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Alternative of retrofitting for ground soft story formation using concrete web stiffeners

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ABSTRACT

Many of the high-rise structures are designed today to have an open base story for multiple reasons like parking, recreational area etc. Since infills are absent at this location the relative stiffness of the story decreases as compared to the above stories, due to which soft story formation may occur. For this purpose, to demonstrate rectification of soft-story formation a G+10 infilled framed structure is considered and 10 models are created, 9 models having different aspect ratios of web stiffener and 1 model without web stiffener. The stiffness of ground story (plinth level), inter-story drift and displacements are calculated and compared for all the 10 stories.

Keywords: *Soft story, retrofitting for the soft story, concrete web stiffeners, Push over analysis.*

1. INTRODUCTION

The open base stories are susceptible to reduced column stiffness thus causing a weak column strong beam frame which results in soft story formation. The plastic hinges are primarily formed in the columns and due to this lateral deformation is increased at that level. Soft stories have large inter-story drifts under lateral loads of seismic action. The stories are said to be soft story when the stiffness of the story becomes less than 70% of the stiffness of above story or less than 80% of the average of the 3 stories above it (Wai- Fah Chen, 2005). The soft stories in buildings are generally retrofitted for increasing the sectional area thus increasing the stiffness of the story, another method is installing a rigid steel moment frame for increasing the stiffness of the system. This paper presents a relatively cost-effective and architecturally aesthetic system for increasing lateral stiffness, by providing concrete web stiffener (haunch type) at the junction of column and beam.

2. STRUCTURAL MODELLING

2.1 Dimensional Data

A G+10 storied building with aspect ratio (H:L) of 1.15 in X direction having 6 bays of 5m width each and 1.725 in Y direction having 5 bays of 4m width each is modelled. The floor to floor height is 3m, and total height of building is 34.5m. Beams of uniform size 300x400mm are used and columns of uniform size 450x600mm are used. The thickness of web stiffener is taken equal to width of beam connecting the stiffener.

10 building models are created, 1 model having no web stiffener and 9 models having different aspect ratios of web stiffeners. Building Model having no web stiffener is denoted as BM-0, refer Table 1 for other building denotation. Refer **Error! Reference source not found.** for typical web stiffener

