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Disregarding the Effect of Openings in Infill Walls in Indian Seismic Code: A Scrutiny

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Abstract

This study attempts to scrutinize the provision of IS 1893(Part–I): 2016 in neglecting the effect of openings in infill walls in the context of earthquake performance of the same. It evaluates the effect of openings as per FEMA-273 & ATC-40 and compares the result with the provisions of Indian code. The comparative seismic performance, in terms of base shear and top displacement, using the response spectrum of IS 1893(Part–I): 2016, is done on an irregular block of the Jorhat Engineering College old building situated in Seismic Zone-V. Two models of the frame structure are made in SAP 2000®. Modelling of infill is done as Equivalent-Strut, pin-jointed to the RC frame, the width of the strut taking care of effect of openings as per FEMA-273 & ATC-40. The width of the infill wall with openings is found to be 61.465mm whereas, without opening it is 503.80mm. In contrast, as per IS provision the width of infill is 486.27mm. Nonlinear Static Pushover Analysis is performed in SAP 2000®. The building base shear capacity for pushover analysis according to FEMA-273&ATC-40 with infill is 10626.107kN and Maximum displacement is 0.042m. In contrast, provisions of IS 1893(part-I):2016 yield the base shear capacity with infill as 20231.365kN and Maximum displacement was 0.063m. An increase in base shear in the latter case may be attributed to the bigger strut width as per IS provision. The formation of plastic hinges is also more in the latter case. It is concluded that IS codal provisions resulted in a doubly stiffer structure.

Keywords: Masonary Infilled Frame, Equivalent Diagonal Strut, Non-linear Static Pushover Analysis.

1. Introduction

Reinforced concrete frames with masonry infill walls are most common in building construction practice around the globe. Masonry walls are generally considered as non-structural elements and their stiffness contributions are generally ignored in practice. Of late, Indian Seismic code [3] has treated infill walls as structural element quantifying its effect equivalent to the bracing of the frame against lateral loadings. If infills are designed properly, these can increase the overall strength, lateral resistance and energy dissipation of the structure. Infill walls increase the lateral stiffness and thereby reduce the lateral deflections and bending moments in the frame. This improved performance makes it more realistic to consider infill wall as a structural element in the earthquake resistant design of structure. According to FEMA-273[2] & ATC-40[1], the stiffness of the infill is modelled as "Equivalent Diagonal Strut Method", where infill wall is idealized as diagonal strut and frame is modelled as beam or truss element. To account for the presence of openings a reduction factor is applied to reduce the width of diagonal strut. In contrast, Indian Seismic code [3], makes no distinction in modelling provision of walls, with or without opening. It is worth enquiring whether the Indian Standard provision is safe in neglecting the reduction in strength of masonry infill walls with opening. The provision of FEMA-273[2] & ATC-40[1] in considering such opening is used as a benchmark here and checked against Indian Codal provisions by conducting a comparative study of seismic performance of a model of an plan-irregular building in seismic Zone-V. The comparative seismic performance is done in SAP2000® using Nonlinear Static Pushover analysis.

2. Lliterature review

Sachin S and Hemant BK (2012) [6] observed that Openings in infill walls significantly reduce the lateral strength and stiffness of RC frames, and alter their failure modes. The paper reviews and compares past relevant studies and seismic codes of different countries on in-plane lateral load behaviour and modeling approaches for masonry infill RC frames with openings.

Nikhil *et al*. (2013)[4] studied the performance of masonry-infilled reinforced concrete (RC) frames including open first storey of with and without opening. A symmetrical frame of college building (G+5) located in seismic zone-III was considered by modeling of initial frame .It was observed that infill panels increased the stiffness of the structure and

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increase in the opening percentage led to decrease on the lateral stiffness of infilled frame.

Phadnis *et al.*(2016)[5] modelled a G+10 reinforced concrete framed building where width of strut was calculated by using equivalent strut method. Seismic performance of various configurations of infill in reinforced concrete frames was observed by performing Nonlinear Static Analysis in SAP 2000®. The results of infill frames were compared with bare frame model.

