RESEARCH ARTICLE

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Enhancement Factor for Collapse Resistance of RC Buildings Considering Brick Infills

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Abstract

Progressive collapse is described as the removal or damage of one or more primary load carrying elements of the structures leading to the partial or full collapse of structures. For assessment of resistance towards collapse, various methods have been found in good literature and guidelines like alternate path method, strengthening or enhancement in local elements, strengthening of the girders, truss formulation at upper-level storey etc. In the present study, attempts have been focused on the contribution of brick infill walls on building resistance to collapse with different opening ratios. Three buildings structures have been considered in the present study having 4-storey, 7-storey and 10-storey (bare frame) with removal cases of four columns on at a time. The worst column removal scenario has been considered to check the influence of brick infill wall panels with different opening ratios. The structure is designed as per relevant IS codes and masonry work for brick infill have been considered with first class bricks. The present study recommends the enhancement factor for the contribution of brick infill wall panels for collapse resistance assessment of bare RC frame structure.

Keywords: Collapse Assessment, Column Removal, Non-Linear Analysis, Progressive Collapse, Pushdown Analysis, Strut Modelling.

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Introduction

SMRF structural system has been considered for the formulation of space frame and the same has been designed as per IS code. Firstly, collapse assessment has been performed on bare structural RC frame for different four column removal cases and for the worst scenario of column removal, further contribution of brick infill walls has been implemented. 115 mm thick first class brick has been considered for the present study and the opening in the wall has also been addressed. Non-linear static analysis is performed for collapse assessment. Generally, in design offices, the brick infill walls are not modeled for analysis and design purpose and thus, an imperial formula of brick infill walls intended by the relevant codes are considered for design purpose. In this study, the brick infill walls have been modeled as a diagonal compressive strut and their influence on collapse contribution were considered. At last, based on the analysis, enhancement factors have been proposed to consider infill walls contribution to collapse resistance assessment. Thus, designer can analyze the bare fame structure for collapse assessment and directly use the recommended value as multiplying factor to consider the contribution of brick infills for collapse resistance.

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Structural configuration and Design parameters

The considered models in the present study is rectangular in plan with 3 m storey height with 6 bay of 5m spacing in X-direction & 4 bay of 3 m spacing in Y-direction. A sample of typical plan and 3-D model of the structural model are as shown in Figure 1. The structure has been analyzed and designed for Gravity and Lateral load as per IS Code. The structural member sizes of beams, columns and slabs are mention in the Table 1 in detail and Loading parameters are mentioned in Table 2. The structure is considered situated in seismic zone III founded on a medium soil according to IS 1893:2016 (Part I).

Collapse Loading and Column Removal Cases (Bare frame)

For design of structure, load combination mentioned in IS:456-2000 & IS:1893-2016 have been considered. Collapse loading has been adopted from GSA guidelines and modified accordingly as per Indian Codal Provision requirement. Collapse load is considered 2.4DL+2.0LL at and above all floors for particular column removal locations, whereas 1.2DL+1.0LL at other than removal locations. Marked four columns locations are considered for column removal cases one at a time. Figure 2 shows the schematic collapse loading arrangement and column removal cases with circle marks for the present study.

Modelling Details

Modelling details of the structure is described below as:

Details of Modelling:

ETABS has been used for modeling, analysis, and design of structure and collapse assessment, non-linear static analysis has been performed. A 3D computer model is created and user-defined plastic hinges are incorporated. Compression strut representing the brick infills have been modeled using the standard formulation given in the IS code. Modification for the strut have been considered for opening in walls based on the GSDMA literature. For user defined hinges and moment-rotation data was generated using the Engissol tool for reinforcement arrangements in cross section and presence of axial loads. A set of moment-rotations relationships have been calculated for beams and columns considering the basics of cross-section properties as $\theta y=(My/EI)*Lp$ and $\theta p=(Mp/EI)*Lp$, where $(M/EI)=\emptyset$ and $Lp=0.08L+0.022dfy$ (Paulay and Priestley, 1992). A set of axial

