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Seismic Evaluation of Infilled Reinforced Concrete Framed Buildings by Using Pushover Analysis

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ABSTRACT

Many existing buildings lack the seismic strength, because they were designed for only gravity loads or built prior to the implementation of these codes. Hence it is required to assess the performance level of such buildings for safety of the structure. In present study three gravity designed buildings 8, 12 and 16 storied are considered. Seismic evaluation of these buildings is carried out with nonlinear static pushover analysis using SAP2000 software. Performance points and performance levels of these buildings are determined by capacity spectrum methods. All three buildings are found in life safety to collapse prevention (LS-CP) range for design basis earthquake condition. Then infill walls as a retrofitting schemes is employed for Strengthing of these buildings, performance level requirement of operational to immediate occupancy (B-IO) under design basis earthquake is aimed at. The results are compared based on performance point, hinge formation pattern, yield strength and lateral stiffness.

Keywords - *Hinge formation pattern, Lateral stiffness, Pushover, Shear wall and infill wall, Yield strength*

1. Introduction

The widespread damage to reinforced concrete buildings during past earthquakes in India such as Bhuj (26 January, 2001), Chamoli (30 March, 1999), Latur (30 September, 1993) exposed the construction practices being adopted in India, and generated a great demand for seismic evaluation and retrofitting of buildings. Strengthening of structures proves to be a superior option catering to the economic considerations and immediate accommodation problems rather than complete replacement of buildings [1]. Therefore, seismic retrofitting or strengthening of building structures is one of the most important aspects for mitigating seismic hazards especially in earthquake prone areas. There are number of technics available for seismic retrofitting for RC buildings. Retrofitting may be carried out on a global basis or at local basics. At global basics it may be done by adding extra load-resisting elements such as steel frames or steel braces to the structure or on a local basis by retrofitting the existing structural elements. Steel bracing can be a very effective method for global strengthening of buildings. Some of the advantages are the ability to accommodate openings, the minimal added weight to the structure and in the case of external steel systems minimum disruption to the function of the building and its occupants. Concentric steel bracing systems have been investigated for the rehabilitation of non-ductile buildings by many researchers.

In present study an attempt has been made to study effect of infill walls on seismic parameters such as performance levels, hinge pattern formation, yield strength, lateral stiffness of RC buildings. To serve the purpose 3 gravity designed buildings 8, 12 and 16 storey are evaluated as per guidelines laid by FEMA356 and ATC40. These buildings found seismically deficient and strongly required Strengthing. Hence a comparative study of has been made between a bare frame models and infill wall models.

2. Modeling of RC Buildings

Three buildings 8, 12 and 16 stories are considered for this study. Buildings are designed only for gravity loadings as per IS456:2000 as an ordinary moment resisting frame. The buildings are situated in zone V. The plan area of all three buildings is 25 m× 20m as shown in fig.1.Plinth height above GL is 0.55 m. Depth of Foundation is 0.65 m below GL. Height of each typical storey is 3.1m. Slab Thickness is 150 mm for all three buildings. External wall thickness is 230 mm and internal wall thickness is 150 mm. Grade of concrete is M 20 and for steel it is Fe 415.

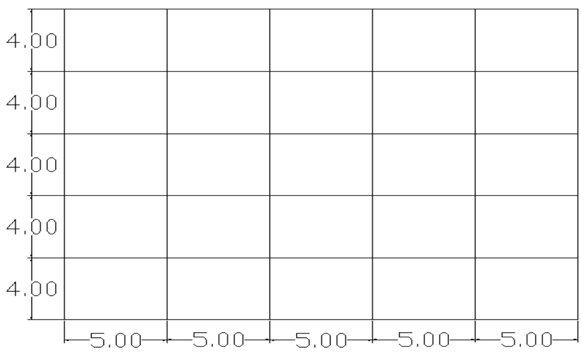

fig.1 plan of building (Note: All dimensions are in m)

The buildings are modeled by using SAP2000 finite element software. Line element having 6 DOF per node is used to model beams and columns. The slab is not modeled it is considered as rigid diaphragm and hence, self-weight due to slab is imposed directly on adjacent beams as dead load as per IS456:2000 yield line pattern. Infill walls are also not modeled but their dead weight is considered as uniformly distributed load on beams. Effect of soil structure interaction is ignored in analysis and bottom of each column is assumed to be fixed. Effective stiffness values for column and beams are taken from table no 6.5 from FEMA-356.

