Structural Response of High Rise Buildings For Different Soft Storey Heights and Approaching Methodology

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Abstract— Earthquakes are natural hazards under which disasters are mainly caused by damage or collapse of buildings and other man-made structures. Due to accommodation of vehicles and their movements at ground levels infill walls are generally avoided, which creates soft storey effect. It should be noted that 70 to 80 % of buildings of urban areas in India fall under the classification of soft storey. This soft storey is also called as Open ground storey or Weak storey. It is a typical feature in the modern multi-storey constructions. Such features are highly undesirable in buildings built in seismically active areas; this has been verified in numerous experiences of strong shaking during the past earthquakes. The majority of buildings that failed during the Bhuj earthquake (2001) and Gujarat earthquake were of the open ground storey type. The collapse mechanism of such type of building is predominantly due to the formation of soft-storey.
As per Indian Standard IS 1893: 2002, 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. This Multiplication Factor value however does not account for number of storeys, number of bays, type and number of infill walls present, etc, and hence it is independent of all of the above factors. 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.
This study includes analysis of (G+7) RCC Framed building analysed using Seismic Coefficient Method (SCM) as per IS 1893: 2002. In modelling the masonry infill panels, Equivalent diagonal Strut method is used. This study basically includes Four models namely, Frame without masonary infill effect (Bare frame), Masonary Infill frame, Frame with Tie-beam (Tie-beamed frame) and Frame with Bracings (Braced frame) which are analysed for Soil type I (Hard) considering time period for seismic analysis as per Program calculated and as per Codal provision. The response of columns in Open ground storey are discussed and conclusions are made in this study analysed on ETABS software.

Index Terms— Soft storey, Multiplication Factor, Storey Shears and Moments, Equivalent diagonal Strut, Seismic Coefficient Method, Bare frame, Masonary Infill frame, Tie-beamed frame, Braced frame, Hard soil, Program calculated, Codal provision.

1 Introduction

MANY urban multi-storey buildings in India today have open first storey as an unavoidable feature. This is primarily being adopted to accommodate parking or reception lobbies in the first storeys as shown in Figure1. The upper storeys have brick infilled wall panels. The Indian seismic code classifies a soft storey as one whose lateral stiffness is less than 70%of the storey above or below [IS:1893,2002]. Interestingly, this classification renders most Indian buildings, with no masonry infill walls in the first storey, to be "buildings with soft first storey."

In the aftermath of the Bhuj earthquake, where severe damages to the buildings with soft storey was observed thus to assure safe design, 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 said as a multiplication factor (MF). This multiplication factor (MF) is supposed to be the compensation for the stiffness discontinuity.Thus inorder to check the applicability of this multiplication factor following study is carried out where structures or models with different themes were analysed as Bare frame, Masonary Infill frame, Tie-beamed frame, Braced frame and results are obtained.

This study basically involves comparison of storey shear and moments of Bare frame with three different modelled frames for soil type I and approaching methods (Program calculated and Codal provision).The seismic effect on Soft storey columns is studied by grouping them.

Group 1: Corner exterior columns.
Group 2: Longer direction peripheral columns.
Group 3: Shorter direction peripheral columns.
Group 4: Interior columns.

Figure 1: Some Typical Example of Open Ground Storey Building.

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Ratios are developed based on storey shear and moments of respective column group. The other governing factor in this study is height variation of Soft storey from 4m to 5m.This gives over all view or idea of the entire study.

2 Descprition And Structural Modelling

2.1 Geometry

For the study, four different models of an eight storey building are considered. The building has five bays in X direction with spacing of 4.5m and three bays in Y direction with spacing of 4m. The plan dimension 22.5 m × 12 m. Typical storey height is 3 m for each floor except for bottom storey with variation in height from 4m to 5m (interval being 0.2m each). This geometry remains same throughout the study. The only influencing factor is change in the column dimensions in Program calculated and Codal provision. The column size decreases from Bottom to Top. The plan (as shown in figure 2.1 and 2.2) and grouping of column (as shown in figure 2.3 to 2.6)

