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EVALUATION OF RESPONSE REDUCTION FACTOR OF RC-INFILLED FRAMES

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Abstract

Reinforced concrete (RC) buildings with masonry infill walls are the most common type of structures used for multistory constructions in all over the world. Masonry is one of the most popular and economical construction materials. In structural analyses, infill walls are generally considered to be non-structural elements. However, the response of reinforced concrete structures to seismic loads can be significantly affected by the impact of infill walls; the presence of the infill walls increases the lateral strength and stiffness of the frame structures considerably. In this paper, an improved numerical model for the simulation of the behavior of infill walls subjected to seismic loads is used. The three dimensional four-storied reinforced concrete building is designed for the seismic zone -IV and seismically evaluated for different infill configuration along with consideration of opening in infill to make as a realistic model. Four models are considered, i.e., model I - (Full RC-infilled frame in X and Y direction), model II - (Corner infill at ground storey RC-infilled frame in X and Y direction), model III - (Open ground storey RC-infilled frame in X and Y direction) and model IV - (bare frame in X and Y direction). The nonlinear static adaptive pushover analysis has been carried out by using finite element based Seismostruct software incorporating the inelastic material, behavior for concrete, steel and infill walls. In adaptive pushover analysis, the lateral load distribution is not kept constant but is continuously updated during the each step of the process, according to modal shapes and participation factors obtained by eigen value analysis carried out at each analysis step. The modal responses for the interested modes are evaluated at each step according to the corresponding elastic spectral accelerations. In present study, for spectral amplification considered the accelerogram time-history is the Chi-Chi (Taiwan) earthquake of September 20, 1999. Infill walls have been modeled as “double strut nonlinear cyclic model” also another name is four node panel elements. The recent seismic design scenario is the nonlinearity presents in the structure through a response reduction factor. The response reduction factor is a force reduction factor used to reduce linear elastic response spectra to inelastic response spectra. In other words response reduction factor is the ratio of elastic to inelastic design strength. Response reduction factor is also named as “response modification factor” and “behavior factor” in many Countries. The value of R factor varies from 3 to 5 in IS 1893 part-1 (2016) depending on the type of moment resisting frames i.e., OMRF and SMRF. The Response reduction factor is one of the design tools to show the level of inelasticity presents in the structures so it has great importance in the earthquake engineering field. The Response reduction factor mainly divided in to ductility reduction factor and overstrength factor were computed from nonlinear static adaptive pushover analysis and ultimately response reduction factor is evaluated for all buildings and compared with the values recommended by IS 1893 part-1 (2016). The results depict that, the response reduction factors of full RC-infilled frames are higher than the other frames like an especially bare frames when infill walls are considered. However, the R values of bare frames are lesser than corresponding values recommended in BIS code.

Keywords: Response reduction factor; static adaptive pushover analysis; infill walls

1. Introduction

The recent trend in construction industry is the reinforced concrete buildings with infills. Masonry infill is one of the most popular and versatile construction materials. It is important to calculate the seismic response of reinforced concrete structures with masonry infill walls contribution to resist seismic action. In this study, the most important parameter is the "frame-infill" interaction. Generally, the seismic design codes incorporate the nonlinearity present in the structure by "response reduction factor"(R). The R factor reduces the elastic response to inelastic, i.e., nonlinear response of a structure. In different countries it is identified as "response modification coefficient", "behavior factor" and "response reduction factor". Thus, the primary aim of the present study is to evaluate the actual response reduction factor of RC frame structures for different infill wall configuratios along with the opening in infill.

Fig. 1.1- RC-infilled construction

Researcher Tarek M. Alguhane et al. [1] presented the study on seismic evaluation of 5 storied RC-existing building on account of different infill configuration in frames at Madinah city. From four models, they evaluated four response reduction factors. Chaulagain Hemchandra et al. [2] evaluated the response reduction factor of twelve irregular Reinforced Concrete existing buildings in Kathmandu valley by using pushover analysis and relate the load path, column to beam capacity ratio components with R factor.
Shendkar & Pradeep Kumar [3] worked on the response reduction factor of 2D RC frame for two different types of infill, i.e., semi-interlocked masonry and unreinforced masonry with and without opening in infill and showed that the R-value effectively decreases by considering opening in the infill.