2.1 Nonlinear hinge assignment

In order to model nonlinear behavior in any structural element, a corresponding nonlinear hinge required to be assigned in the building model. The beams and columns are modeled with concentrated plastic hinges at the column and beam faces, respectively. Beams have only moment (M3) hinges, whereas columns have axial load and biaxial moment (PMM) hinges [2]. The moment-rotation relations and the acceptance criteria for the performance levels of the hinges were obtained from FEMA 356 and are directly taken from the SAP 2000 as Auto hinges.

3. Pushover Analysis

After designing and detailing of gravity buildings, a nonlinear statics pushover analysis is carried out using

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SAP2000. For this purpose, a constant gravity load, equals to total dead load plus 25% of live load is applied on structure (IS 1893-part I, 2002). An inverted parabolic distribution over the height is used as the lateral load pattern. The geometrical nonlinearity of the structure due to P-Δ Effects is considered [3].

3.1 Capacity curves and seismic performance level of buildings.

Specimen capacity curves for gravity designed 8 storied buildings in both X and Y directions are shown in fig.2 and fig.3. To decide the retrofit scheme, a performance level approach is adopted [1]. The performance based approach identifies a target building performance level under an anticipated earthquake level. For retrofit of the buildings requirement of life safety (LS) under design basis earthquake (DBE) is aimed at. The coefficients CA and CV in SAP 2000 are taken to model the design spectrum as per the Code requirement to get the performance point. Seismic zone is V and zone factor (Z) is 0.36. The demand spectrum for Design basics earthquake (DBE) is obtained from peak ground acceleration (PGA) of (Z/2 × g = 0.18g) [4]. The soil conditions have been considered as medium and CV = 1.36 × Z/2 for medium soil as per IS 1893:2002. Therefore, the demand spectra are plotted with CA = 0.18g and CV = 1.36 × 0.18g = 0.2448g for 5% initial damping [5],[6],[7] .

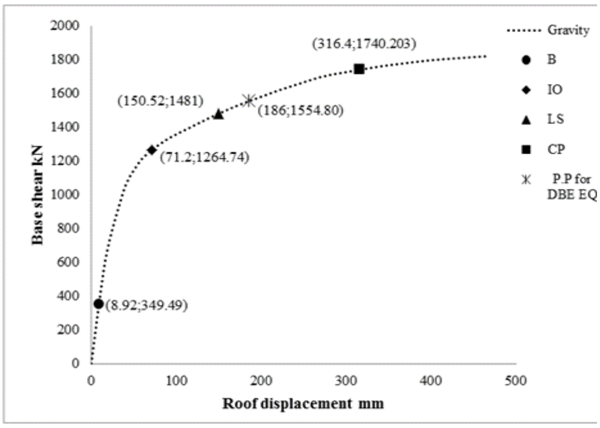


Fig.2 Pushover curve for 8 storied gravity designed Building in X direction

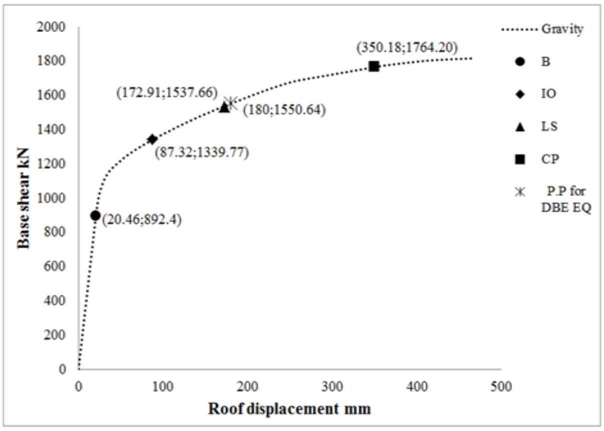
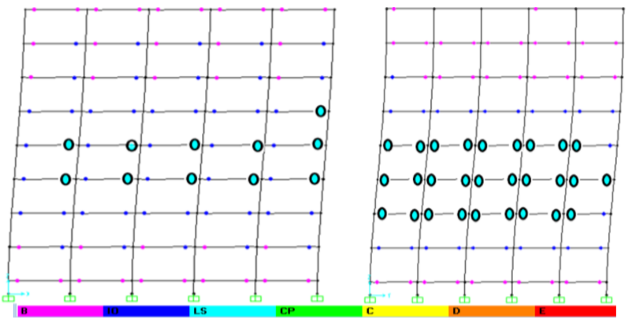