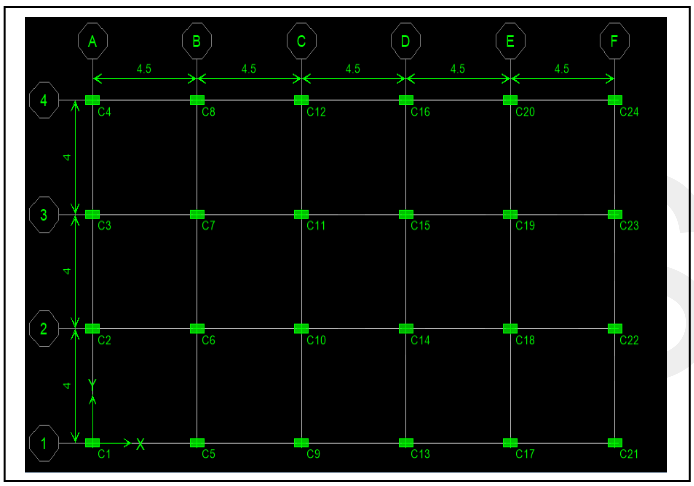

Figure 2.1: Plan for (G+7) Program Calculated

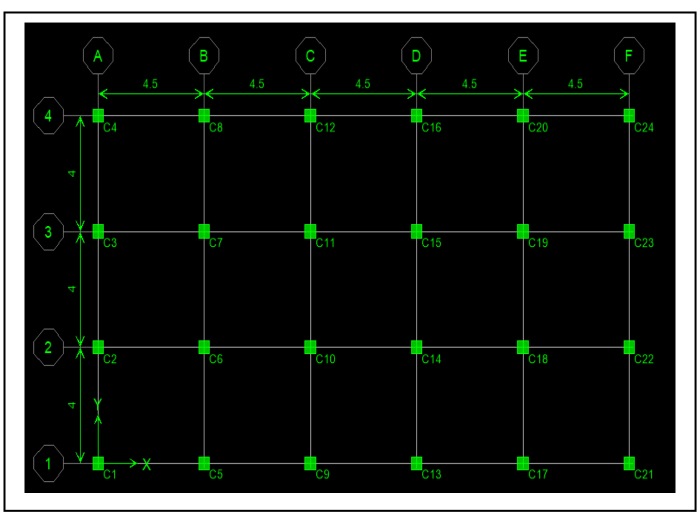

Figure 2.2: Plan for (G+7) Codal Provision

Grouping of Column

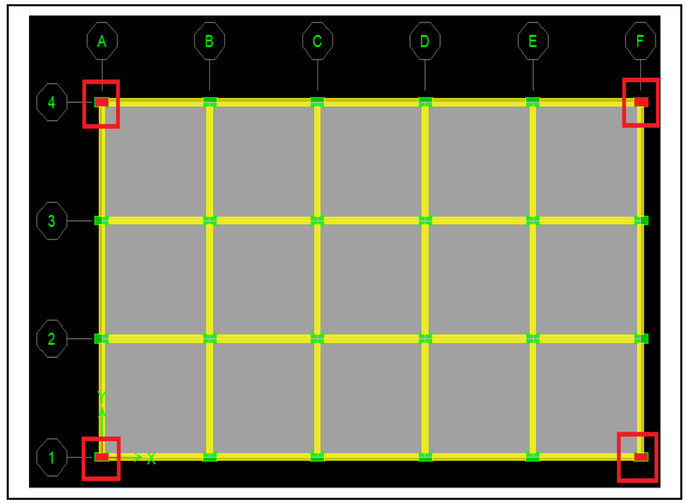

Figure 2.3: Group 1(Corner exterior columns)

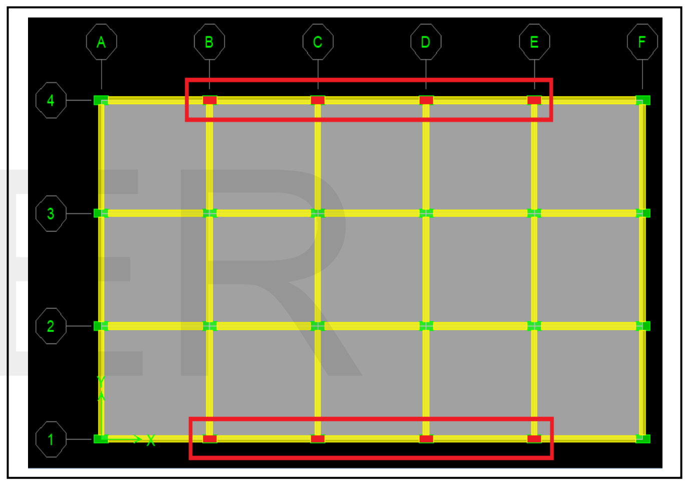

Figure 2.4: Group 2(Longer direction peripheral columns)

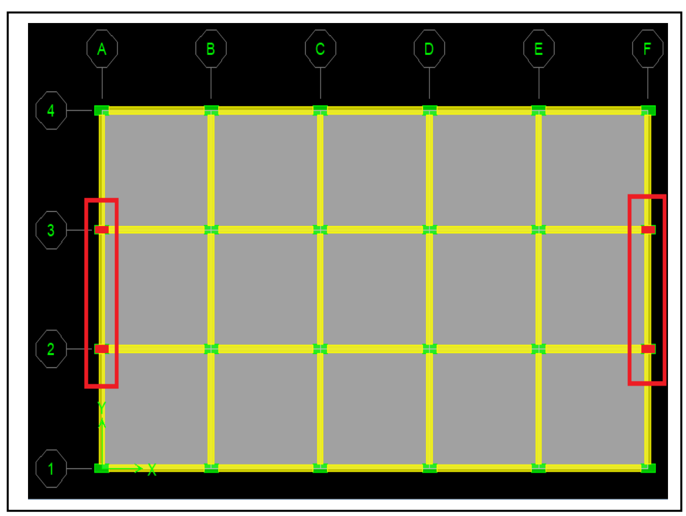

Figure 2.5: Group 3(Shorter direction peripheral columns)

