey building with soft storey at GL & 4th floor retrofitted with steel X bracing.
11. G+12 storey building with soft storey at GL & 8th floor retrofitted with steel X bracing.
12. G+12 storey building with soft storey at GL & 12th floor retrofitted with steel X bracing.

5.3 Load calculation

Following loads are considered for the analysis of the buildings. The loads are taken in accordance with IS: 875.

5.3.1. Gravity loads

Slab load (Dead slab)

a) Intensity of slab load = 0.15 x 1 x 25 = 3.75 kN/m.

b) Wall load

External wall load intensity = 0.23 x (3.2-0.7) x 20 = 11.5 kN/m.

Internal wall load intensity = 0.150x(3.2-0.7)x20=7.5 kN/m.

c) Floor finish load (Dead FF)

Intensity of floor finish load = 1.5x1 = 1.5 kN/m.

d) Roof treatment load (Dead RT)

Intensity of roof treatment load = 1.5 x 1 = 1.5 kN/m.

5.3.2. Live loads

a)Intensity of live load =4x1 = 4 kN/m.

6. Performance level of structure and elements

Each Building Performance Level is made up of a Structural Performance Level that describes the limiting damage state of the structural systems and a Nonstructural Performance Level that describes the limiting damage state of the nonstructural systems. The performance levels are the discrete damage states identified from a continuous spectrum of possible damage states. The structural performance levels based on the roof drifts are as follows:

a) Immediate occupancy (IO) b) Life safety (LS) c) Collapse prevention (CP) The three levels are arranged according to decreasing performance of the lateral load resisting systems.

7. Capacity curves and seismic performance levels of buildings.

Pushover curves for buildings with soft storey at a) GL & 4th floor b) GL & 8th floor

In this method without retrofitted models are created. To decide the retrofit scheme, a performance level approach is adopted. The performance based approach identifies a target building performance level under an anticipated earthquake level. The coefficients C_A and C_V in SAP2000 are taken to model the design spectrum as per the IS1893 (Part1):2016 requirement to get the performance point. Seismic zone is V and zone factor (Z) is 0.36. The demand spectrum for design basis earthquake is obtained from peak ground acceleration (PGA) of (Z/2 x g = 0.18g). The soil is considered as medium and C_V = 1.36 x Z/2 for medium soil as per IS: 1893-2002. Therefore, the demand spectra is plotted with C_A = 0.18g and C_V =1.36 x 0.18g = 0.2448g for 5% initial damping.

Performance point and performance levels for basic models

It is observed that open ground soft storey building suffered damage though the seismic performance level is B-IO, since the plastic hinges are developed at ground soft storey column level, which may start progressive damage to building. Hence these building require strengthening in both directions. Table 01

storey	X	Y	level
GL&4th	5350.919,123	5350.919,123	B-IO
GL &8th	5606.610,125	5606.610,125	B-IO
GL &12th	5782.512,127	5782.512,127	B-IO

8.1 Addition of infill masonry walls

Adding infill masonry walls is most simple system to increase stiffness of the storey. Masonry walls are rigid and acts as partition between compartments. It controls overall drift of the building. The brick infill is considered as a nonstructural element. But providing brick infill increases the stiffness and base shear.

Table 02

storey	X	Y	level
GL&4th	5350.919,123	5350.919,123	B-IO
GL &8th	5606.610,125	5606.610,125	B-IO
GL &12th	5782.512,127	5782.512,127	B-IO

After modeling the infill walls with proper arrangement without disturbing the purpose of parking at GL and the purpose of upper soft storey, the performance of the building is represented by the capacity curve and hinge formation pattern. table shows the comparison of pushover curve for without retrofitted models and building with modeling of infill as retrofitting scheme. From the comparison of pushover curve it is seen that performance of the soft storey building is modified with the provision of infill walls at soft stories. Base shear of soft storey with infill is greater than the basic model. The performance point in terms of base shear and roof displacement is given in Table above.