Fig.3 Pushover curve for 8 storied gravity designed Building in Y direction

Fig.4 to fig.6 shows the hinge formation patterns at performance point for 8, 12 and 16 storied gravity designed building in both X and Y direction.



(a) X direction (b) Y direction

Fig.4 Hinge formation at performance point for 8 storied building

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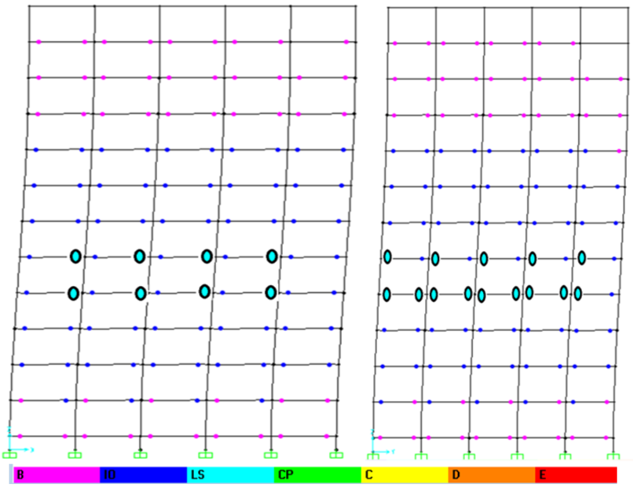
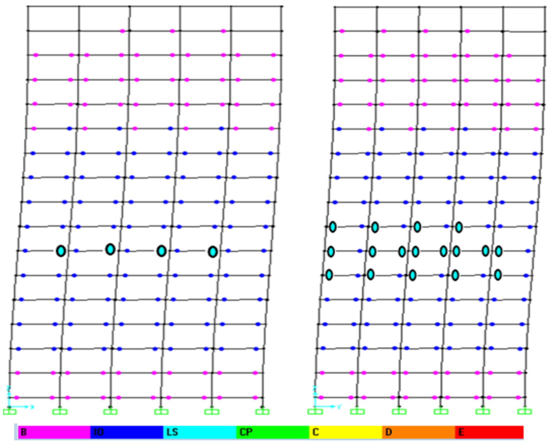


(a) X direction (b) Y direction

Fig.5 Hinge formation at performance point for 12 storied building



(a) X direction (b) Y direction

Fig.6 Hinge formation at performance point for 16 storied building

From fig. 4 to fig. 6 it is clear that gravity designed building suffered very serious damage. Plastic hinges are concentrated at middle storeys only. Beams in Y direction suffered more damage than beams in X direction. Table 1 show the performance point and performance levels for gravity designed buildings; in both directions.All three buildings are at LS-CP range. Hence buildings required strengthening in both directions.

It is observed that as building height increases base shear value and roof displacement also increases. The value of base shear at performance point is maximum for 16 storied building it is 1.19 times and 1.06 times more than 8 and 12 storied building in X direction. Whereas in Y direction it is 1.80 times and 1.07 times more than 8 and 12 storied buildings base shear values at performance point.