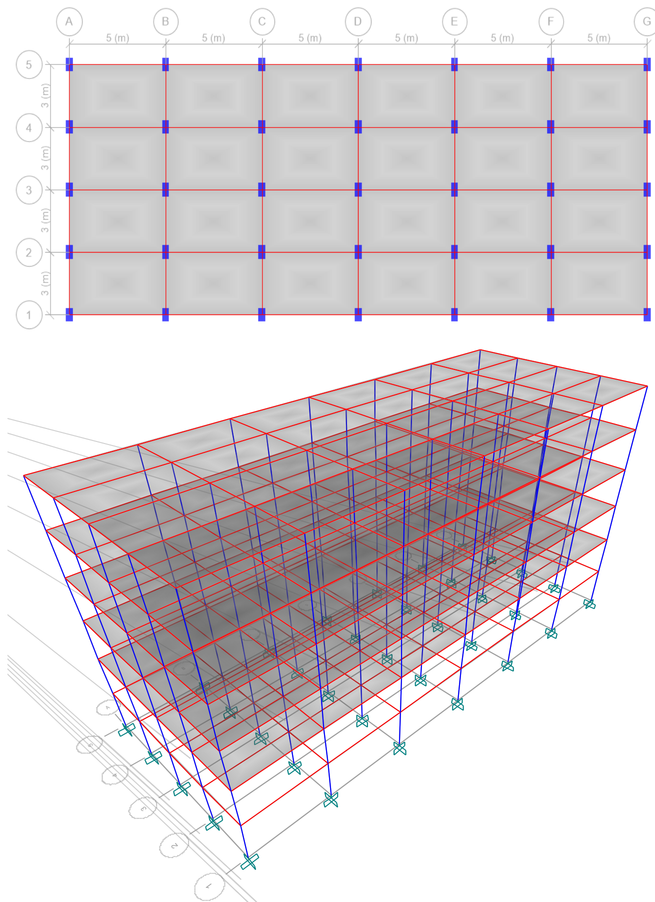

Figure 1: Plan and 3D model of Building Structure

Table 1: Geometrical parameters

Nos. of Storeys	*H/B ratio of building*	*Height of building (m)*	*Plan dimension at plinth level (m)*	*Column Sizes (mm)*	*Beam Sizes (mm)*	*Slab Thk. (mm)*
4-Storey	1.25	15.00	Dx=30.00m Dy=12.00m	350x650	230x600	150
7-Storey	2.00	24.00				
10-Storey	2.75	33.00				

*Concrete Grade M30, Steel Grade Fe500 for all structural members

Table 2: Loading Parameters

Load Type	*Description*
Dead Load	Cross section x Material density
Live Load	LL=4.0kN/m^2 as area load on slab
SDL Load	1.2kN/m^2 as area load on slab
Wall Load	6.9kN/m (UDL on Beams) (i.e-0.115x3x20=6.9kN/m)
Seismic Parameters & Natural Periods (sec) (IS:1893-2016)	Z=0.16 (Zone-3), Soil Type-2 (Medium Soil), Importance factor (I=1.2), Response reduction factor (R=5.0),
	Natural Period of 4-Storey - Tx=0.25, Ty=0.39
	Natural Period of 7-Storey - Tx=0.39, Ty=0.62
	Natural Period of 10-Storey - Tx=0.54, Ty=0.86

*Seismic Co-efficient method used for Lateral load analysis as per IS:1893-2016.

hinges has been calculated from the cross section capacity of strut, considering the mean compressive strength of brick prism as per IS:1905 for locally available first class bricks. As the brick is considered as brittle material, force-controlled hinges are considered to define its ultimate capacity. The results are calculated and reported as maximum collapse load attempt by structure at the failure of any structural member with and without considering the influence of brick infills.

Modelling of Diagonal Compression Strut

Diagonal struts, to represent the presence of brick infill walls for collapse assessment have been modelled as per describe procedure in IS:1893-2016. The procedure mentioned in the code is focused on the lateral loads due to earthquake and accordingly the modelling parameter is derived. In the present study, the same concept has been utilized with modification as gravity loads are more dominant than the lateral load after removal of column. For modeling strut, thickness is considered the same as masonry wall thickness and for height and length of wall panel, equivalent width of strut have been derived. Considering the opening in the walls, the reduction factor has been multiplied to modify the width of diagonal strut. Strut is considered as pinned joint at both ends to intending the axial force only in it. Compressive strength of brick and mortar is considered as 10.5N/mm2 and 5.0N/mm2 respectively. Figure 3 shows typical layout of diagonal strut.