Table 1: Building models

a↓ \ b→	5%	15%	25%
5%	BM-1	BM-2	BM-3
15%	BM-4	BM-5	BM-6
25%	BM-7	BM-8	BM-9

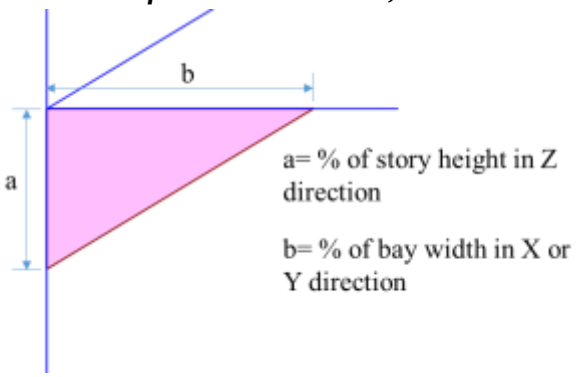

Fig. 1: Typical web stiffener

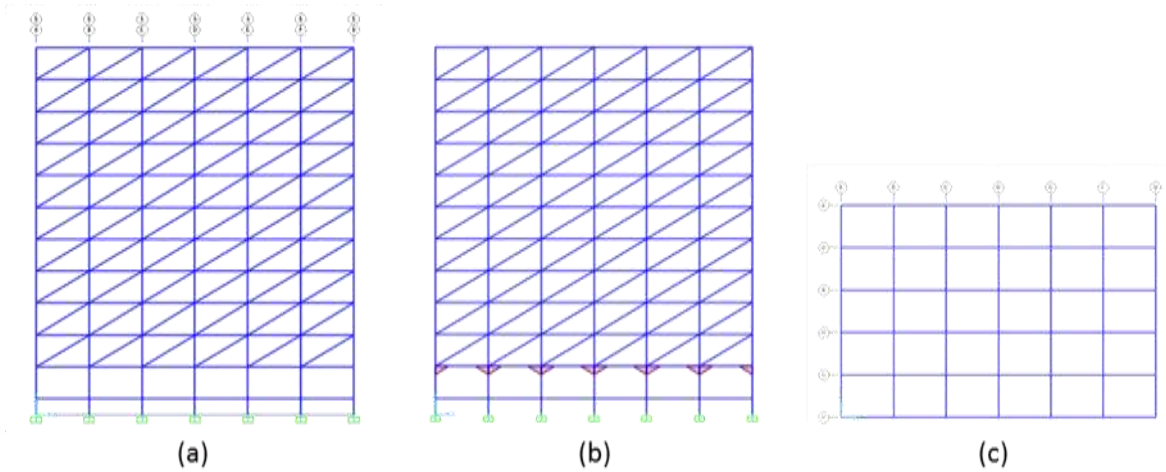

Fig. 1: (a) BM-0, (b) Typical BM with web stiffener, (c) Plan

2.2 Infill wall modeling

Infill walls are modeled as a diagonal strut. The stress-strain curves for infills having intermediate strength mortar 1:0.5:4.5 is considered as given by (Hemant B. Kaushik, 2007). The width of infill wall is taken from the equation given in (IS1893:2016) clause 7.9.2.2.

$$w_{ds} = 0.175 * \alpha_h{}^{-0.4} * L_{ds} \tag{1}$$

$$a_h = h\sqrt[4]{\frac{E_m t sin2\theta}{4E_f I_c h}} \tag{2}$$

Where 'h' is the height of infill in inches, Em is Young's modulus of infill in pounds per square inch, Ef is the modulus of elasticity of frame in pounds per square inch, Ic moment of inertia of column in inch4, refer Fig. ***2***.

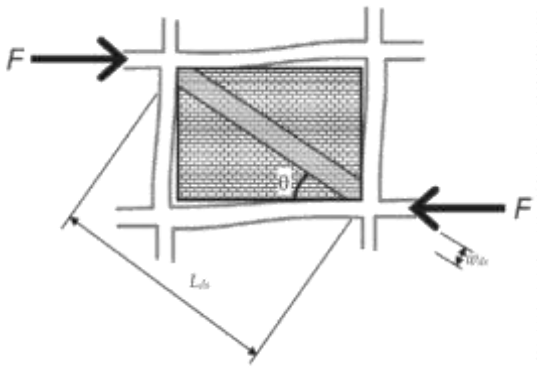

Fig. 2: Equivalent diagonal strut model for un reinforced masonry (URM) infills

3. MATERIALS

Mander's unconfined concrete with 5% damping and grade M40 was used to the model beam, column, and web stiffeners. Steel of grade Fe 415 is used for rebar and confining bars. Unreinforced brick masonry with intermediate mortar strength having combined prism strength of 6.6MPa is used for infills.

4. METHODOLOGY

To simulate the response of the model under maximum earthquake, pushover analysis is performed so as to form soft story at the plinth level. SAP 2000 v 20 is used to perform the pushover analysis. Seismic coefficient Ca and Cv as described in (ATC40, 1996) are taken to be 0.4 each. Hinges for beams, columns, and infills are as defined in (ASCE 41, 2014). On completion of the pushover analysis displacement at every story is noted in X & Y direction. Later inter-story drifts is found for all stories. Shear 2-2 is noted in a single column at every level in X direction and shear 3-3 is noted in a single column at every level in Y direction. Later story stiffness is calculated by taking the ratio of shear at a particular level to the inter story drift at that level. It must be noted that, all the parameters only at the plinth level are of greater significance and results are compared in all the models particularly for this story only.

5. RESULTS AND DISCUSSION

5.1 Displacement

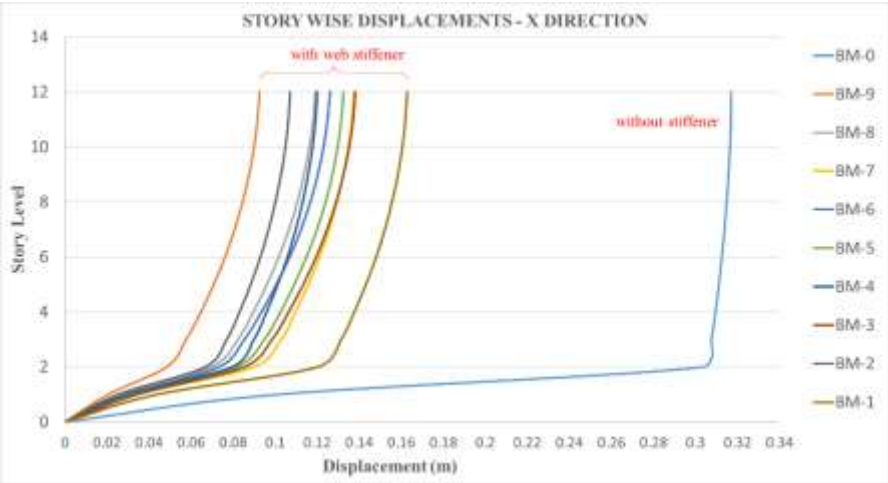

Fig. 3: Story-wise displacement (X direction)