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Table no. 1 Performance point and performance level

Building	Gravity				Seismic performance level
	X direction		Y direction		
	Base shear (in KN)	Roof displacement (in mm)	Base shear (in KN)	Roof displacement (in mm)	
8 storey gravity designed	1553.94	186	1550.39	179.59	LS-CP
12 storey gravity designed	1745.62	246	1709.74	249	LS-CP
16 storey gravity designed	1864.83	315	1829.61	319	LS-CP

3.2 Evaluation of global performance characteristics of structure

To determine the various seismic parameters idealized force-displacement capacity curve was evaluated based on the method recommended FEMA356. The nonlinear force-displacement relationship between base shear and displacement of the control node was replaced with an idealized relationship to calculate the effective lateral stiffness, Ke, and effective yield strength, Vy, of the building as shown in fig.7. This relationship was taken as a bilinear, with initial slope Ke and post-yield slope α. Line segments on the idealized force-displacement curve was located using an iterative graphical procedure that approximately balances the area above and below the curve [8],[9]. The effective lateral stiffness, Ke , was taken as the secant stiffness calculated at a base shear force equal to 60% of the effective yield strength of the structure. The post-yield slope, α, determined by a line segment that passes through the actual curve at the calculated target displacement [10], [11].[12].

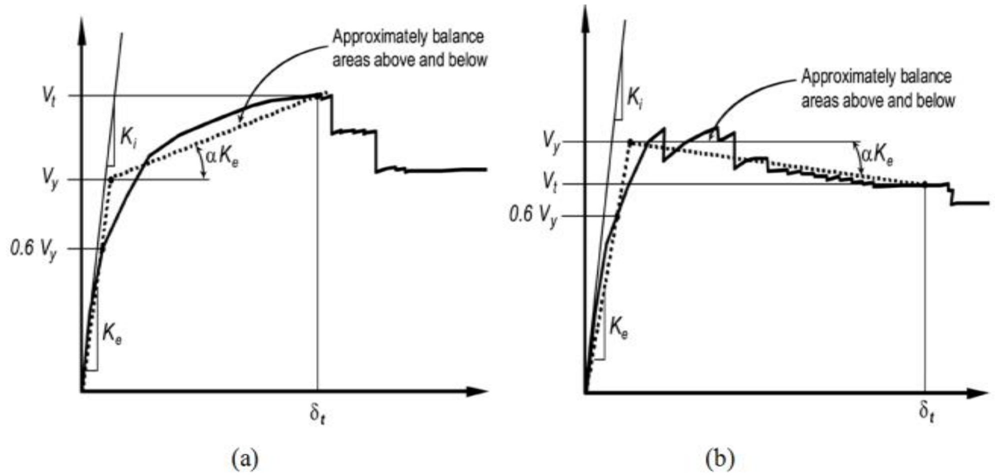

Fig. 7 Idealized force displacement curve for (a) positive yield slope (b) negative yield slope [2]

Table no.2 shows the seismic parameters for three buildings obtained from bilinearization of capacity curves.

Table no 2 Seismic parameters for 8, 12 and 16 storey gravity designed building.

Seismic parameters	8 storied		12 storied		16 storied	
	X direction	Y direction	X direction	Y direction	X direction	Y direction
Time period for cracked section (T sec)	1.7407	1.7407	2.01	2.01	2.24	2.24
Effective lateral stiffness (KekN/mm)	29.17	41.56	44.41	46.09	50.38	49.75
Post yield stiffness (αKekN/mm)	1.31	1.28	1.08	1.04	1.28	1.23
Idealised yield strength (VykN)	1342	1330	1510	1475	1612	1592
Target displacement (Δmax mm)	390	390	576	576	762	762
Yield displacement(Δy mm)	42	32	34	32	32	32

From the results obtained above it is clear all three 8,12 and 16 storey gravity designed buildings failed to give the performance of linear (B) immediate occupancy (IO). It also clear that all three buildings are lack in their lateral load carrying capacity and deficiencies are distributed in many stories as therefore the lateral strength and stiffness of the system should be improved. To improve their performance infill walls are used as retrofitting strategy.