8.2 Addition of RC structural walls

Adding structural walls is one of the most common structure-level retrofitting methods to strengthening existing structures. This approach is effective for controlling global lateral drifts and for reducing damage in frame members. Generally, repair of an existing shear wall or infilling one of the bays in the frame structure is used. In order to reduce time and cost, shot-Crete or precast panels can be used. The research shows that with the infilling process, details play an important role in the response of panels and the overall structure. The infilling process tends to stiffen the structure such that the base shear can increase. The overturning effects and base shear are concentrated at the stiffer infill locations. Therefore, strengthening of the foundation is typically required at these locations

Table 03

storey	X	Y	level
GL&4th	273.723,93	7273.723,93	B-IO
GL &8th	8335,92	8335,92	B-IO
GL &12th	9248.394,91	9248.394,91	B-IO

It is seen that after providing the shear walls at corner the performances point of building gets increased. The hinges are not formed in columns and hinges from beams get reduced.

8.3 Use of steel X bracing

The addition of steel bracing can be effective for the global strengthening and stiffening of existing buildings. Concentric or eccentric bracing schemes can be used in the selected bays of an RC frame to increase the lateral resistance of the structure. The advantage of this method is that an intervention of the foundation may not be required because steel bracings are usually installed between existing members. Increased loading on the existing foundation is possible at the bracing locations and so the foundation still must be evaluated. In addition, the connection between the existing concrete frame and the bracing elements should be carefully treated because the connection is vulnerable during earthquakes

Table 04

storey	X	Y	level
GL&4th	6000,118	6000,118	B-IO
GL &8th	6047.532,119	6047.532,119	B-IO
GL &12th	6077.64,120	6077.64,120	B-IO

From the capacity curves and table it is seen that the performance of structure is modified with addition of bracings in the structure.

9. Comparison of capacity curves of soft storey building with various retrofitting strategies in X and Y direction

Fig 1 to fig. 5 represents the comparison of capacity curve (base shear vs. roof displacement) for basic gravity model and the retrofitting strategies for building with soft storey at 1) GL &4th floor 2) GL &8th floor 3) GL &12th floor in X and Y direction.

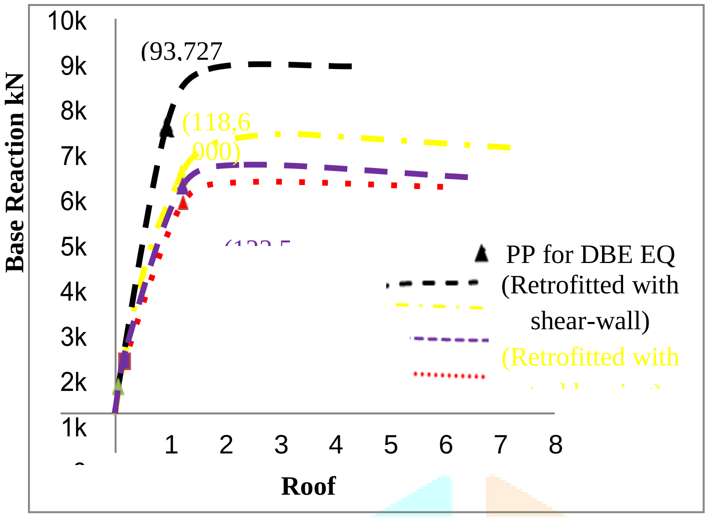

Fig.1 Capacity curve for various retrofitting strategy for G+12 building (with soft Storey at Ground level and 4th Floor Level) in X direction