Shendkar and Pradeepkumar [4] presented the numerical simulation of RC semi-interlocked masonry (SIM) and unreinforced masonry (URM) frame and response reduction factor is evaluated by using pushover analysis in seismostruct software and the R-value shows higher in RC SIM panel frame as compared to RC URM panel frame. Smyrou et al. [5] described the implementation of "inelastic infill panel element" for masonry infill panel within a fiber-element based seismostruct program. They assessed analytical results, compared the same with experimentally obtained from the pseudo dynamic test and also defined characteristic values for material and geometrical properties of infill.

In this study, the objectives are:

1. To find the actual response reduction factor of RC-infilled frames for different infill configuration along with the opening in infill by using static adaptive pushover analysis.
2. To compute the actual R factor evaluated from the analytical results and compare with the values recommended by BIS code.

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2. Adaptive Pushover Analysis

Adaptive pushover analysis is an alternative solution for nonlinear dynamic analysis of structures. In case of tall structures, ignoring the effect of higher modes is one of the limitations in pushover analysis but now it is posible to consider higher modes effect in adaptive pushover case. So the researchers Kalkan & Kunnath [6] and Gupta & Kunnath [7] proposed to consider higher mode effects depending on adaptive pushover procedures. The applied load is revised at each incremental step depending on the current dynamic properties.

Researcher Antoniou and Pinho [8] worked on a force-based adaptive pushover analysis, in which the lateral load is continuously updated at each single step during the eigen-value analysis. In this advanced method, spectral amplification part is used for updating the load vectors. As per the literature for adaptive pushover case, one can introduce the record of earthquake ground motion and define the level of damping. In present study, for spectral amplification considered accelerogram time-history is the Chi-Chi earthquake (Taiwan) Date: 20 September, 1999 taken from Pacific Earthquake Engineering Research Center (PEER) database.

3. Response Reduction Factor

The response reduction factor is defined as the ratio of elastic strength to inelastic design strength. The R factor mainly hangs on 3factors, i.e., ductility factor, overstrength factor, and redundancy factor and it is mathematically expressed as:

$$R = R_{\mu} \times \Omega \times R_R \quad (1)$$

R = Response reduction factor, Rμ = ductility reduction factor, Ω = overstrength factor and R_R = redundancy, it is mathematically represented as [2]:

$$2R = R_{\mu} \times \Omega \quad (2)$$

Table 3.1- Recommended values of ‘Response reduction factor’ [9]

Frame System	R value
Ordinary Moment Resisting Frame	3
Special Moment Resisting Frame	5

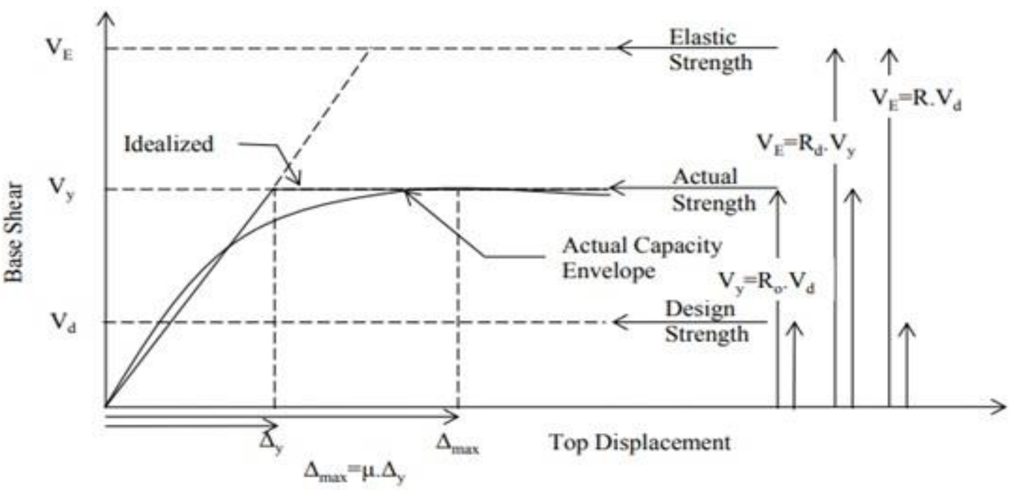

Fig. 3.1- Relation between Response reduction factor, over-strength factor and ductility reduction factor [10]

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3.1. Ductility Reduction Factor