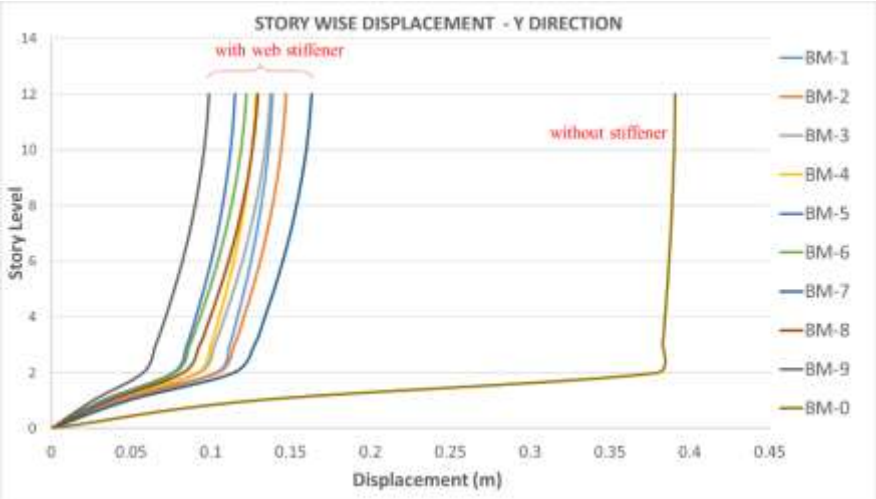

Fig. 4: Story-wise displacement (Y direction)

Table 2: Percent reduction in displacement at plinth level.

Building Model	BM-1	BM-2	BM-3	BM-4	BM-5	BM-6	BM-7	BM-8	BM-9
% Reduction in displacement-X	60%	78%	72%	74%	73%	76%	70%	77%	84%
% Reduction in displacement-Y	73%	73%	76%	76%	80%	80%	70%	78%	85%

As it is evident from Fig. 3, Fig. 4 and Table 2there is a significant reduction in displacement, as the vertical height 'a' and width 'b' of stiffener increases the displacement decreases, BM-9 showed the greatest reduction with 84% and 85% in X & Y direction respectively.

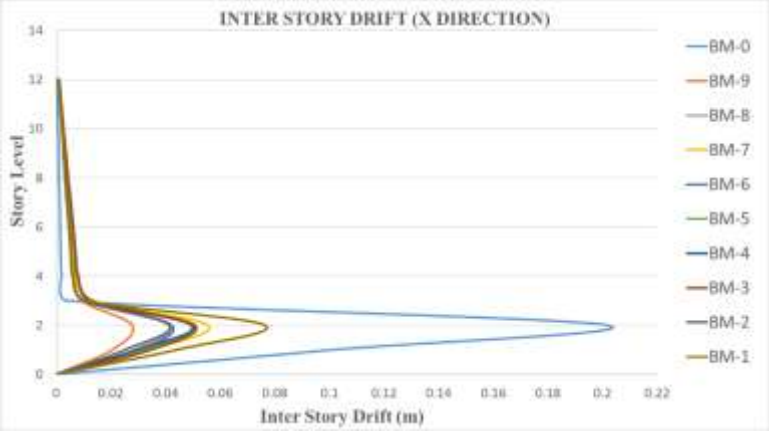

Fig. 5: Inter Story Drift (X-Direction)