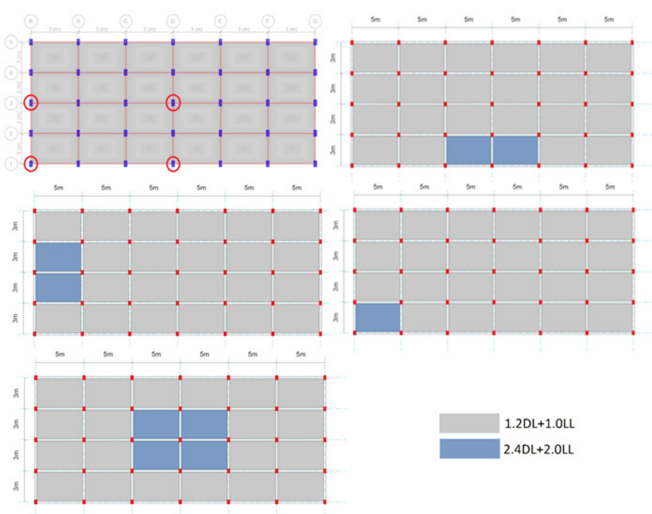

Figure 2: (i) Column Removal Case (ii) Long Bay Column Removal (iii) Short Bay Column Removal (iv) Corner Column Removal (v) Centre Column Removal (vi) Legend for Collapse Loading Marks

Sample Calculation of Strut Width & Its Axial Capacity

Estimating in-plane stiffness and strength of URM infill walls is based on the modulus of elasticity Em (in MPa) of masonry infill walls. It is taken as: E_m=550f_m, where f_m is the compressive strength of masonry prism (in MPa) obtained as per IS:1905. $f_m = 0.433 f_b^{0.64} f_{mo}^{0.36}$. Here, f_b=compressive strength of brick in MPa; and f_{mo}= compressive strength of mortar, in MPa. Width, W_{ds} of equivalent diagonal strut is taken as, $0.175\ \alpha_h^{-0.4} L_{ds}$. Here L_{ds} is diagonal length of strut and $\alpha h = h \sqrt[4]{\frac{E_m t \sin 2\theta}{4 E_f I_c h}}$.

θ is angle of inclination of strut with respect to horizontal. Further sample calculation is shown in Tables 3 and 4.

$f_m = 0.433 f_b^{0.64} f_{mo}^{0.36} = 0.433 x(10.5^{0.64}) x(5.0^{0.36}) = 3.48$ N/mm^2

$E_m = 550 f_m = 550 x 3.48 = 1914.44$ N/mm^2

Modulus of Elasticity of Frame $E_f = 5000\sqrt{fck} = 5000 x 30 =$ 27386.13 N/mm^2 (M30 grade is considered for all members)

Moment of Inertia of Adjoining Members = $(230 x 600^3)/12$ = 4140000000.00 mm^4 (Here, in push down analysis, the adjoining member will be Beams and not the Columns as the loads are applied from above, hence in the present study length of panel will be the height of storey and height of panel will be length of beam refer Figure 3 for the same).

Results and Discussions

The results obtained for the bare frame models and with struts by non-linear static methods are compared and