It has been observed that while ample studies are conducted on comparing the structural behaviour of bare frame and frame with infill, no study has been observed which scrutinize the provisions of Indian Seismic Code. This very aspect is the subject of the present work.

2. Description of frame structure

The building under consideration is a plan-irregular double-storeyed block of Jorhat Engineering College building as shown in Fig. 1.

Indian Seismic Code[3] defines plan irregularities as in Fig. 2.

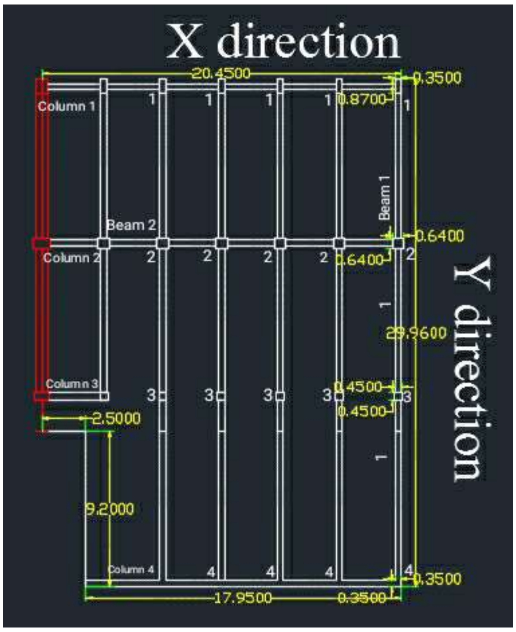

Fig. 1. Plan view of the model showing different sizes of beams and columns

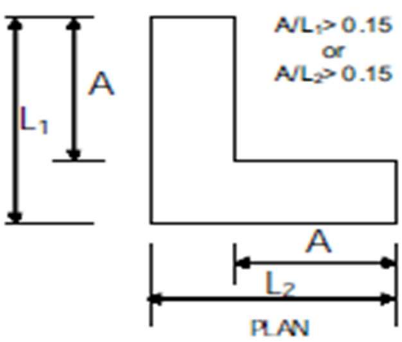

Fig. 2. Plan Irregularity (clause 7.1, Fig. 3B, IS 1893(Part-I):2016) [3]

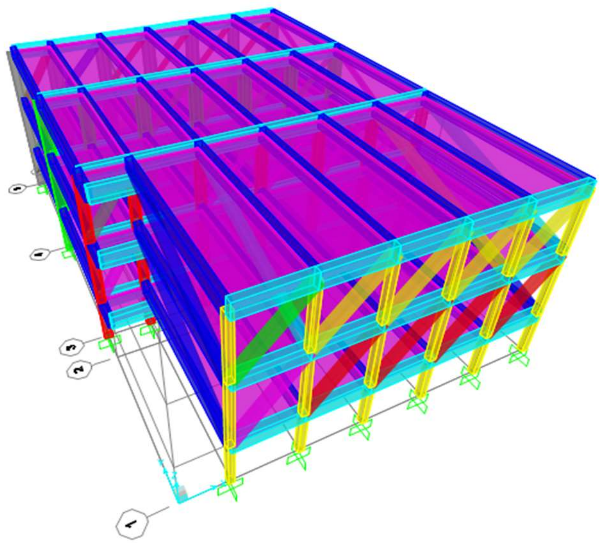

Fig. 3. 3D view of Infill wall positions showing different sizes of beams and columns

In the considered structure, along Y-direction A/L_1 is 9.2/29.96 i.e 0.30>0.15.Thus the classification as plan irregualar is valid.