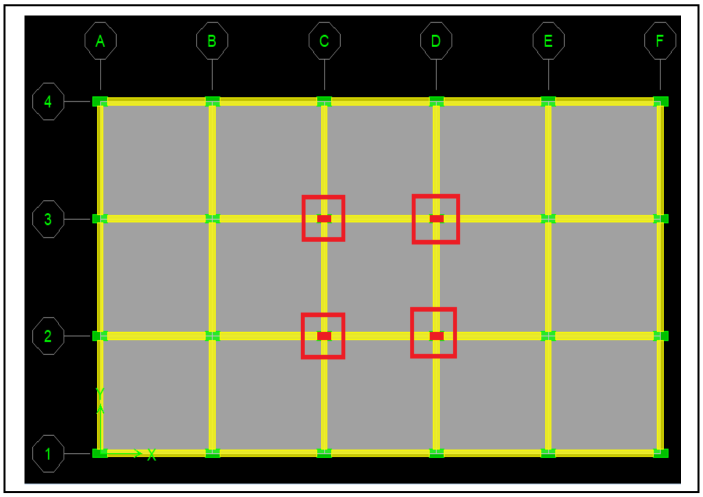

Figure 2.6: Group 4 (Interior columns)

2.2 Analysis Data

Following data is used in the analysis of the RC frame building models

- Type of frame: Special RC moment resisting frame fixed at the base
- Seismic zone: V
- Number of storey: Eight
- Floor height: 3 m
- Depth of Slab: 0.15 m
- Size of beam, Tie beam and Bracing: (0.23 ×0. 45)m
- Size of column provided as per design requirement :
  Time period for seismic analysis considered as Program calculated:
  Bottom (0.35×0.75)m
  Middle (0.30×0.68)m
  Top (0.30×0.60)m
  Time period for seismic analysis considered as per Codal Provision :
  Bottom (0.60×0. 60)m
  Middle (0.50×0.50)m
  Top (0.45 ×0.45)m
- Spacing between bay: X-direction 4.5 m
  : Y-direction 4 m
- Floor finish: 1 KN/m²
- Materials: M 25 concrete, Fe 500 steel
- Thickness of masonary infill wall: 0.15 m
- Density of concrete: 25 KN/m³
- Density of masonary infill: 20 KN/m³
- Type of soil: Hard
- Seismic Coefficient Method: As per IS 1893(Part-1):2002
- Damping of structure: 5 percent

2.3 Modeling Of Equivalent Diagonal Strut

Equivalent Diagonal Strut Method is used for modelling the masonary infill wall. In this method the infill wall is idealized as diagonal strut as shown in figure 2.7

The width of the diagonal strut is given by researcher Mainstone as in equation i and ii

$w = 0.175\ (\lambda\ h)^{-0.4} d'$……………………………….i

Where, $\lambda = \sqrt[4]{\frac{E_i t \sin 2\theta}{4 E_f I_c h'}}$ ………………………..ii

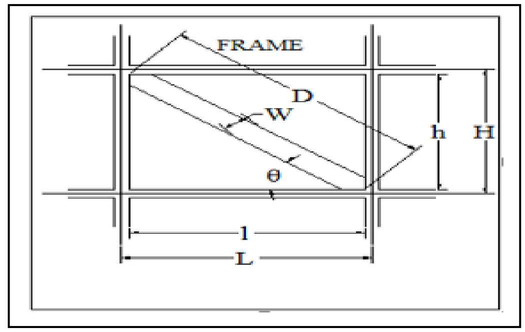

Figure.2.7 Diagonal strut modelling of infill panel

Ei = modulus of elasticity of masonary infill material
Ef = modulus of elasticity of frame material
L = beam length between centre lines of columns
L' = length of infill wall
h = column height between centre lines of beams
h' = height of infill wall
Ic = moment of inertia of column
t = thickness of infill wall
d' = diagonal length of strut
θ = angle between diagonal of infill wall and the horizontal in radian

3 Models Considered For Analysis

Following four models are analysed using Seismic Coefficent Method-

1) Model 1: Frame without masonary infill effect (Bare Frame-as shown in figure 3.1).
2) Model 2: Frame with Masonary Infill effect (as shown in figure 3.2).
3) Model 3: Frame with Tie-beam (as shown in figure 3.3).
4) Model 4: Frame with Bracings (as shown in figure 3.4).