The ductility reduction factor provides a measure of the global nonlinear response of a structure. For any structure, it mainly depends on ductility and fundamental time period. The displacement ductility is expressed as

$$\mu = \frac{\Delta_{max}}{\Delta_y} \tag{3}$$

Δ_{max} = maximum displacement corresponding to peak base shear of pushover curve and Δ_y = yield displacement, calculated by reduced stiffness method. [11]

The R-μ-T relationships developed by researcher Newmark and Hall [12] used to evaluate R_μ as follows:

If, Time period< 0.2 Seconds $\quad R_\mu = 1$

If, 0.2 seconds <Time period< 0.5 Seconds $\quad R_\mu = \sqrt{2\mu - 1}$ (4)

If, Time period> 0.5 Seconds $\quad R_\mu = \mu$

3.2 Overstrength Factor

It represents measure thereserved strength present in a structure. It may be expressed as

$$\Omega = \frac{V_y}{V_d} \tag{5}$$

V_y = ideal yield base shear and V_d = the design base shear.

The main sources of overstrength factor are: (i) material strength (ii) load factors and its combination (iii) participation of nonstructural element like infill walls, and (iv) redundancy.

3.3. Redundancy factor

Redundancy is usually defined as the gap between local yield point to the global yield point of a structure. Any building should have a high degree of redundancy for lateral resistance. In this study, the redundancy factor is incorporated into the overstrength factor.

4. Model Description

For this study, three-dimensional building 4-storey with 3 bay frames in both directions, i.e., X and Y direction, each span 4 m and floor height 3m, symmetrical on plan is considered. The building is to be considered in seismic zone ‘IV' and designed for lateral earthquake load. The building is modeled by using seismostruct software. Four models are studied as follows:

1. Full RC-infilled frame, 2. Corner infill at ground storey RC-infilled frame, 3. Open ground storey RC-infilled frame, 4. Bare frame. The models of the building are shown in Fig. 4.1 and Fig. 4.2 shows the plan of the building. Material and sectional properties are given in Table 4.1

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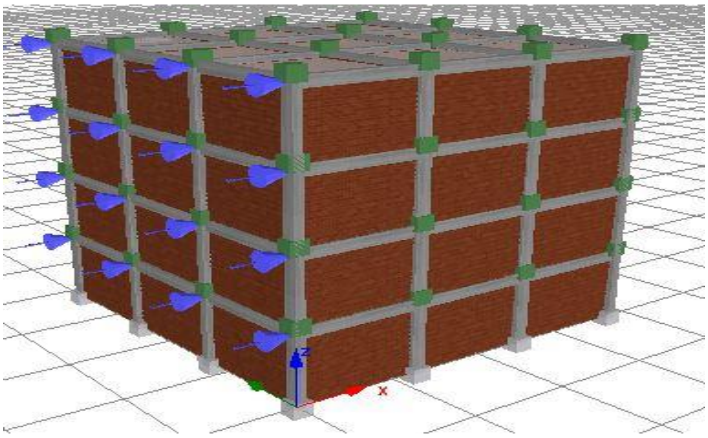