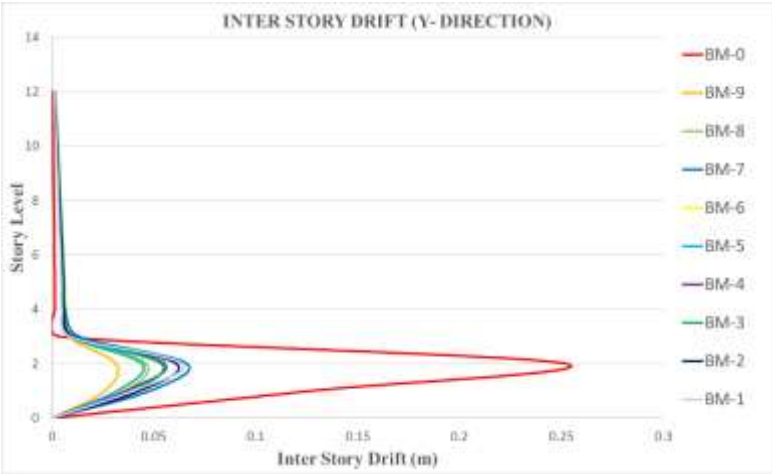

Fig. 6: Inter Story Drift (Y-Direction)

Table 3: Percent reduction in inter-story drift at plinth level.

Building Model	BM-1	BM-2	BM-3	BM-4	BM-5	BM-6	BM-7	BM-8	BM-9
% Reduction in ISD-X	62%	79%	75%	75%	76%	79%	72%	79%	86%
% Reduction in ISD-Y	75%	76%	79%	78%	82%	83%	74%	82%	88%

From Fig. 5 and 6 it can be seen that there is a significant reduction in inter-story displacement (ISD) at plinth level all the building models reduce the ISD more than 60%. Building model BM-9 has the greatest reduction in ISD in both the direction X & Y.

5.2 Percent increase in stiffness at plinth level

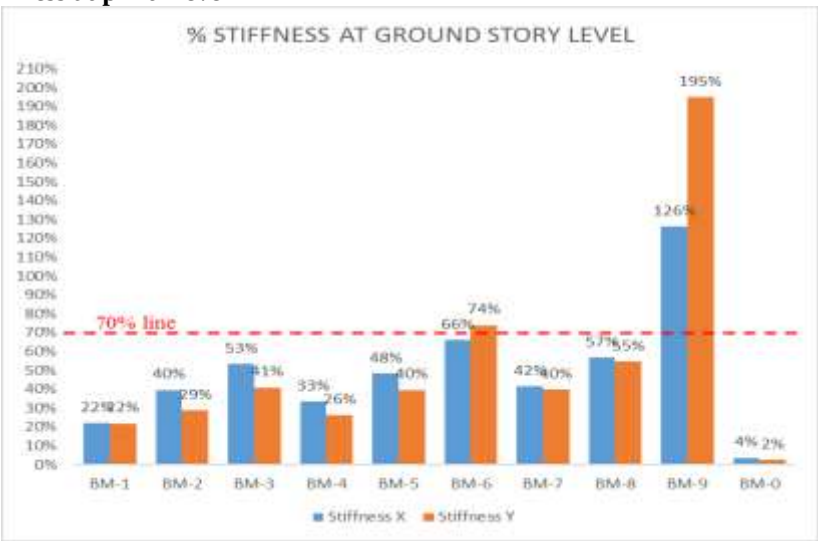

Fig. 7: Percent increase in stiffness at plinth level due to the application of stiffeners

It is seen that all the building models with web stiffener increased the stiffness to a certain extent as per the vertical depth and horizontal width of the web stiffener, but it was seen that only BM-9 successfully increased the stiffness beyond 70% in both the directions X & Y. Hence it can be concluded that the web stiffener required for rectification of soft-story must at least have a web depth 'a' equal to 25% of story depth and web width 'b' (refer **Error! Reference source not found.**) equal to 25% of bay width. The volume of concrete required for this retrofitting procedure using web stiffener is given by equation

$$V_{web} = \frac{1}{2} * n * a * b * w_{beam} \quad (3)$$

Where n= total no of web stiffeners used in one direction; a is the depth of web stiffener; b is the width of web stiffener; wbeam is the width of the beam connecting the web stiffener. The volume of concrete required for BM-9 is equal to 15.75m3, and cost of material M40 concrete amounts to approximately Rs 89,000/-

6. CONCLUSION

- The lateral stiffness is considerably increased using web stiffeners.
- The depth and width must be at least 25% of the height of column and width of bay respectively.
- Adequate shear reinforcement must be ensured at the point where web stiffeners are terminated in the connecting column and beam.

7. REFERENCES

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BIOGRAPHY

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