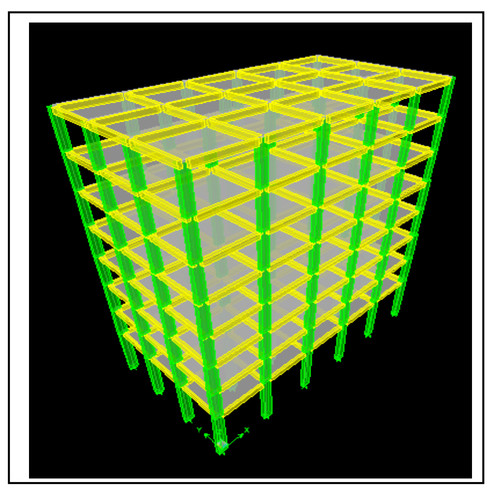

Figure 3.1: Model 1- Frame without masonary (Bare frame)

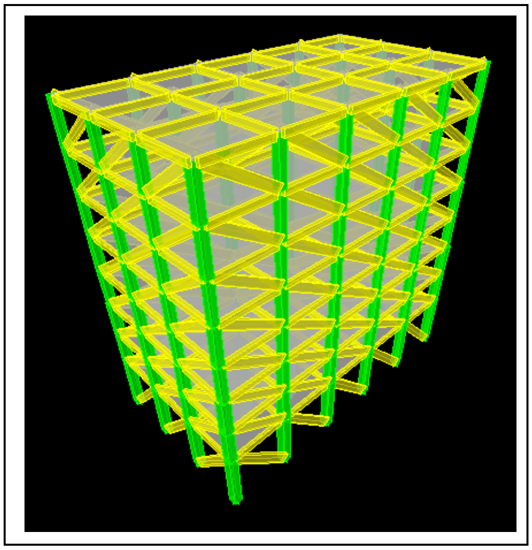

Figure 3.2: Model 2- Frame with Masonary Infill effect (Infill frame)

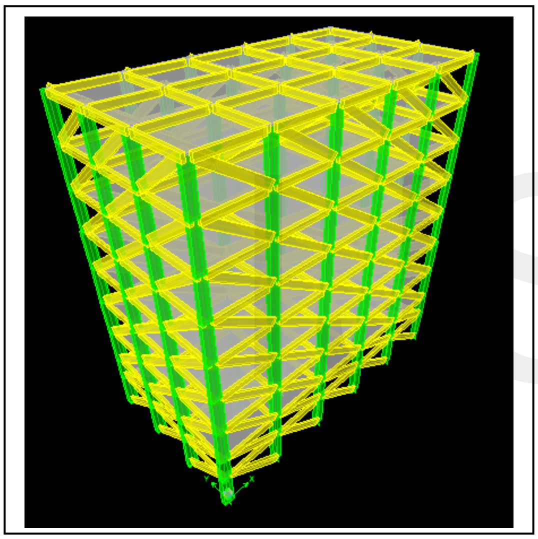

Figure 3.3: Model 3- Frame with Tie-beam

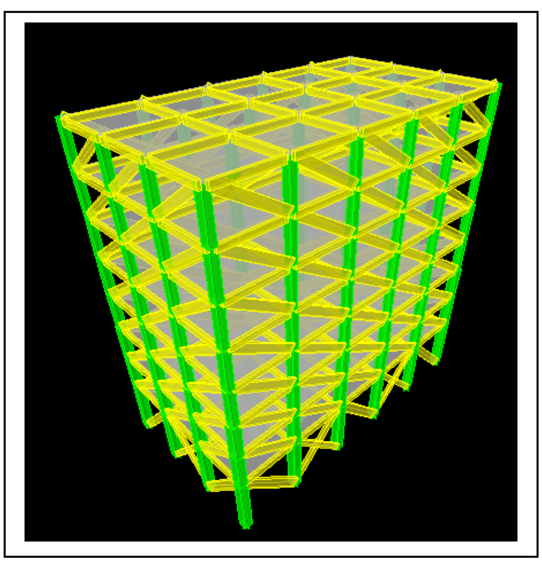

Figure 3.4: Model 4- Frame with Bracings

Above four models has been analysed and the results obtained using Software are presented.

4 Results And Discussion

As observed from the tables (4.1 to 4.6). The shear force and bending moment demand are severly higher for ground storey columns with respect to first storey column. Therefore ratios are developed in regard to the shear force and bending moment of soft storey columns.

$$RPu = \frac{\text{Axial force of bottom storey column for frame with (INFILL/TIE-BEAM/BRACED FRAME)}}{\text{Axial force of bottom storey column for frame with. out masonary infill effect (BARE FRAME)}}$$

$$RMu_2 = \frac{\text{Bending moment of bottom storey column for frame with (INFILL/TIE-BEAM/BRACED FRAME)}}{\text{Bending moment of bottom storey column for frame with out masonary infill effect (BARE FRAME)}}$$

$$RMu_3 = \frac{\text{Bending moment of bottom storey column for frame with (INFILL/TIE-BEAM/BRACED FRAME)}}{\text{Bending moment of bottom storey column for frame with out masonary infill effect (BARE FRAME)}}$$

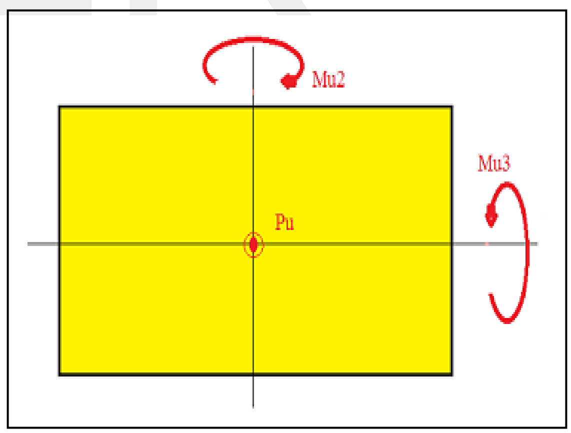

Figure 4.1: Schematic representaion of directions (Axial comp. force and Bending moments)