Fig. 4.1(a) - Full RC-infilled Frame

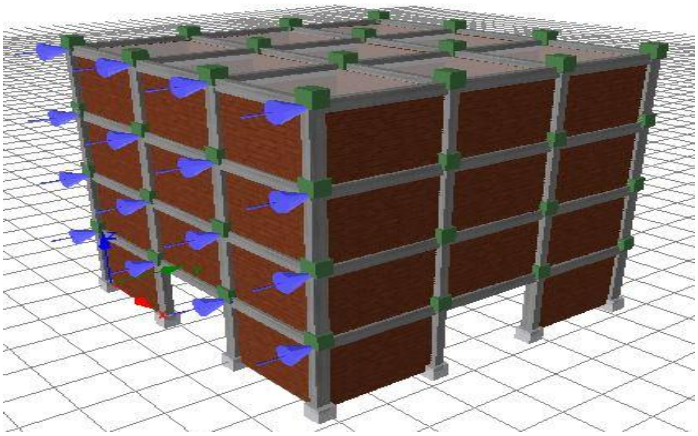

Fig. 4.1(b) - Corner Infill at Ground Storey RC-infilled frame

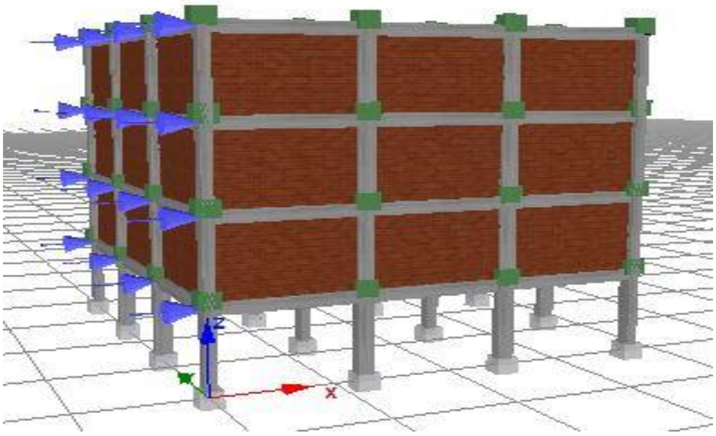

Fig. 4.1(c) - Open Ground Storey RC-infilled Frame

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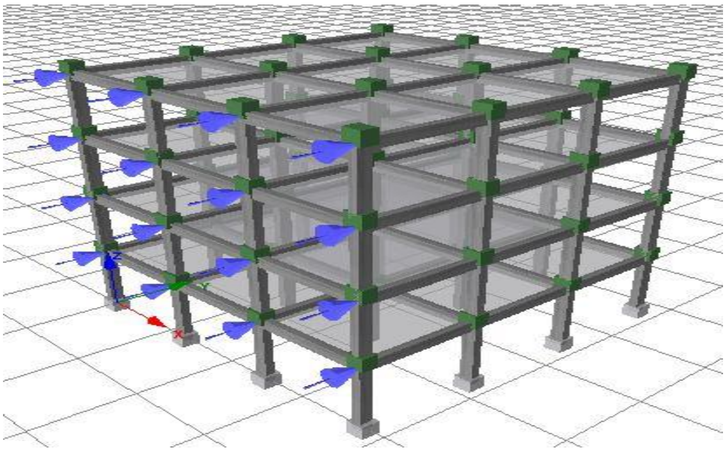

Fig. 4.1(d) - Bare Frame

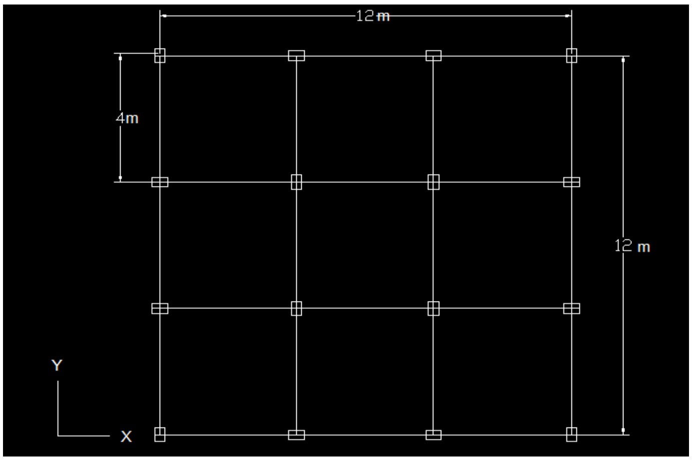

Fig. 4.2 - Plan of the building

Table 4.1- Structural details of the building

Type of structure	Special Moment Resisting Frame
Number of storey	4
Seismic zone	IV
Floor Height & Bay length	3m & 4 m along the X and Y direction
Infill wall & Comp. strength of masonry	230 mm & 5 MPa
Young's modulus of masonry	2750 MPa
Type of soil	Medium stiff soil
Column size (mm)	300 X 450
Beam size (mm)	250 X 450
Slab depth (mm)	150
Live load (kN/m^2)	3
Material	M -25 grade concrete and Fe-415 reinforcement
Damping & Importance factor of structure	5% & 1.5

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4.1 Infill Panel Element

Four node panel masonry elements [13], which considers separately shear and compressive behavior of masonry infill and represents the hysteretic response. This model is also known as "double strut nonlinear cyclic model". The presence of an opening in infill will directly affect the structural integrity of structures, which can be incorporated by minimizing the width (diagonal strut). The stiffness reduction factor to consider opening effect in infill in numerical modeling is given by

$$W_{do} = (1-2.5A_r) \times W_d \tag{6}$$

Where, W_d is the width of diagonal strut, W_{do} is the width of diagonal strut with opening in infill, A_r= The Ratio of opening area to the overall, i.e., face area of infill. The Eq. (6) is valid for opening in walls with the range of 5% to 40% [3].In this paper, 20 % opening in infill is considered.

