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Research Article

# Evaluation of Seismic Behavior for Multistoried RC Moment Resisting Frame with Open First Storey

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***Abstract***

*Presence of infill walls in the frames alters the behavior of the building under lateral loads. However, it is common industry practice to ignore the stiffness of infill wall for analysis of framed building. Engineers believe that analysis without considering infill stiffness leads to a conservative design. But this may not be always true, especially for vertically irregular buildings with discontinuous infill walls. Hence, the modeling of infill walls in the seismic analysis of framed buildings is imperative. Indian Standard IS 1893: 2002 allows analysis of open first storey buildings without considering infill stiffness but with a multiplication factor 2.5 in compensation for the stiffness discontinuity. As per the code the columns and beams of the open ground storey are to be designed for 2.5 times the storey shears and moments calculated under seismic loads of bare frames (i.e., without considering the infill stiffness). However, as experienced by the engineers at design offices, the multiplication factor of 2.5 is not realistic for low rise buildings. This calls for an assessment and review of the code recommended multiplication factor for low rise open ground storey buildings. Therefore, the objective of this study is defined as to check the applicability of the multiplication factor of 2.5 and to study the effect of infill strength and stiffness in the seismic analysis of open first storey building.*

***Keywords:*** *Iinfill walls, Equivalent diagonal strut, Open first storey, Soft Storey, Response spectrum analysis, Equivalent Lateral Force, Pushover Analysis, Multiplication Factor, Seismic Analysis.*

## 1. Introduction

Due to increasing population since the past few years car parking space for residential apartments in populated cities is a matter of major concern. Hence the trend has been to utilize the ground storey of the building itself for parking. These types of buildings (Fig.1) having no infill masonry walls in ground storey, but infilled in all upper storeys, are called Soft stories buildings. They are also known as 'open storey building'.

**Fig.1** Soft Story for Parking Space

There is significant advantage of these category of buildings functionally but from a seismic performance point of view such buildings are considered to have increased vulnerability. From the past earthquakes it was evident that the major type of failure that occurred in soft story buildings included snapping of lateral ties, crushing of core concrete, buckling of longitudinal reinforcement bars etc. Due to the presence of infill walls in the entire upper storey except for the ground storey makes the upper storeys much stiffer than the open ground storey. Thus, the upper storeys move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey itself. In other words, this type of buildings sway back and forth like inverted pendulum during earthquake shaking, and hence the columns in the ground storey columns and beams are heavily stressed. Therefore it is required that the ground storey columns must have sufficient strength and adequate ductility. The vulnerability of this type of building is attributed to the sudden lowering of lateral stiffness and strength in ground storey, compared to upper storeys with infill walls.

In the aftermath of the Bhuj earthquake, the IS 1893 code was revised in 2002, incorporating new design recommendations to address soft story buildings. Clause 7.10.3(a) states: The columns and beams of the soft storey are to be designed for 2.5 times the storey shears and moments calculated under seismic loads of bare frames. The factor 2.5 can be told as a multiplication factor (MF). This multiplication factor (MF) is supposed to be the

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compensation for the stiffness discontinuity. Other national codes also recommend multiplication factors for this type of buildings. The conservative nature of this empirical recommendation of IS code was first pointed out by Kanitkar and Kanitkar (2001), Subramanian (2004) and Kaushik (2006). Hence the aim of this paper is to check the applicability of the multiplication factor of 2.5 in the ground storey beams and column when the building is to be designed as soft storey framed building.

## 2. Basic Concept

As per the IS1893-2002 code Clause 7.1,

Soft Storey-

As per this provision of the code, a soft storey is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storey above.

Extreme Soft Storey-

As per this provision of the code, a extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average lateral stiffness of the three storey above.

**Fig.2** Failure of Soft Story Building

The building with soft story behaves differently as compared to a bare framed building (without any infill) or a fully infilled framed building under lateral load. A bare frame is much less stiff than a fully infilled frame; it resists the applied lateral load through frame action and shows well-distributed plastic hinges at failure. When this frame is fully infilled, truss action is introduced. A fully infilled frame shows less inter-storey drift, although it attracts higher base shear (due to increased stiffness). A fully infilled frame yields less force in the frame elements and dissipates greater energy through infill walls. The strength and stiffness of infill walls in infilled frame buildings are ignored in the structural modeling in conventional design practice. The design in such cases will generally be conservative in the case of fully infilled framed building. But things will be different for a soft story framed building. Soft story building is slightly stiffer than the bare frame, has larger drift (especially in the ground storey), and fails due to soft storey-mechanism at the ground floor as shown in Fig.2. Therefore, it may be in conservative to ignore strength and stiffness of infill wall while designing soft story buildings.