4.1 Ratios Observed by considering Time period for seismic analysis using software (Program Calculated)

TABLE 4.1

RATIOS OBTAINED FOR DIFFERENT GROUPS AND SOFT STOREY HEIGHTS ARE SUMMARIZED FOR FRAME WITH MASONRY INFILL

STOREY HEIGHT	GROUP 1			GROUP 2			GROUP 3			GROUP 4		
	RPu	RMu2	RMu3	RPu	RMu2	RMu3	RPu	RMu2	RMu3	RPu	RMu2	RMu3
4	0.88	0.26	0.88	0.69	0.36	0.69	0.77	0.26	0.77	1.41	0.34	0.19
4.2	0.88	0.26	0.88	0.69	0.29	0.69	0.77	0.3	0.77	1.41	0.32	0.19
4.4	0.88	0.27	0.88	0.76	0.26	0.76	0.7	0.35	0.7	1.41	0.3	0.21
4.6	0.88	0.27	0.88	0.76	0.25	0.76	0.7	0.36	0.7	1.41	0.29	0.21
4.8	1.29	1.11	1.29	1.16	1.07	1.16	1.15	1.05	1.15	1.05	1.03	1.05
5	1.29	1.11	1.29	1.16	1.07	1.16	1.16	1.05	1.16	1.05	1.03	1.05

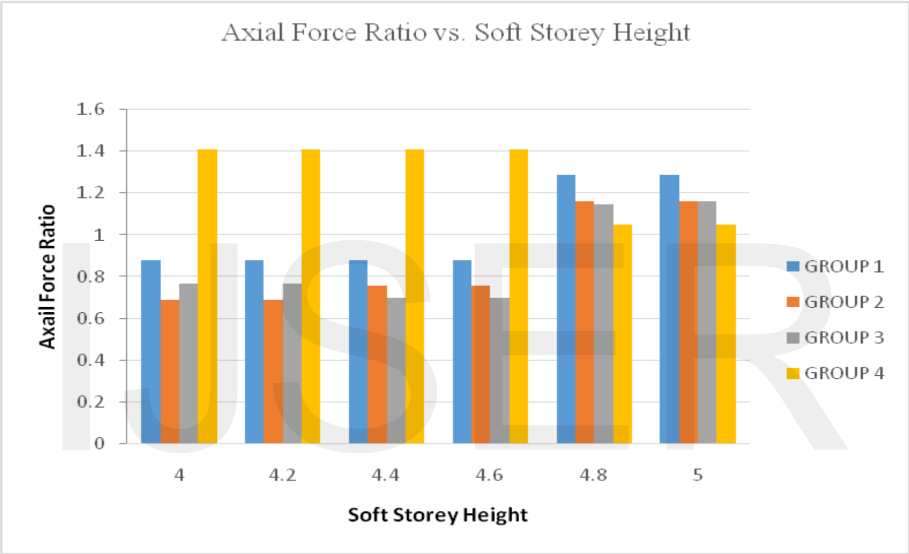

Fig 4.2: Variations of Axial Force for different soft storey heights and column groups

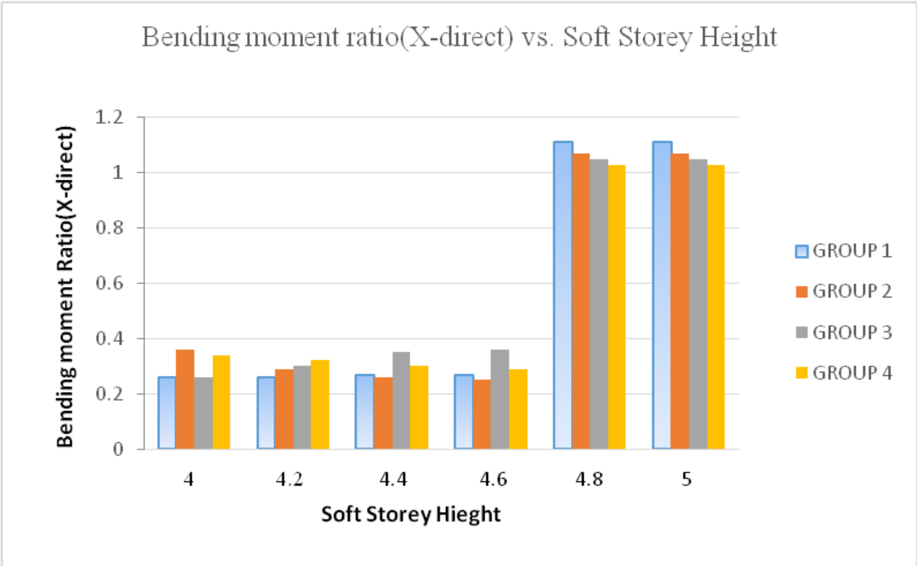

Fig 4.3: Variations of Bending moment(X-direct.) for different soft storey heights and column groups