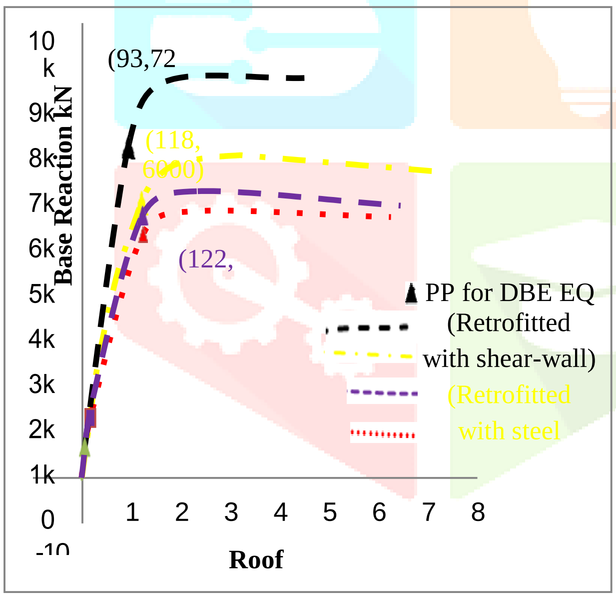

Fig.2 Capacity curve for various retrofitting strategy for G+12 building (with soft Storey at Ground level and 4th Floor Level) in Y direction.

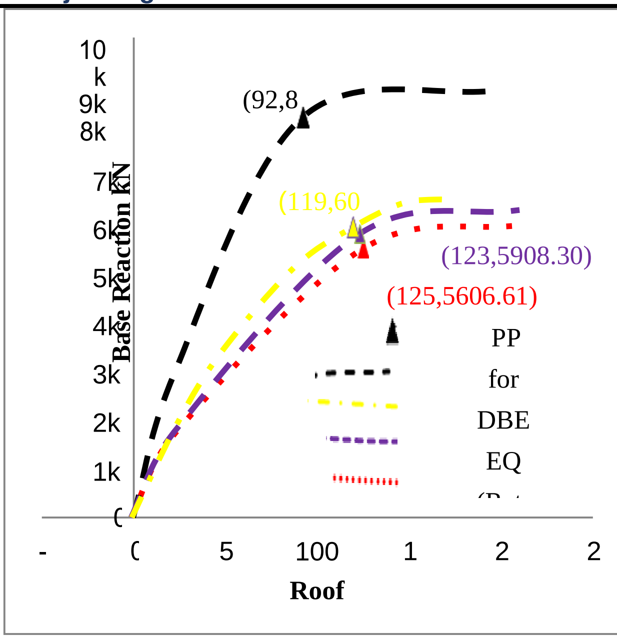

Fig.3 From the capacity curves and table it is seen that the performance of structure is modified with addition of bracings in the structure.Fig..3 Capacity curve for various retrofitting strategy for G+12 building (with soft Storey at Ground level and 8th Floor Level) in X direction.

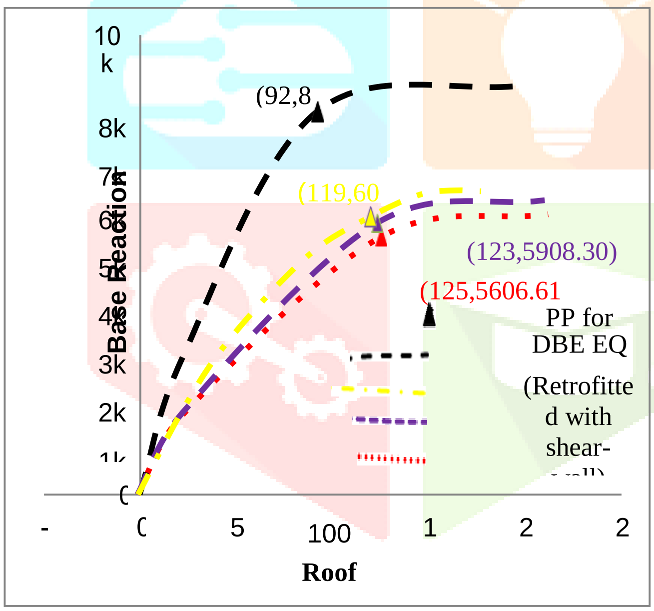

Fig.4 Capacity curve for various retrofitting strategy for G+12 building (with soft Storey at Ground level and 8th Floor Level) in Y direction.