## 3. Example Building Frames

For the analysis purpose three models has been considered namely as:

**Model A:** Four storied (G+3) Special moment resisting frame.

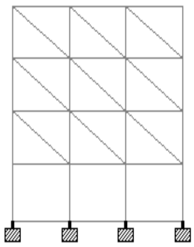
**Model B:** Seven storied (G+6) Special moment resisting frame.

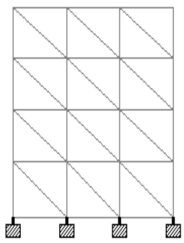
**Model C:** Ten storied (G+9) Special moment resisting frame.

There are following cases of each model have been considered for the analysis.

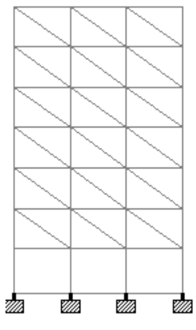
**Model A:**
Case 1: Four storied (G+3) building in which first storey is open and other stories are having infill wall (Model A-1).
Case 2: Four storied (G+3) building in which all stories are having infill wall (Model A-2).
**Model B**:
Case 1: Seven storied (G+6) building in which first storey is open and other stories are having infill wall (ModelB-1).
Case 2: Seven storied (G+6) building in which all stories are having infill wall (Model B-2).
**Model C:**
Case 1: Ten storied (G+9) building in which first storey is open and other stories are having infill wall (Model C-1).
Case 2: Ten storied (G+9) building in which all stories are having infill wall (Model C-2).

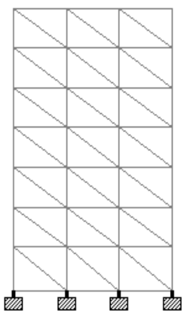
In all models and cases infill walls are modeled as equivalent diagonal strut element.



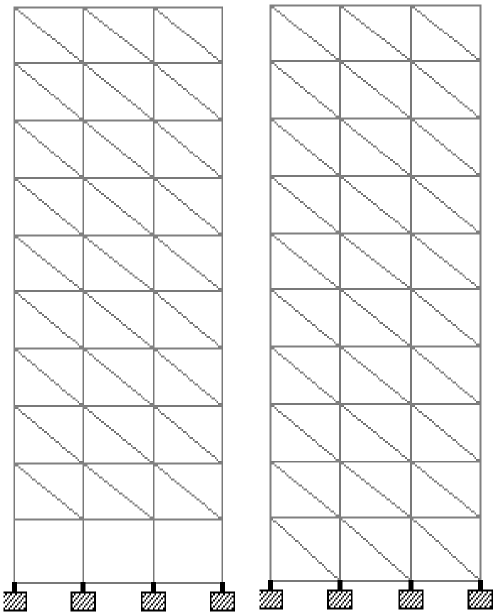


**Model A-1** **Model A-2**





**Model B-1** **Model B-2**



**Model C-1** **Model C-2**

**Table No.1** Details of Building Models

| | | |
|---|---|---|
| 1 | Type of Structure | Multistory rigid jointed plane frame (SMRF) |
| 2 | Seismic Zone | V |
| 3 | Number of stories | Four (G+3), Seven (G+6) And Ten (G+9) |
| 4 | Floors Height | First Floor- 3.8 m<br>Above first floor- 3.5 m |
| 5 | Infill wall | 250mm thick brick masonry wall along X direction and Y direction |
| 6 | Type of soil | Medium |
| 7 | Size of column | 450 mm X300 mm |
| 8 | Size of Beam | 450 mm X300 mm |
| 9 | Depth of Slab (RCC) | 120 mm |
| 10 | Live load | a) On roof = 1.5 KN/ $m^2$<br>b) On floor = 3.5 KN/ $m^2$ |
| 11 | Terrace Water Proofing | 1.5 KN/ $m^2$ |
| 12 | Floor Finishes | 0.5 KN/ $m^2$ |
| 13 | Material | M 20 Grade concrete & Fe 415 Reinforcement |
| 14 | Unit weights | a) Concrete = 25 KN/Cum<br>b) Masonry = 20 KN/Cum |
| 15 | Modulus of Elasticity of Concrete | 22360.67 N/$mm^2$ |
| 16 | Modulus of Elasticity of masonry | 6975 N/$mm^2$ |
| 17 | Total Height of Building | 14.3 m for G+3, 24.8 m for G+6 And 35.3m for G+9 |
| 18 | Clear Cover of Beam | 25 mm |
| 19 | Clear Cover of Column | 40 mm |
| 20 | Damping in Structure | 5% |
| 21 | Importance factor | 1.5 |