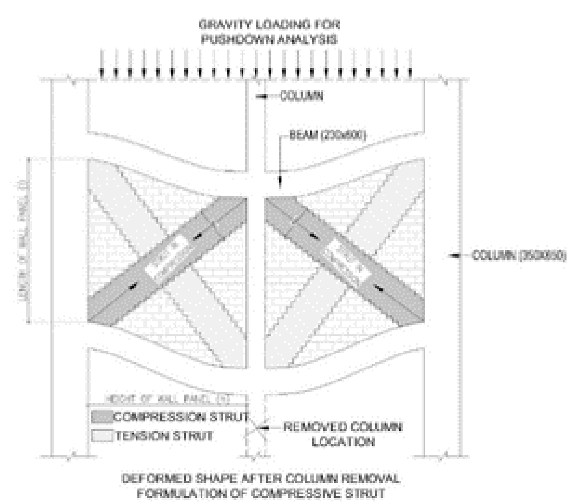

Figure 3: Typical compression sturt width

Table 3: Sample Calculation for Diagonal Compression Strut

Length of Panel (m)	*Height of Panel (m)*	*Diagonal Length of Strut L_{ds} (m)*	*Inclination Angle (θ) (degree)*	*Co-efficient α_h*	*$W_{ds} = 0.175\alpha_h^{-0.4} L_{ds}$ (mm)*	*Average Width of Strut for Modelling (mm)*
3.0	5.0	5.83	59.04	2.71	685.3	629.65 ≈ 630.00
3.0	3.0	4.24	45.00	1.90	574.0	

Table 4: Reduce Width for Diagonal Compression Strut Considering Opening in Walls

Reduce Width of Strut For Opening & Axial Capacity			
Opening Ratio to the Wall	*Reduction factor (ϱw)*	*Final Sizes for Modelling (c/s of strut)*	*Axial Load Capacity of Strut = limiting stress x C/S area x Crack MOI*
Full Wall Panel	1.00	115 x 630 (t x W_{ds})	3.48 x 115 x 630 x 0.7 = 176.48kN
10% Opening	0.75	115 x 473 (t x W_{ds})	3.48 x 115 x 473 x 0.7 = 132.37kN
20% Opening	0.50	115 x 315 (t x W_{ds})	3.48 x 115 x 315 x 0.7 = 88.24kN
30% Opening	0.25	115 x 158 (t x W_{ds})	3.48 x 115 x 315 x 0.7 = 44.12kN

*Reduction factor (ϱw) = 1.0-2.5(Ar), where Ar = ratio of opening. *t x W_{ds} = thickness x width of strut = cross Section of strut. MOI = Moment of Inertia

Table 5: Collapse Load Attempted by Structure with & without Infill Wall Panels

Type of Structure	*(G+4 Storey) H/B=1.25*	*(G+7 Storey) H/B=2.00*	*(G+10 Storey) H/B=2.75*	*Recommended Enhancement Factor*
Bare Frame Structure (Without Infill)	86.61%	90.41%	94.94%	NA
Full Wall Panel .(0% Opening)	96.00%	97.17%	96.25%	[(96.00/86.61)+(97.17/90.41)+(96.25/94.94)]/3 = **1.066 ≈1.07**
10% Opening in Wall	95.06%	95.65%	95.89%	[(95.06/86.61)+(95.65/90.41)+(95.89/94.94)]/3 = **1.055 ≈1.06**
20% Opening in Wall	92.82%	93.85%	95.61%	[(92.82/86.61)+(93.85/90.41)+(95.61/94.94)]/3 = **1.039 ≈1.04**
30% Opening in Wall	90.70%	92.31%	95.03%	[(90.70/86.61)+(92.31/90.41)+(95.03/94.94)]/3 = **1.023 ≈1.02**

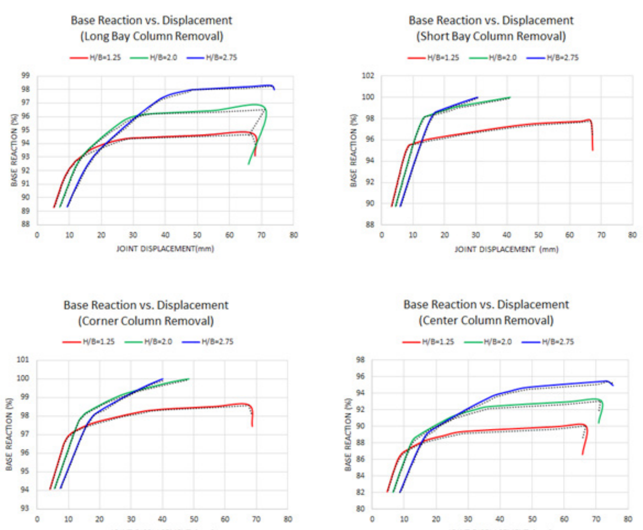

Figure 4: Pushdown curve for Bare Frame (i) Long Bay Column Removal (ii) Short Bay Column Removal (iii) Corner Column Removal (iv) Center Column Removal