4. Design and Modelling of Infill Wall

The single strut model is the most widely used as it is simple and evidently most suitable for large structures [3]. Thus, RC frames with unreinforced masonry walls can be modeled as equivalent braced frames with infill walls replaced by equivalent diagonal strut which can be used in rigorous nonlinear pushover analysis. The weight and mass of all the brick masonry walls are applied on the supporting beams. When an infill wall is located in a lateral load resisting frame, the stiffness and strength contribution of the infill wall are considered by modeling it as an equivalent diagonal compression strut [4],[5],[6]. The required properties of an equivalent strut are the effective width, thickness, length and elastic modulus [7]. The thickness is assumed same as that of the infill wall. The length is calculated from the dimensions of the corresponding infill panel. The elastic modulus of infill E_i is equated to E_m, the elastic modulus of the masonry. As per FEMA356, E_m is taken as 550 $\times f_m$, where f_m is the basic compressive strength of the masonry, hence E_m= 2035N/mm^2 and elastic modulus of concrete E_c = 2236N/mm^2.Thus, the only remaining property to be determined is the effective width of the equivalent strut. For a nonlinear analysis, such as pushover analysis, in addition to the above properties, the axial load versus deformation behavior along with the failure load of the equivalent strut are also required and it is taken directly from FEMA356.The effective width (a) has found to depend on the following variables [2], [12], [13].

1. The relative stiffness of the infill to the frame, expressed in terms of λ hinf.
2. The aspect ratio of the infill panel

Figures 8 to figure 13 shows capacity curves drawn as per ATC 40 for Gravity designed buildings and buildings retrofitted with infill walls. It is clear that retrofitting increase base shear value and decrease roof displacement at performance point. It is observed that buildings provided with infill walls provide performance level of operational (B) to immediate occupancy (IO) at performance point.

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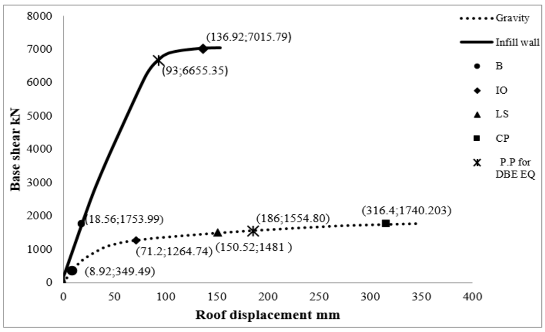