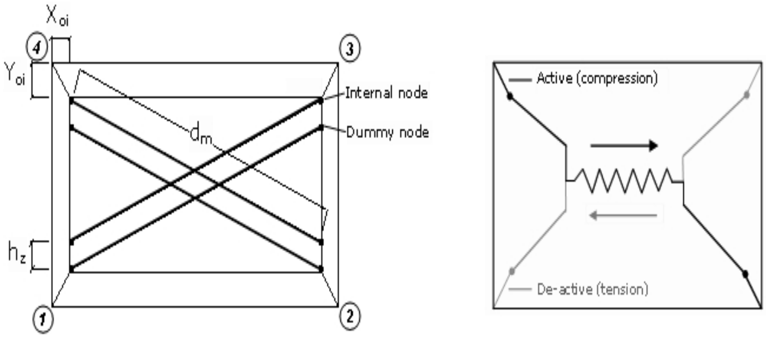

Fig. 4.3 - Inelastic Infill Panel Element [13]

Table 4.2 - Dimensions and detailing of column

Column	Size (mm)	Main Reinforcement	Lateral Ties
All columns of the structure	300 X 450	4 nos. of 16 mm dia. at corner and two nos. of 16 mm on the longer side.	8mm Dia. @ 100 mm c/c

Table 4.3 - Dimensions and detailing of beam

Beam	Size (mm)	Main Reinforcement	Shear Reinforcement
All beams of the structure	250 X 450	2 nos. of 16 mm diameter at top and bottom	8mm Dia.@ 100 mm c/c

5. Results and Discussion

5.1 Pushover Curves

The utilization of nonlinear static analysis came into practice in1970's but the potential of nonlinear static pushover analysis method has been identified during the last two decades. The parameters like strength, ductility, R factors are evaluated from adaptive pushover analysis curves.Thereby, the significance of infills, which play an important role in the RC frame, has been quantified. Using these pushover curves, one can get the capacity of the whole structure. From Fig. 5.1, it is inferred that RC-infilled frames have the maximum capacity as compared to bare frames because of the influence of infill in the seismically active zone.

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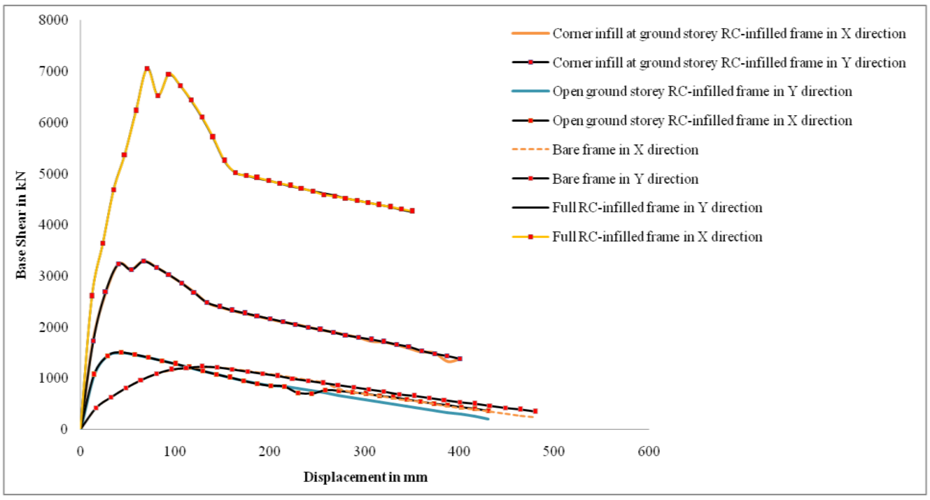