The structure is modeled as a 3-D frame using SAP2000®.The element sizes are as follows:

Beam1 (along Y-axis):350×870mm
Beam2 (along X-axis):380×970mm
Column1:350×870mm
Column2:640×640mm
Column3:450×450mm
Column4:350×350mm
Slab thickness = 150mm
Plan area (sq m.) = 20.45m× 29.96m
Dead loads are calculated considering the unit weight of concrete as 25 kN/m^3.
Dead load =1×0.15×25=3.75 kN/m² [5]
Live load =1.5 kN/m²(for roof) & 3 kN/m²(for floors)[6]
These loads are applicable for institutional buildings.
Floor to floor height =4.48 m (ground storey) and 4.14m(other floors)
Modulus of Elasticity (E_c) $=5000\sqrt{f_{ck}} = 5000\sqrt{20} = 22360.68$ N/mm^2.[4]
Foundation is assumed to be fixed. Infill walls are modelled as equivalent concentric diagonal strut connected at the beam-column joints by pin joints.

3. Modeling of equivalent struts

4.1 Modeling using FEMA-273 rules (With and without openings) [2]

To calculate the initial stiffness of the equivalent strut, effective width, length, thickness and elastic modulus are important. The infill properties of the equivalent strut are listed in Table-1. The infill panel is represented by an equivalent diagonal strut of width a, and net thickness t_w as shown in Fig. 4.

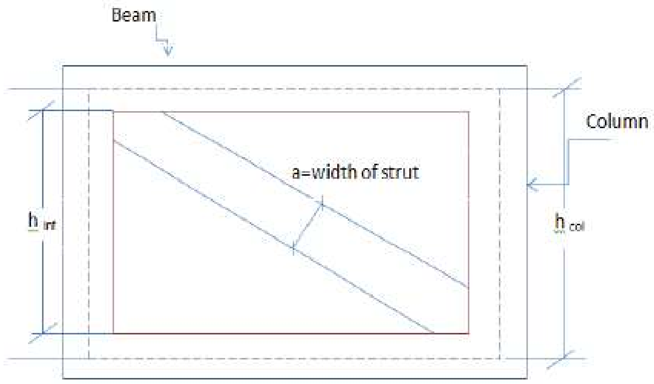

Fig. 4. Equivalent Strut Idealization of infill walls [5]

Table-1. Properties of infill wall[4]

Infill material properties	values
Modulus of Elasticity	5500 MPa
Shear Modulus	1018 MPa
Thermal coefficient	0.0000081/.C
Poisson's Ratio	0.15

The width of equivalent struts without openings are calculated as per the following relations-

Width (W_{eff}) = $0.175(\lambda_1 \times H)^{-0.4} \times w^{/}$ (1)

$$\lambda_1 = \left[\frac{\boldsymbol{Em\, t\, \sin(2\theta)}}{\boldsymbol{4Efe\, Icol\, hinf}}\right]^{1/4} \quad (2)$$

where,

H = column height between centre lines of beams.

H_{inf} =height of infill panel

E_{fe} =expected modulus of elasticity of frame material

E_m =Expected modulus of elasticity of infill material

I_{col} =moment of inertia of column

$w^{/}$ =diagonal length of infill panel

t =thickness of infill panel and equivalent strut

Θ =diagonal angle $=\tan^{-1}\frac{H}{L}$

Unit weight of Masonry =19 kN/m^3

Unit weight of Concrete =25 kN/m^3

L =bay length of the frame

Say, External wall =230 mm

Internal wall =230mm

In presence of openings a reduction factor is applied to reduce the width of the strut-

$$\lambda = 1\text{-}2 \propto \boldsymbol{w}^{\,\mathbf{0.54}} + \propto \boldsymbol{w}^{\,\mathbf{1.14}} \quad (3)$$

Where, $\propto w$ = Infill wall opening %

Opening % $=\dfrac{\boldsymbol{Area\ of\ opening}}{\boldsymbol{Area\ of\ infill\ wall}}$