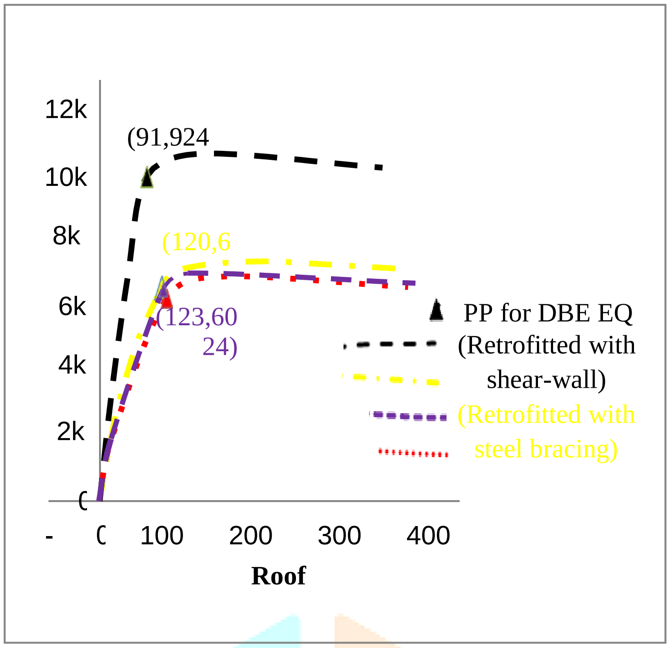

Fig.5Capacity curve for various retrofitting strategy for G+12 building
(with soft Storey at Ground level, 12th Floor Level) in X and Y direction

From these comparisons of capacity curves it is clear that performance for the models retrofitted with infill walls and bracing is closer to the models without retrofitted. But the performance of the models retrofitted with shear walls is modified as compared to without retrofitted models and models retrofitted with infill walls and bracing.

Table 05 Comparison of performance point for various retrofitting strategy

soft storey at	Gravity		Infill wall		Steel X brace		Shear wall	
	X direction (kN, mm)	Y direction (kN, mm)	X direction (kN, mm)	Y direction (kN, mm)	X direction (kN, mm)	Y direction (kN, mm)	X direction (kN, mm)	Y direction (kN, mm)
GL & 4th floor	5350.91,123	5350.91,123	5771.32,122	5771.32,122	6000,118	6000,118	7273.72,93	7273.72,93
GL & 8th floor	5606.61,125	5606.61,125	5908.3,123	5908.3,123	6047.53,119	6047.53,119	8335,92	8335,92
GL & 12th floor	5782.51,127	5782.51,127	6024.24,123	6024.24,123	6077.64,120	6077.64,120	9248.39,91	9248.39,91

From table 05 it is clear that as the soft storey is shifted to upper level the base shear increases. The performance of the building when retrofitted with shear walls is better as compared to other retrofitting strategy. The displacement of the building is much reduced when retrofitted with shear walls as compared to without retrofitted models. The performance of the buildings is better when retrofitted with bracing as compared to without retrofitting models and models retrofitted with infill walls.

10. Conclusions

This study highlights the poor seismic performance of RCC buildings with soft storey at different level along with soft storey at ground level. The study is carried out for three buildings i.e. building with soft storey at a) GL &4th floor, b) GL &8th floor, c) GL &12th floor. All buildings are modeled in SAP 2000 and nonlinear static procedure (NSP) or pushover analysis is carried out. Buildings were found to be deficient due to formation of hinges in columns at ground level soft storey as well as in columns of upper soft storey. Hence it is seen that buildings are failed by soft storey mechanism in GL hence retrofitting is suggested. It is also seen that most of the hinges are formed inbeams. As a result different strengthening schemes are used to improve performance of deficient buildings. All these different retrofitting strategies are aimed to improving performance level for DBE condition. Based on results following conclusions are drawn.