Fig. 5.1 - Comparison of Pushover Curves

5.2 Capacity Base Shear

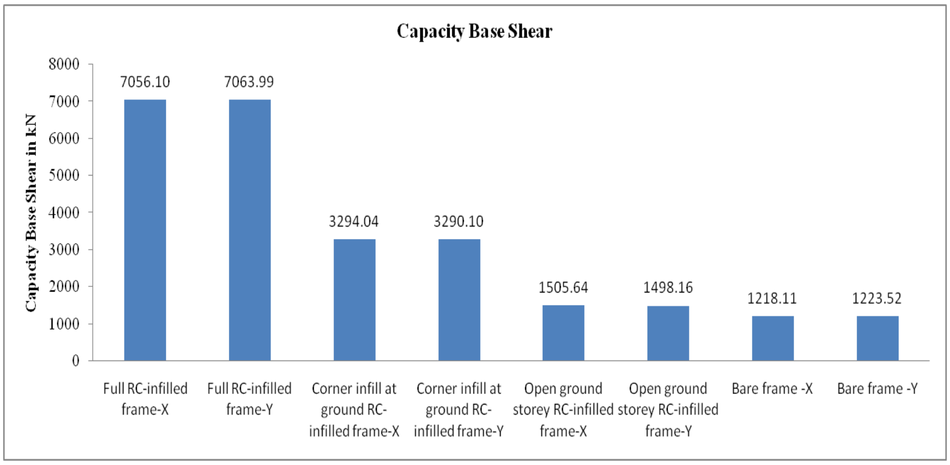

Fig. 5.2 - Comparison of Capacity Base Shear

Capacity base shear is lower in bare frames as compared to Full RC-infilled frames. Due to the symmetry of the building in both directions, i.e., X and Y direction, there is a very small variation in base shear of different models in both directions, i.e., X and Y. Averagely (average value in X and Y direction) 114.45 % base shear increases in Full RC-infilled frame as compared to corner infill at ground RC- infilled frame. Similarly, in case of corner infill at ground RC- infilled frame and open ground storey RC-infilled frame, there is a variation of base shear by averagely 119.19 % and the base shear increased by averagely 23.02 % in open ground storey RC-infilled frames as compared to the bare frame. Therefore, consideration of infills gives about 5.78 times more capacity base shear than bare frames only.

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5.3 Ductility

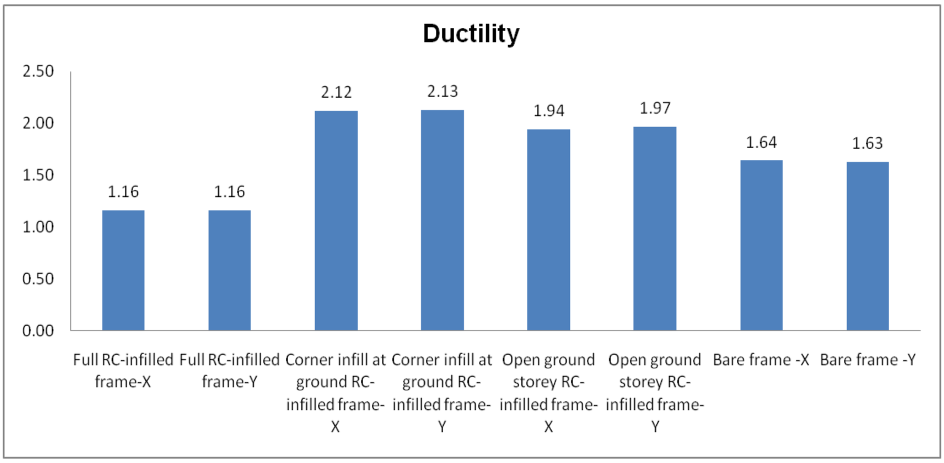

Fig. 5.3 - Comparison of Ductility

Ductility is evaluated by using Eq. (3), from Fig. 3.1. Ductility obtained is higher in corner infill at ground RC- infilled frame as compared to all other frames, because, few infill panels are present at the corner of ground level and the remaining portion of the ground storey is empty. So due to the mutual interaction of infills at ground storey gives minimum yield displacement. Similarly, in case of open ground storey, also known as soft storey RC-infilled frame, the ductility is close to that of corner infill at ground RC- infilled frame because of nearly same infill configuration at a ground storey. Averagely, 19.63 % ductility increases in open ground storey RC-infilled frame as compared to bare frame, because of absence of infill panel at ground level (i.e., sudden change in stiffness). Also initial stiffness of open ground storey RC-infilled frame is more as compared to bare frame. Due to that reason yield point of open ground storey RC-infilled frame is less as compared to bare frame.