## 4. Modeling of Infill Walls

Modeling masonry structures is a task that involves a detailed descriion of materials. Masonry is a material that exhibits distinct directional properties due to the mortar joints which act as planes of weakness.

In present study, infills wall in stories are modeled as equivalent diagonal strut (Proposed by Hendry in 1998) and its equivalent width (W) of a strut is given as,

$$W=\frac{1}{2}\sqrt{\alpha_h^2+\alpha_l^2}$$

To determine $\alpha_h$ and $\alpha_l$ which depends on the relative stiffness of the frame and on the geometry of the panel.

$$\alpha_h=\frac{\pi}{2}\left[\frac{4E_f I_c h}{E_m\, t \sin 2\theta}\right]^{\frac{1}{4}}$$

$$\alpha_l=\pi\left[\frac{4E_f I_b l}{E_m\, t \sin 2\theta}\right]^{\frac{1}{4}}$$

Where,

$E_m$ and $E_f$ = Elastic modulus of the masonry wall and frame material, respectively

t, h, l = Thickness, height and length of the infill wall, respectively

$I_c$, $I_b$ = Moment of inertia of the column and the beam of the frame, respectively

$\Theta = \tan^{-1}(h/L)$

## 5. Storey Stiffness

(1) Column Stiffness of each storey-
Column Stiffness = $(12EI)/L^3$

(2) Infill Stiffness of each storey
Stiffness of Infill Wall = $(AE_m \cos^2 \Theta)/ l_d$

A = Area of Diagonal Strut
E = Elastic Modulus of the Concrete
$E_m$ = Elastic Modulus of the Masonry Wall
$\Theta = \tan^{-1}(h/L)$
$l_d$ = Diagonal Length of Strut
L = Length of the Column

The modulus of elasticity for the bricks is calculated As per Masonry Institute of America, (MIA 1998)

Em=750fm, 20 GPA (Max)

Where fm= Compressive Strength of Masonry and it has been taken from the Table no.E-1, Page No.-8 and Fig No. E-10 Page no 8 of SP 20)

## 6. Linear Analysis-Response Spectrum Analysis (RSA) &Equivalent Lateral Force Analysis (ELFA)

Response spectrum analysis and Equivalent Lateral Force analysis of the all building models are carried out in ETABS to find the multiplication factors (MF). Stiffness of infill walls in each bay is calculated as discussed in section 5. Truss elements are provided diagonally as equivalent struts wherever infill wall is present in the models. RSA is done for the response spectrum corresponding to medium soil for 5% damping as per IS 1893 (2002), for all the frames.

## Results from Response spectrum analysis (RSA)

**Table No.2** RSA Result for G+3 Building Model

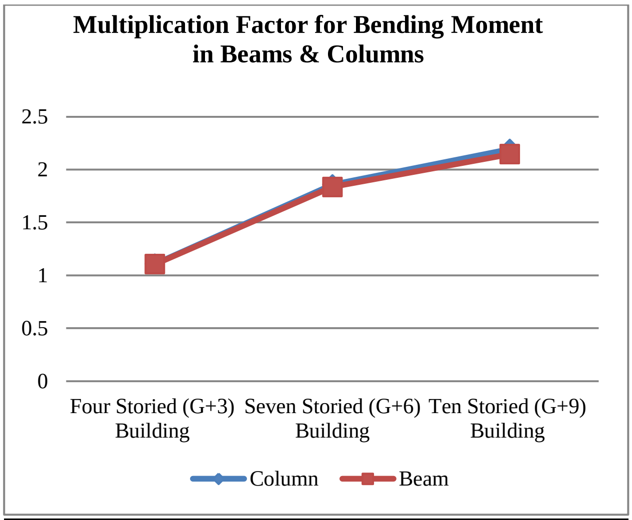
| Model > | | Four Storied (G+3) Building with open first storey (Model A-1) | Four Storied (G+3) Building with infill wall in all stories (Model A-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 377.005 | 340.11 | 1.10847961 |
| Beam (Ground Storey) | Max B.M. | 117.13 | 105.88 | 1.10625236 |