10.1 Performance of soft storey kept at different level

- Soft storey buildings designed as per IS: 456-2000 are seismically deficient. These buildings are unable to produce sufficient lateral load resisting capacity during an earthquake to avoid sever damages. In all the three buildings with soft storey at different level the linear hinges are formed in columns of bottom soft storey at performance point.
- At performance point in all beams B-IO hinges are formed and in brick wall CP-E level hinges are formed.
- It is observed that as the uppers soft storey in multistory building is kept at higher level the base shear of building increases.
- As the soft storey is shifted to higher level the intensity of hinge formation becomes lower and lower.
- As the soft storey is shifted to higher level the displacement of building increases.
- As the soft storey is shifted to higher level the Ta of building decreases.

10.2 Effect of infill walls

- It is observed that when brick infills are provided as a retrofitting strategy the base shear of building is increased and also displacement gets reduced in both X and Y direction as compared to without brick infill in soft storeys.
- The Ta of building is reduced but which is not in permissible limit.
- Hinges formed in beams are reduced to some extent but hinges formed in columns at ground soft storey are not removed completely. Hence it cannot be used as retrofitting strategy. The hinges are also formed at Centre of infill walls.

10.3 Effect of shear walls

- The study of hinge formation patterns in case of buildings retrofitted with RC shear walls show that hinges are not developed in columns.
- Hinges formed in beams are at operational level (B) at performance point.
- Hinges crosses collapse (C) level in case of masonry struts.
- After retrofitting with shear walls it is observed that the base shear carried at performance point is increased also Ta is decreases which are in permissible limit.
- Roof displacement of the buildings when they are retrofitted with shear walls is less as compared to steel X braces and infill walls.
- As the shear walls are provided up to the upper soft storey the roof displacement decreases and base shear increase.

10.4 Effect of steel X braces

- The study of hinge formation patterns in case of buildings retrofitted with steel X braces show that hinges are not developed in columns.
- Hinges formed in beams are at operational level at performance point.
- Hinges formation in bracing are at B-IO level for soft storey at 4th, 8th and 12th floor.
  It is observed that most of the steel braces fail in compression because of buckling at performance point, if stronger braces are used; failure mechanism may be transferred to a column which is not accepted. Hinges crosses collapse(C) level in case of masonry infills at 4th, 8th, 12th. The hinges are formed at center of masonry infill strut.
- After retrofitting with steel X bracing it is observed that the base shear carried at performance point is increased.
- The displacement of building when retrofitted with X bracing is reduced than that of retrofitted with infill walls.
- The Ta of building is reduced but which is not in permissible limit.

10.5 Comparison between three retrofitting strategies

- It is seen that when alternate brick walls are provided as a retrofitting scheme the hinges from columns of bottom storey are not removed hence it is not very efficient as a retrofitting strategy.
- When bracings are provided as a retrofitting strategy the hinges from columns get removed completely. Hinges are formed in bracing.
- When soft storey of building is retrofitted with shear walls the hinges from columns get totally removed at the performance point. The hinges from beams are reduced to linear level and hinges formed in walls are CP range which is acceptable criteria in FEMA356. It is because of shear walls increase stiffness of the building more than other two retrofitting schemes.
- Roof displacement for infill walls and steel X braces are found to be closer.
- The Ta of model retrofitted with shear wall is in permissible limit.
- At performance point, maximum roof displacement is observed in steel X braces as compared to model retrofitted with shear walls because steel itself is more ductile material than concrete; also steel braces contributes negligible mass and stiffness to the original mass and stiffness of the structure.
- At performance point, maximum roof displacement is observed in infill walls as compared to model retrofitted with shear walls because stiffness of shear wall is greater than infill wall.
- A number of different strengthening systems can be adopted to improve the seismic performance of deficient buildings. The

performance of particular retrofitting strategies depends upon the structural properties of original deficient building. In this case shear walls placed in outer bay as well as steel X bracings improved the performance to desired level. But performance is better when shear walls are provided in outer bays at corner.

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