5.4 Ductility Reduction Factor

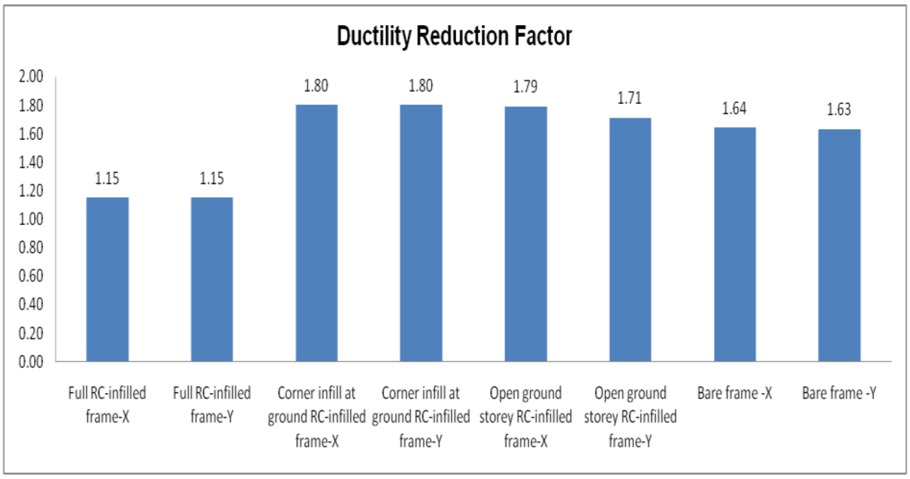

Fig. 5.4 - Comparison of Ductility Reduction Factors

The ductility reduction factor is evaluated by using Eq. (4), on the basis of the ductility and time period. It is the least for RC-infilled frames.The ductility reduction factor is highest in corner infill at ground RC- infilled

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frame compared to all other cases, similar to ductility case. Averagely 2.85 % ductility reduction factor increases in corner infill at ground RC- infilled frame as compared to open ground storey RC-infilled frame. In case of bare frame, the ductility reduction factor is same as ductility because bare frame goes under a long-period structure.

5.5 Overstrength Factor

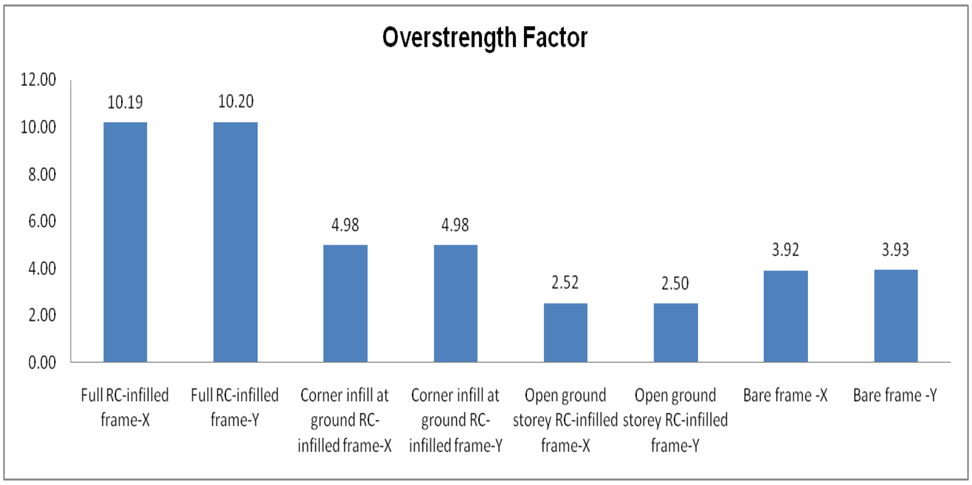

Fig. 5.5 - Comparison of Overstrength Factor

Overstrength factors are evaluated by using Eq. (5), based on Fig. 3.1. The overstrength factor is higher in full RC-infilled frame as compared to all other frames because infill panels are present in the frame. Averagely (average value in X and Y direction) 98.40 % overstrength factor increases in corner infill at ground RC-infilled frame as compared to open ground storey RC- infilled frame due to the number of infill panels more at a ground storey. In case of open ground storey RC-infilled frame and bare frame, there is a variation of overstrength factor by averagely 56.17 % because due to soft storey effect, the probability of failure of members at a ground storey is more in case of open ground storey RC-infilled frame as compared to the bare frame.