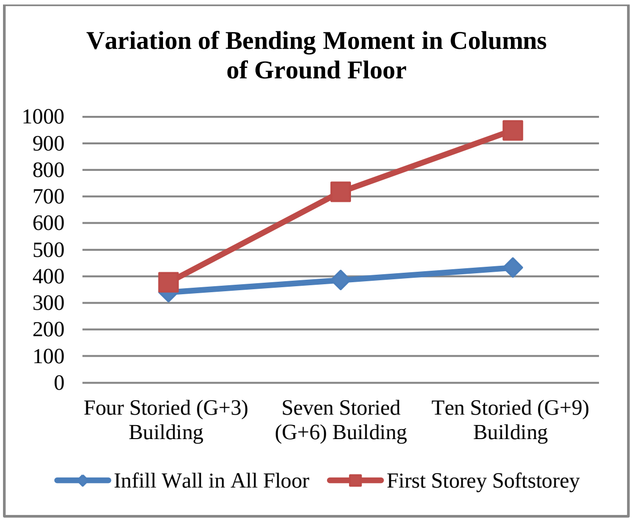
**Table No.3** RSA Result for G+6 Building Model

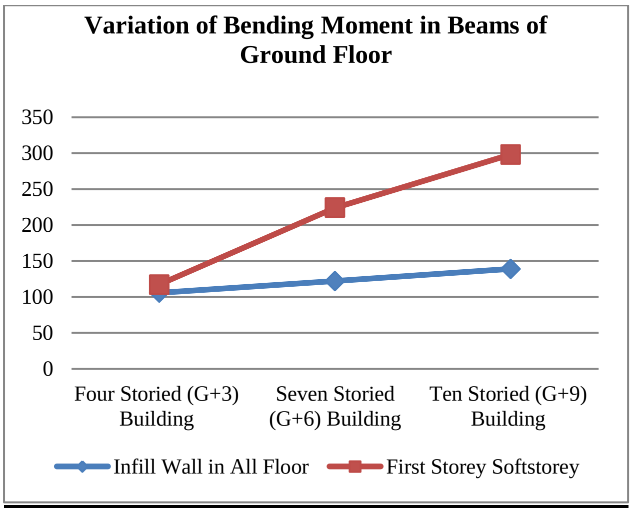
| Model > | | Seven Storied (G+6) Building with open first storey (Model B-1) | Seven Storied (G+6) Building with infill wall in all stories (Model B-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 717.332 | 385.95 | 1.85861381 |
| Beam (Ground Storey) | Max B.M. | 224.028 | 122.023 | 1.83594896 |

**Table No.4** RSA Result for G+9 Building Model

| Model > | | Ten Storied (G+9) Building with open first storey (Model C-1) | Ten Storied (G+9) Building with infill wall in all stories (Model C-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 949.015 | 432.602 | 2.19373696 |
| Beam (Ground Storey) | Max B.M. | 298.232 | 138.969 | 2.14603256 |




## Results from Equivalent Lateral Force Analysis (ELFA)

**Table No.5** ELFA Result for G+3 Building Model

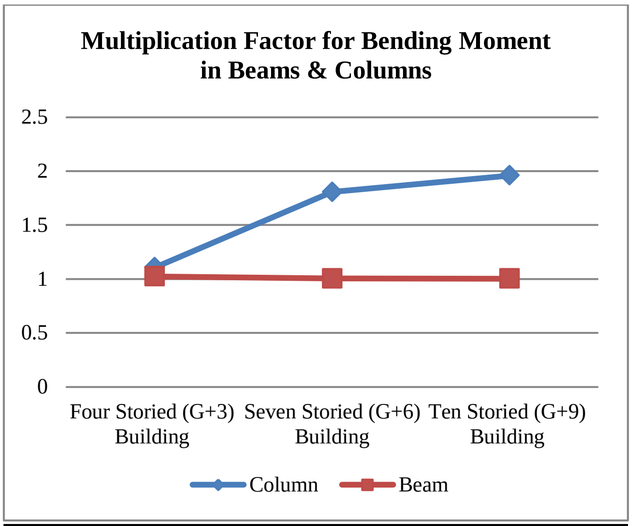
| Model > | | Four Storied (G+3) Building with open first storey (Model A-1) | Four Storied (G+3) Building with infill wall in all stories (Model A-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 56.796 | 51.299 | 1.10715608 |
| Beam (Ground Storey) | Max B.M. | 40.447 | 39.498 | 1.02402653 |