Fig.8 Capacity curve for 8 storied infill wall building in X direction

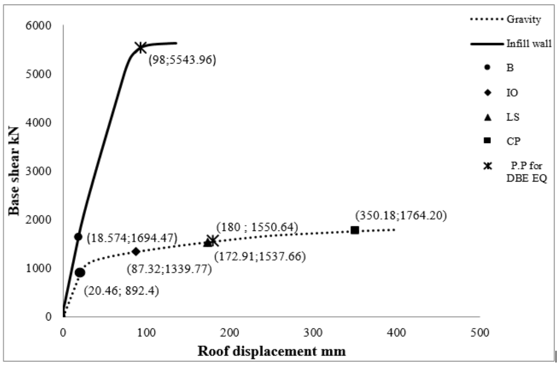


Fig.9 Capacity curve for 8 storied infill wall building in Y direction

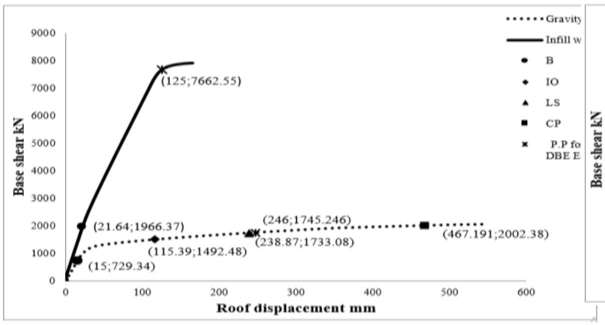


Fig.10 Capacity curve for 12 storied infill wall building in X direction

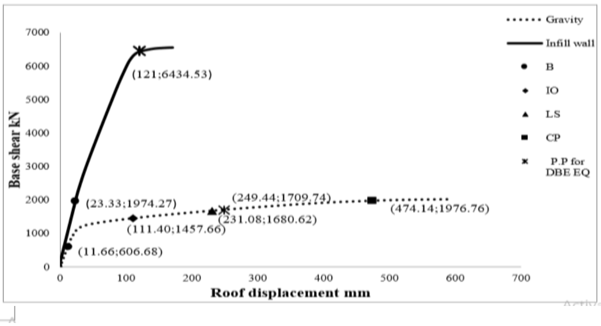


Fig. 11 Capacity curve for 12 storied infill wall building in Y direction

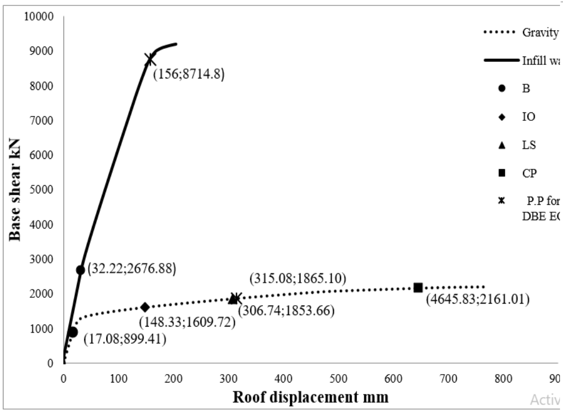
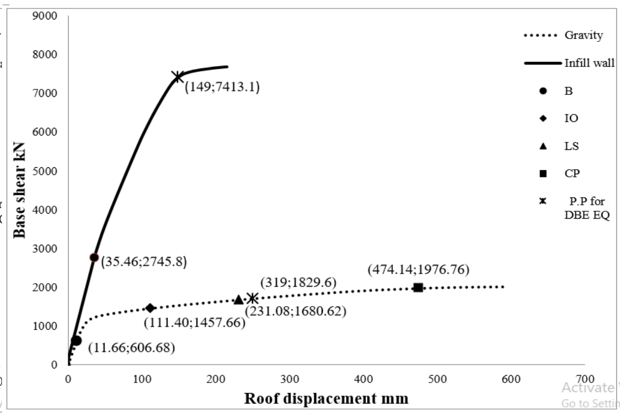


Fig.12 Capacity curve for 16 storied infill wall building in X direction



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g.13 Capacity curve for 16 storied infill wall building in Y direction