5.6 Response Reduction Factor

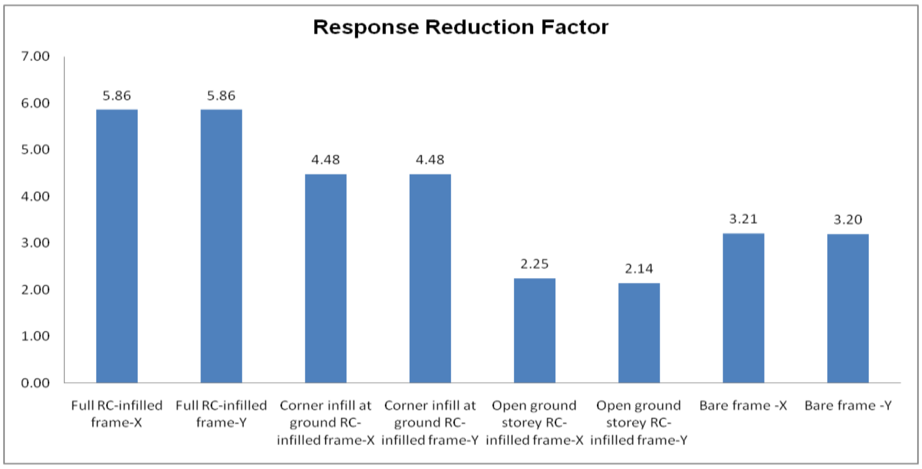

Fig. 5.6 - Comparison of Response Reduction Factors

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R factor is evaluated by using the Eq. (2), based on Fig. 3.1. The Response reduction factor is higher in full RC-infilled frame as compared to all other frames. The R factor increases in full RC-infilled frame as compared to corner infill at ground RC- infilled frame by averagely (average value in X and Y direction) 30.80 %. The R factor is very less in open ground storey RC-infilled frame as compared to all other frames so it is highly vulnerable to the seismic action as compared to other frames. The R factor is maximum for full RC-infilled frame and 2.66 times more than open ground storey case.

5.8 Damage of frames

Material strain limit approaches, used to check the damage patterns of different frames, are (i) yield for steel: 0.0025, (ii) crushing for unconfined concrete: 0.0035, (iii) crushing for confined concrete: 0.008, (iv) fracture for steel: 0.06 [14]

Table 5.1- Damage values of all frames

Frame System	First yielding of steel		First crushed unconfined concrete		First crushed confined concrete		First Fracture point for steel	
	Base Shear (kN)	Displ. (mm)	Base Shear (kN)	Displ. (mm)	Base Shear (kN)	Displ. (mm)	Base Shear (kN)	Displ. (mm)
Bare frame	960.82	64	1217.58	128	970.66	240	699.82	336
Open ground storey RC-infilled frame	1442.81	28.67	1505.64	43	1145.06	129	549.19	358.33
Corner infill at ground RC-infilled frame	2694.10	26.67	3125	53.33	2482.32	133.33	1542.39	360
Full RC-infilled frame	4688.56	35	6529.16	81.67	5254.25	151.67	-	-

As seen from Table 8.1, the value of base shear at different damage levels is high in full RC-infilled frame compared to all other frames & it displaced less due to presence of infills. The ductility is large in corner infill at ground RC-infilled frame as compared to other frames because of the difference between yielding and fracture point is maximum. The value of base shear in bare frame at different damage levels is less as compared to others. It can also be concluded from the table above that the case of Open ground storey RC-infilled frame is most vulnerable to seismic actions.

6. Conclusions

Based on the present study, the conclusions are:
(i) The base shear values are higher in full RC-infilled frame as compared to all other frames. The incorporation of infill panels in frame structures expressively enhances the stiffness of structures and it results into the reduction in fundamental periods.
(ii) Ductility and ductility reduction factors are high in corner infill at ground storey RC-infilled frames as compared to all other frames, because yield displacement point is minimum as compared to all other frames due to high stiffness allows higher drift.

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(iii) Over-strength factor is significantly affected by the presence of infill in the frame. Also, as a result of it, the response reduction factor of full RC-infilled frame is highest among all other frames in seismically active zones.
(iv) The computed values of '*R*' for bare frames obtained by adaptive pushover analysis of buildings are lesser than the value suggested in the IS 1893 (Part I):2016. To note, after incorporation of infills in frames for different infill configuration along with opening, the computed values of 'R' for open ground storey, i.e., soft storey RC-infilled frame are less than the value recommended by IS 1893 (Part 1):2016.
(v) As per this study, open ground storey RC-infilled frame and bare frame are unsafe as ultimately R values of these frames are less than the recommended value by BIS code.
(vi) The R factor is overestimated in BIS code, for bare frames, i.e., a moment-resisting frame without infills, leading to significantly lower estimate of the design base shear resulting into a more seismically vulnerable structure.

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