$w^{/}$ = 5.74m

h = 4.48m

t_w = 0.230m

Calculations-

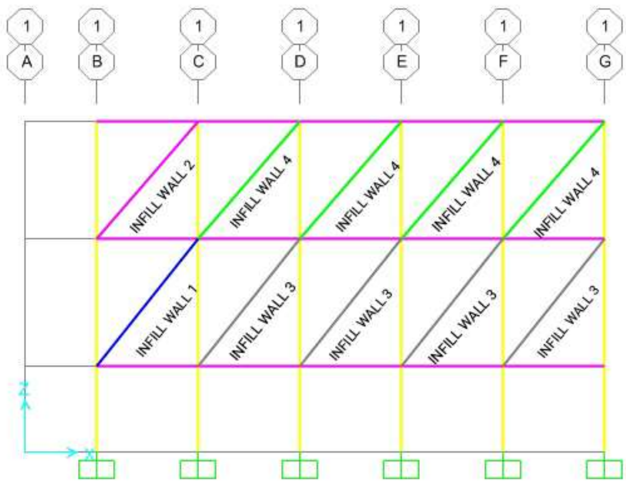

Fig. 5. Infill wall positions for equivalent strut calculation

Infill Wall 1 (without openings)

$\Theta = \tan^{-1}\frac{4.48}{3.59}$

=51.29°

$\lambda_h = [\frac{5500\times230\times\sin(2\times51.29)}{4\times22360.68\times0.875\times10\text{\^{}}9\times4.48\times10\text{\^{}}3}]^{1/4}$

$=1.369\times10^{-3}$/mm

$W_{eff} = 0.175(\lambda_h \times H)^{-0.4} \times w^{/}$

$=0.175(1.369\times10^{-3}\times4.48\times10^{3})^{-0.4}\times5.74\times10^{3}$

=486.27 mm

=0.48627 m

Infill Wall 3 (with openings)

$w^{/}$ = 5.74m

h = 4.48m

t_w = 0.230m

opening %= 4.32/16.083 =0.268

$\lambda = 1-2\times(0.268)^{0.54}+(0.268)^{1.14}$

= 0.241/mm

$W_{eff} = 0.175(0.241\times4.48\times10^{3})^{-0.4}\times5.74\times10^{3}$

= 61.465mm

The above procedure is repeated for 20 other infill walls.

Table-2. Width of infill wall (with or without openings)

Infill wall no (without openings)	Width (mm)	Infill wall no (with openings)	Width (mm)	Infill wall no (with openings)	Width (mm)
2	473.72	4	62.92	15	104.63
7	487.17	5	93.23	16	69.04
8	468.77	6	97.00	17	101.67
9	487.17	11	97.00	18	100.97
10	468.77	12	126.60	21	139.51
19	622.60	13	134.20	22	139.74
20	638.88	14	105.60		

Table-3. Width of strut

Infill wall no (without openings)	Width (mm)	Infill wall no (with openings)	Width (mm)	Infill wall no (with openings)	Width (mm)
2	473.72	4	473.72	15	110.52
7	487.17	5	473.72	16	72.86
8	468.77	6	486.27	17	110.52
9	487.17	11	486.27	18	110.52
10	468.77	12	486.27	21	144.17
19	622.60	13	473.27	22	144.78
20	638.88	14	110.52		

4.2 Modeling as per Indian Seismic Code[3]

As per Clause 7.9.9.2(b)[3] ,the relation to calculate the width of equivalent strut without openings are same as FEMA-273, where ends of diagonal struts shall be considered to be pin-jointed to RC frame.
But if there is a presence of openings in the infill wall , no reduction of strut width is required as per Clause 7.9.2.2(c)[3].
The calculated width of strut as per Indian Seismic Code[3] code is given in Table-3.

4. Results and Discussion:

5.1 Comparison of Dynamic Properties

The time period for the two models under consideration are presented in Table–4.

It has been observed that the Indian codal provisions results in a stiffer structure in comparison with FEMA-273 model.

5.2 Comparative Pushover Analysis

Analysis result as per as per SAP2000® is presented in this section.