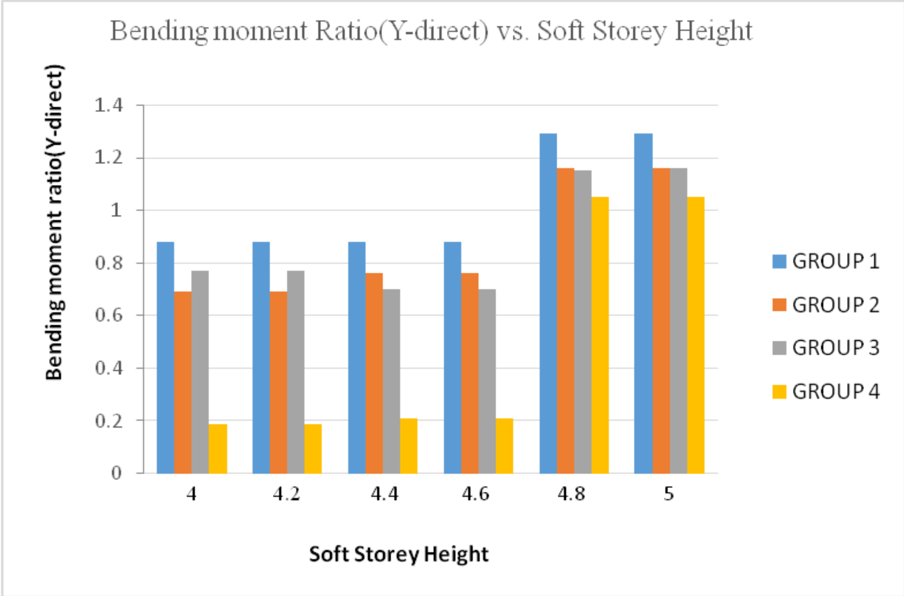

Fig 4.4: Variations of Bending moment (Y-direct.) for different soft storey heights and column groups

TABLE 4.2

RATIOS OBTAINED FOR DIFFERENT GROUPS AND SOFT STOREY HEIGHTS ARE SUMMARIZED FOR FRAME WITH TIE-BEAM

STOREY HEIGHT	GROUP 1			GROUP 2			GROUP 3			GROUP 4		
	RPu	RMu2	RMu3	RPu	RMu2	RMu3	RPu	RMu2	RMu3	RPu	RMu2	RMu3
4	0.95	0.69	0.92	0.73	0.26	0.69	0.83	0.05	0.78	1.51	0.372	0.147
4.2	0.95	0.68	0.9	0.73	0.04	0.69	0.8	0.05	0.8	1.51	0.35	0.147
4.4	0.95	0.66	0.87	0.79	0.04	0.72	0.71	0.27	0.71	1.41	0.3	0.11
4.6	0.95	0.62	0.86	0.79	0.04	0.71	0.71	0.26	0.71	1.41	0.29	0.11
4.8	0.96	0.6	0.85	0.79	0.06	0.7	0.71	0.24	0.71	1.41	0.27	0.11
5	0.96	0.57	0.85	0.79	0.06	0.79	0.71	0.23	0.71	1.41	0.26	0.11

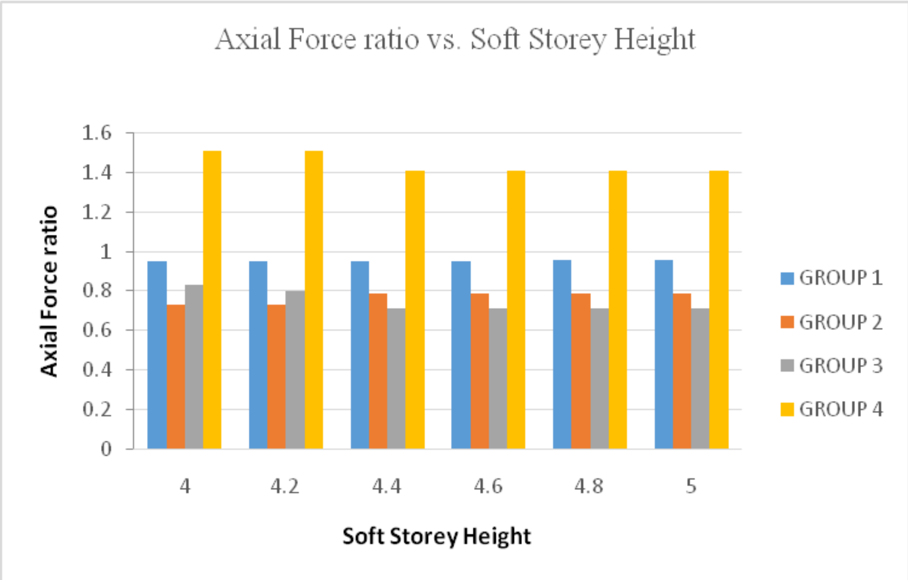

Fig.4.5: Variations of Axial Force for different soft storey heights and column groups