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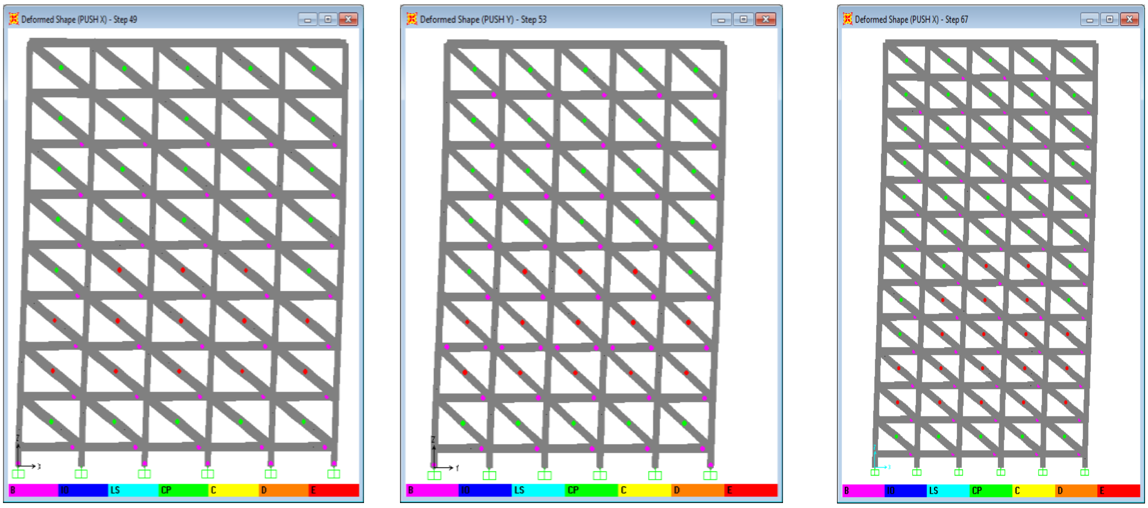
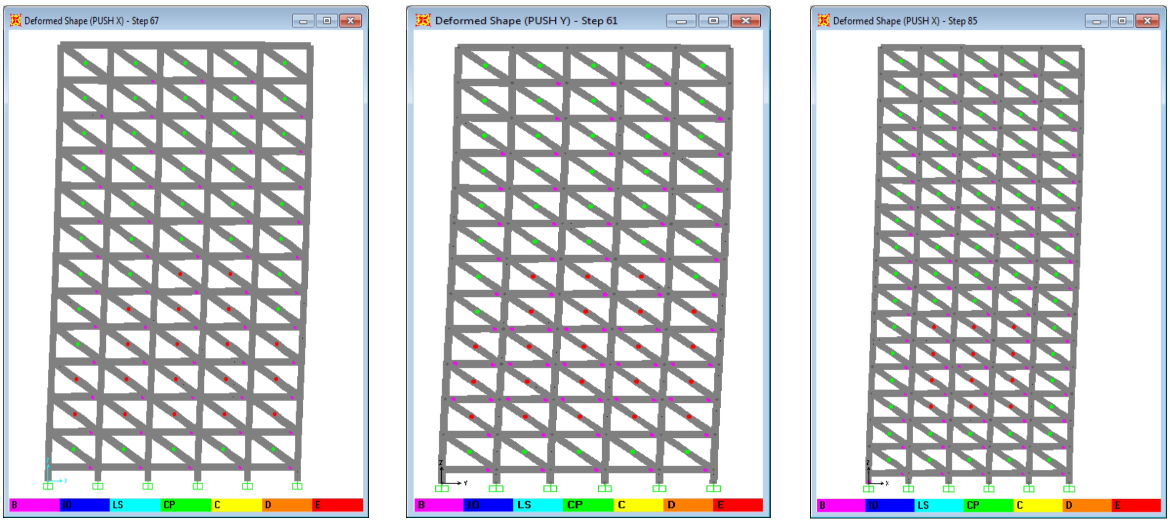
4.1. Hinge Formation Patterns

Fig. 14 and Fig. 15 show hinge formation patterns at performance point for infill wall



(A) (B) (C)

Fig.14 Hinge formation at performance point for (A) 8 storied (B) 12 storied (C) 16 storied buildings in X direction for infill wall walls



(A) (B) (C)

Fig.15 Hinge formation at performance point for (A) 8 storied (B) 12 storied (C) 16 storied buildings in Y direction for infill wall walls

The plastic deformation in case of masonry infill in columns and beams is within limit but it is crosses collapse (C) level in case of masonry strut.

4.2. Evaluation of global performance characteristic of retrofitted structure

The nonlinear force displacement relationship between base shear and roof displacement of retrofitted building is replaced with idealized bilinear relationship to calculate the different seismic parameters as discussed in section 3. Different seismic parameters for 8, 12 and 16 storied gravity and infill wall building are tabulated in Table 3, Table 4 and Table 5 respectively.

Table 3 Comparison of seismic parameters for 8 storied building

Seismic parameters	In X direction		In Y Directions	
	Gravity	Infill wall	Gravity	Infill wall
Time period for cracked section (T sec)	1.7407	1.226	1.7407	1.226
Effective lateral stiffness(KekN/mm)	29.17	82.875	41.56	75.43
Post yield stiffness(αKekN/mm)	1.30	5.393	1.28	5.27
Idealised yield strength(VykN)	1342	6630	1330	5280
Target displacement(Δmax mm)	390	153.76	390	135.75
Yield displacement(Δy mm)	46	80	32	70

Table 4 Comparison of seismic parameters for 12 storied building

Seismic parameters	In X direction		In Y Directions	
	Gravity	Infill wall	Gravity	Infill wall
Time period for cracked section (T sec)	2.01	1.60	2.01	1.60
Effective lateral stiffness(KekN/mm)	44.41	74.77	42.22	72.40
Post yield stiffness(αKekN/mm)	1.08	16.37	1.66	7.72
Idealised yield strength(VykN)	1510	6655	1309	5865
Target displacement(Δmax mm)	576	164.86	390	170.467
Yield displacement(Δy mm)	34	89	31	81