discussed as follows. The Pushdown curve for all four column removal cases has been plotted as collapse load attempt by structure vs. removal node displacement. Figure 4 shows pushdown curves for bare frame models. For all four column removal cases the long bay column removal & center column removal cases the structures undergo elastoplastic range before failure, it occurs because of the catenary effect of the more long-span beams framing at a joint, Whereas for short bay and corner column removal cases the structures behave elastically more and little defamation observed beyond the yield point, these happen because of the more short span beams are farming into joint. When short span beams are there, their deformation behavior is governed by flexural-shear, whereas for long span beams, the deformation behaviour is governed by flexural means and catenary effect, after column removal. Pushdown curves show that among all four column removal cases, the structure has less resistance towards collapse load for center column removal. Hence, in the present study, the contribution of brick infills has been focused on removing the center column only. Figure 5 shows the pushdown curve of collapse load carrying capacity for center column removal considering brick infills having different opening ratios.

Pushdown curves for infill wall panels indicate that the collapse resistance of building structure increases, if contribution of infills are considered compared to bare frame. Table 5 shows the load attempted by structure at the failure of any structural member considering the infill walls and bare frame. Observing the curves, it can be shown that the collapse resistance capacity decreases with the increase in the opening in the wall but still, more than the bare frame structure. Based on the results, enhancement factors have been calculated by averaging the attempted loads. Pushdown cure for the infill wall panels shows that as the H/B ratio of the building is increasing, the curves get closers

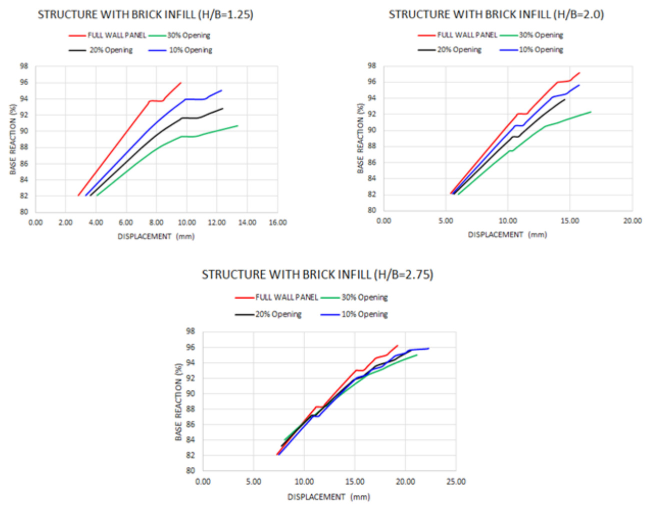

Figure 5: Pushdown curves for Infill Wall panels (Center Column Removal)

to each other thus, the contribution of infill wall panel shall be limited as curves tried to straighten with less margin with respect to the opening.

Conclusions & Recommendations

The following conclusion & recommendations can be drawn from the present analysis & study,

- Collapse resistance of structure are increase with increases of H/B ratio.
- Center column removal of the structures has less resistance toward collapse; hence, attention shall be paid at the design stage to address the real-life project issues.
- The contribution of brick infills shall not be ignored to predict the structure's collapse resistance.
- Brick infill wall panels enhance the collapse resistance of the structure.
- Comparatively, full wall panels and 10% opening of wall panels show good enhancement.
- In general office practice, bare frame structure shall be analyzed for assessment of collapse resistance as it is a convenient amd hands-on way of analysis and recommended enhancement factor can be used directly as a multiplying factor to assess the collapse resistance of structure with considering the infill panels.
- Linear interpolations shall be applicable for opening ratio ranging from 10% to 30%.
- Wall opening for 30%, shows an enhancement factor as 1.02 as lower minimum value, thus opening beyond 30% shall not contribute in collapse resistance and shall be considered as bare frame only.
- Present study has been conducted considering 115mm thick wall and enhancement factor have been suggested. Considering panel thickness as 230 mm thick or more, will not affect the enhancement factor as increasing the wall thickness also increase the dead weight of the structure and eventually the seismic weight and collapse load of the structure. Hence the Demand vs. Capacity ratio will be maintained as same.
- Contribution of brick infills toward collapse resistance shall be taken up to a certain height, as 10-storey only. Beyond that, contribution may not have been considered, and structure shall be considered bare frame only.

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