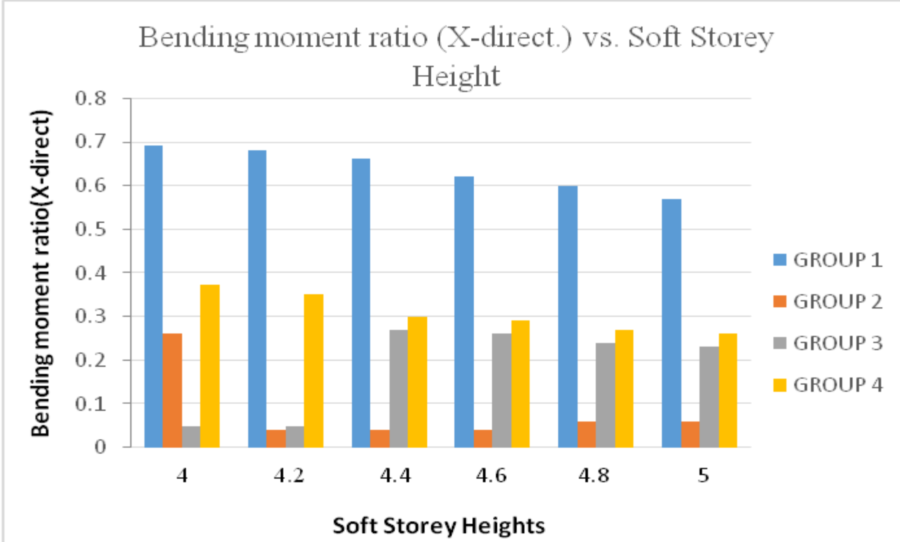

Fig. 4.6: Variations of Bending moment(X-direct.) for different soft storey heights and column groups

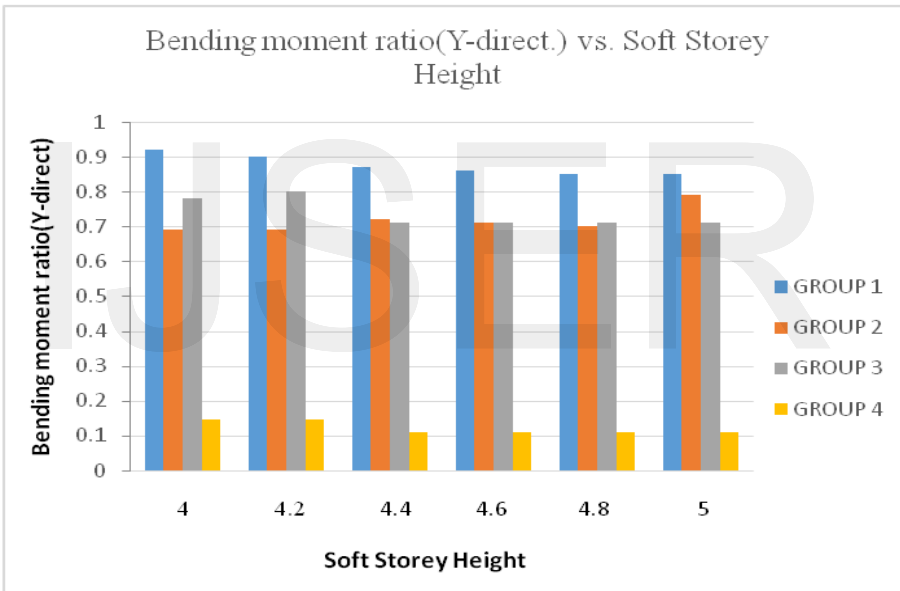

Fig 4.7: Variations of Bending moment(Y-direct.) for different soft storey heights and column groups

Table 4.3

Ratios obtained for different Groups and Soft Storey heights are summarized for Frame with Bracings.

STOREY HEIGHT	GROUP 1			GROUP 2			GROUP 3			GROUP 4		
	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3
4	0.87	0.062	0.87	0.8	0.01	0.8	0.715	0.006	0.715	1.41	0.34	0.001
4.2	0.87	0.063	0.87	0.8	0.01	0.8	0.715	0.006	0.715	1.41	0.32	0.001
4.4	0.87	0.04	0.87	0.7	0.05	0.7	0.81	0.04	0.81	1.41	0.3	0.001
4.6	0.87	0.035	0.87	0.69	0.04	0.69	0.81	0.04	0.81	1.4	0.28	0.002
4.8	0.87	0.034	0.87	0.69	0.03	0.69	0.81	0.03	0.81	1.4	0.27	0.002
5	0.87	0.022	0.87	0.68	0.03	0.68	0.81	0.03	0.81	1.4	0.26	0.003