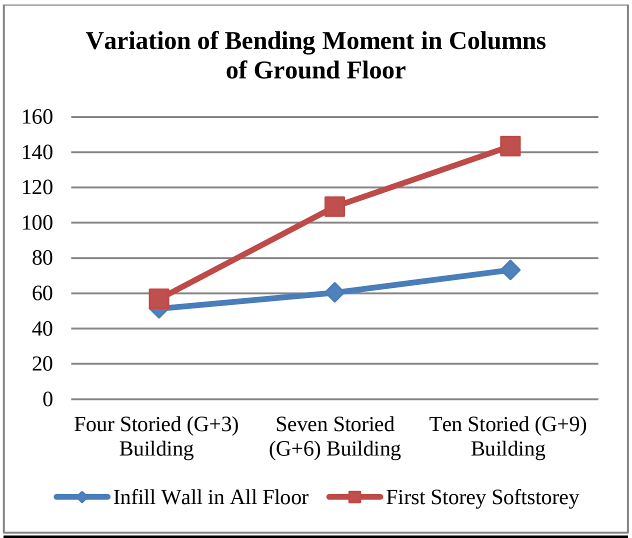
**Table No.6** ELFA Result for G+6 Building Model

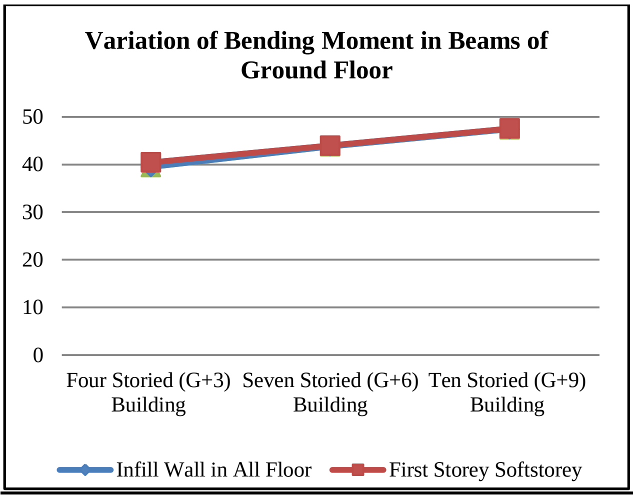
| Model > | | Seven Storied (G+6) Building with open first storey (Model B-1) | Seven Storied (G+6) Building with infill wall in all stories (Model B-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 109.115 | 60.389 | 1.80686880 |
| Beam (Ground Storey) | Max B.M. | 43.999 | 43.803 | 1.00447457 |

**Table No.7** ELFA Result for G+9 Building Model

| Model > | | Ten Storied (G+9) Building with open first storey (Model C-1) | Ten Storied (G+9) Building with infill wall in all stories (Model C-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 143.386 | 73.175 | 1.95949436 |
| Beam (Ground Storey) | Max B.M. | 47.575 | 47.42 | 1.00326866 |




## 7. Nonlinear Analysis- Push Over Analysis (POA)

Nonlinear analysis Pushover Analysis is conducted in ETABS for the same frame models (four storied, seven storied and ten storied) to estimate the magnification factor considering nonlinearities in the infill walls and frame elements.