Table 5 Comparison of seismic parameters for 16 storied building

Seismic parameters	In X direction		In Y Directions	
	Gravity	Infill wall	Gravity	Infill wall
Time period for cracked section (T sec)	2.24	1.903	2.24	1.903
Effective lateral stiffness(KekN/mm)	50.38	68.44	49.75	71.42
Post yield stiffness(αKekN/mm)	1.28	18.14	1.23	7.91
Idealised yield strength(VykN)	1612	7460	1592	6858
Target displacement(Δmax mm)	762	204.53	762	170.46
Yield displacement(Δy mm)	32	109	32	82

5. Discussion and Results

All three buildings 8, 12 and 16 storied gravity designed buildings attained the performance level of Life Safety (LS) - Collapse Prevention (CP) as discussed earlier. The significant improvement in the seismic performance of gravity designed buildings is observed when retrofitted with infill wall.

The result of nonlinear static pushover analysis shows that building retrofitted with, infill wall provided targeted performance level of operational (B)-immediate occupancy (IO).

5.1 Time period for cracked section

It is observed from results that as height of the buildings increases the time period for cracked section also increases. Incorporation of retrofitting reduces time period and hence increases lateral load carrying capacity of buildings. For 8 storied building reduction in time period for cracked section as compared to gravity designed buildings is 29.56%, when retrofitted with infill wall. Similarly for 12 storied building it is 20.39% whereas for 16 storied it is 15.04% due to inclusion of infill wall.

5.2 Ratio of initial stiffness

The increase in initial stiffness is observed in case of retrofitting over bare frame models e.g. for 8 storied building initial stiffness is increased 3.05 folds and 1.9.4 folds in X and Y direction respectively when retrofitted with infill. Similarly for 8 storied building initial stiffness is increased 1.68 and 1.71 time in X and Y direction respectively when retrofitted with infill. And for 16 storied building it is 1.35 and 1.43 in X and Y direction respectively.

5.3 Yield displacement

The yield displacement of the buildings is tracked at top storey, it is observed that retrofitting increases displacement at yield. For 8 storied building the displacement at yield when retrofitted with infill and 26.98% and 50% in X and Y directions. For 12 storied building it is 61.79% and 61.72%, whereas for 16 storied building results are increased by 70.64% and 60.97%

5.4 Performance points and capacity curves

The resulting capacity curves for three retrofitting schemes shows improvement in performance levels. The buildings which were initially at LS-CP level, after retrofitting they are at O-IO level. For gravity designed buildings value of base shear and roof displacement goes on increasing as number of storeys increases. Also, the base shear and roof displacement is maximum in X direction as compare to Y direction. Buildings retrofitted at external bays with infills produces maximum base shear at performance point.

6. Conclusion

Assessment of the performance levels of gravity designed buildings shows that these buildings are seismically deficient. As a result,infill walls are used as retrofitting schemes to improve performance of deficient buildings.Retrofitting strategy is aimed at providing B-IO performance level for DBE condition. Based on results following conclusions are drawn.

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. The study of hinge formation patterns shows that for gravity designed buildingsthe life safety – collapse preventions (LS-CP) hinges are formed at middle storeys only, whereas immediate occupancy- life safety (IO-LS) hinges are formed at upper and lower storeys. It is observed that as building height increases value of base shear and roof displacement also increases at performance point.

The study of hinge formation patterns in case of buildings retrofitted with masonry infill shows that hinges formed in beams and columns are at operational (B) to immediate occupancy (IO) level at performance point. It is concluded that at performance point plastic deformation in columns and beams is within limit but it crosses collapse(C) level in case of masonry struts. It is because the higher stiffness of masonry infills attract more lateral load and transfer it to the columns. The hinges are forms at center of masonry infill strut. Infill wall reduces time period of the structure. The roof displacement increases over respective gravity designed buildings in both X and Y directions respectively. In case of infill walls base shear value at yield point is increased when compared with bare frame gravity designed buildings in X and Y directions respectively.

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