Table-4. Dynamic Properties

Model	Time period	frequency	Eigen value
Indian Code[3]	0.44 (Mode -1)	2.234	197.066
	0.42 (Mode-2)	2.410	225.450
	0.39 (Mode-3)	3.525	420.590
FEMA-273[2]	0.49 (Mode-1)	2.510	210.660
	0.45 (Mode-2)	3.120	353.250
	0.40 (Mode-3)	3.998	610.970

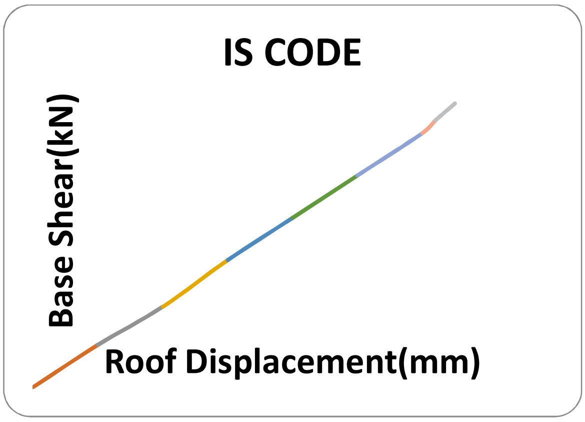

Fig.6. Pushover curve along X- direction as per Indian Code

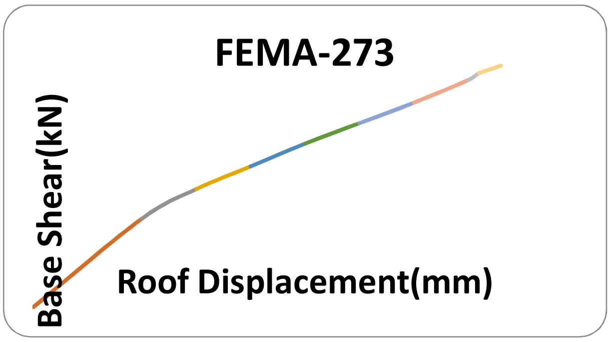

Fig.7. Pushover curve along X- direction as per FEMA-273

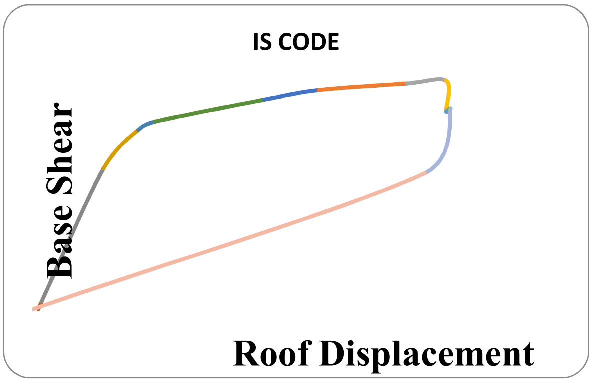

Fig.8. Pushover curve along Y- direction as per Indian Code

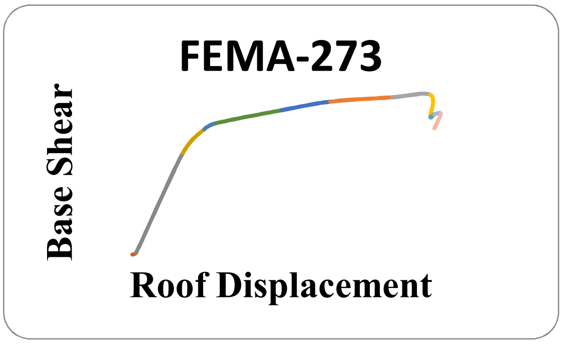

Fig.9. Pushover curve along Y- direction as per FEMA-273

From the above curve it has been observed that the displacement is more while considering IS code[3] along X and Y direction in comparison to FEMA-273[2].

5. Conclusion

The seismic behaviour of a structure for considering infills with and without openings are presented here. From the above consideration it has been observed that the base shear of the structure considering IS codal provision is more. An increase in base shear in the latter case may be attributed to the bigger strut width as per IS provision.

Disclosures

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