**Table No.8** POA Result for G+3 Building Model

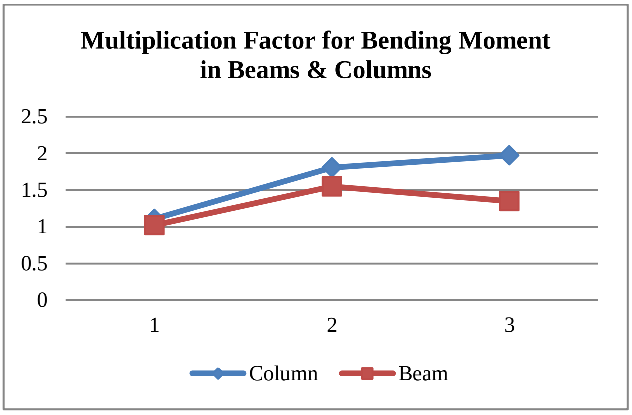
| Model > | | Four Storied (G+3) Building with open first storey (Model A-1) | Four Storied (G+3) Building with infill wall in all stories (Model A-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 113.599 | 102.634 | 1.10683594 |
| Beam (Ground Storey) | Max B.M. | 48.24 | 47.227 | 1.02144959 |

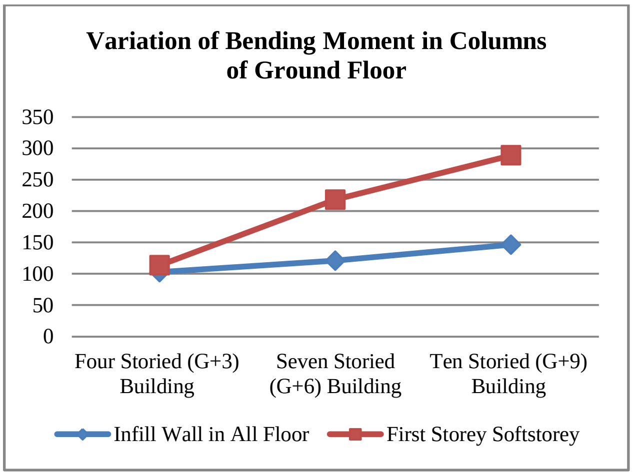
**Table No.9** POA Result for G+6 Building Model

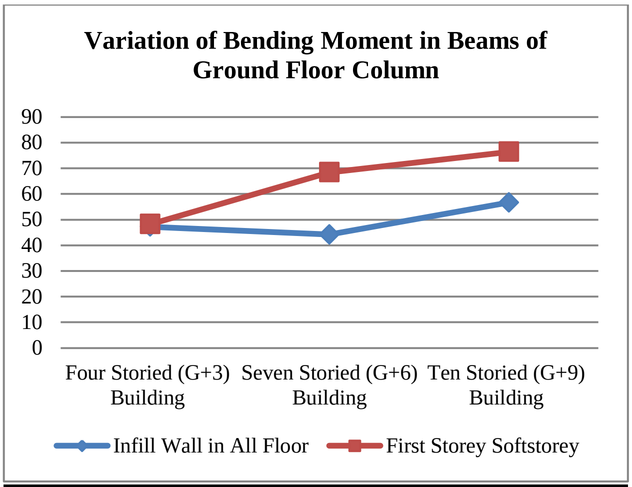
| Model > | | Seven Storied (G+6) Building with open first storey (Model B-1) | Seven Storied (G+6) Building with infill wall in all stories (Model B-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 218.282 | 120.816 | 1.80673089 |
| Beam (Ground Storey) | Max B.M. | 68.445 | 44.197 | 1.54863452 |

**Table No.10** POA Result for G+9 Building Model

| Model > | | Ten Storied (G+9) Building with open first storey (Model C-1) | Ten Storied (G+9) Building with infill wall in all stories (Model C-2) | Maximum Multiplication Factor |
|---|---|---|---|---|
| Column (Ground Storey) | Max B.M. | 288.719 | 146.443 | 1.97154524 |
| Beam (Ground Storey) | Max B.M. | 76.375 | 56.616 | 1.34900028 |




## 8. Conclusions

Open First Storey buildings are considered as vertically irregular buildings as per IS 1893: 2002 that requires dynamic analysis considering strength and stiffness of the infill walls. IS 1893: 2002 also permits Equivalent Static Analysis (ESA) of OGS buildings ignoring strength and stiffness of the infill walls, provided a multiplication factor of 2.5 is applied on the design forces (bending moments and shear forces) in the ground storey columns and beams.

In the present study it is shown that the MF based on linear and non linear analysis is in the range 1.106-1.1084 for a four storied OFS building, 1.806-1.858 for seven storeyed OFS building and 1.959-2.193 for ten storied OFS building. The MF increases with the height of the building, primarily due to the higher shift in the time period.

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