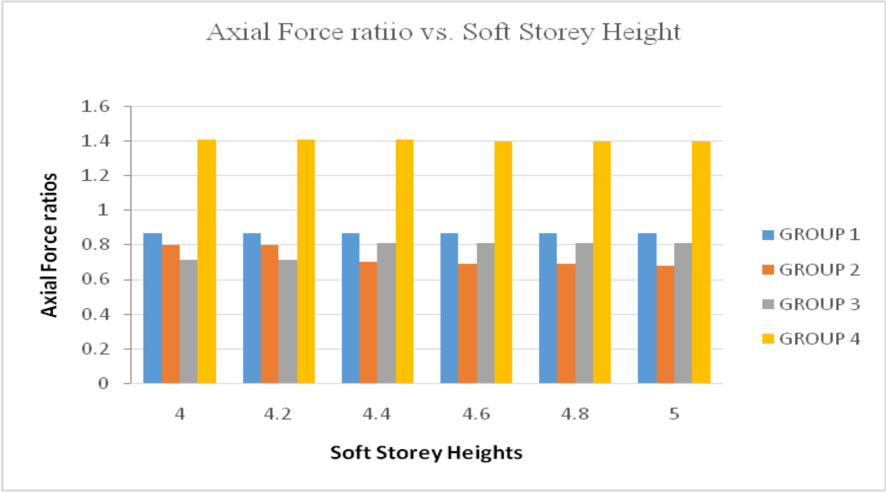

Fig 4.8: Variations of Axial Force for different soft storey heights and column groups

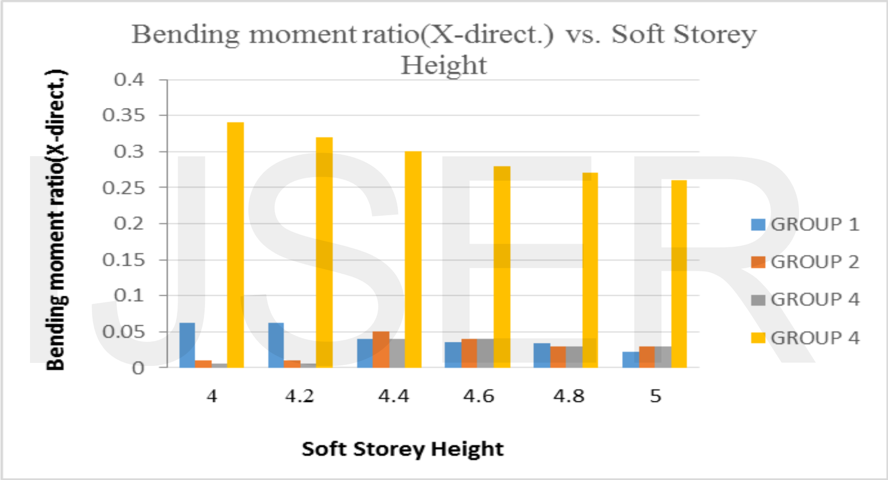

Fig 4.9: Variations of Bending moment(X-direct.) for different soft storey heights and column groups

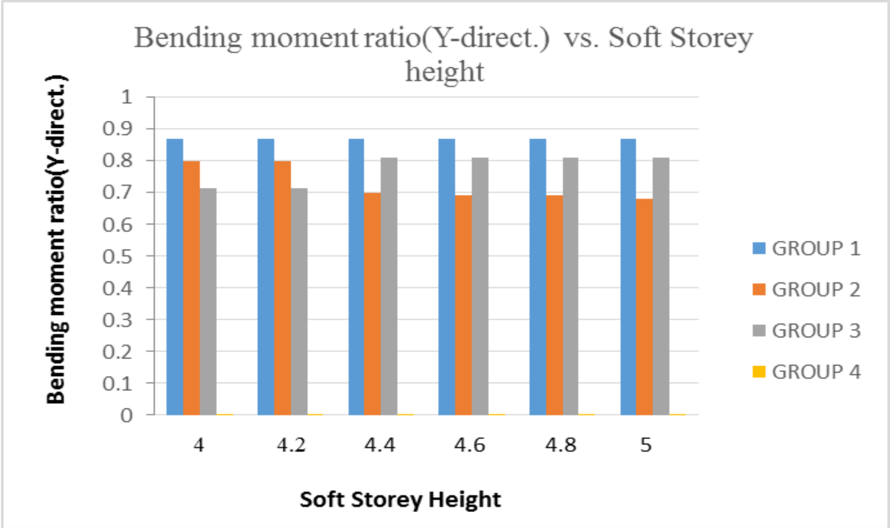

Fig 4.10: Variations of Bending moment(Y-direct.) for different soft storey heights and column groups

4.2 Ratios Observed by considering Time period as per Codal Provision

TABLE 4.4

RATIOS OBTAINED FOR DIFFERENT GROUPS AND SOFT STOREY HEIGHTS ARE SUMMARIZED FOR FRAME WITH MASONRY INFILL.

STOREY HEIGHT	GROUP 1			GROUP 2			GROUP 3			GROUP 4		
	RPu	RMu2	RMu3	RPu	RMu2	RMu3	RPu	RMu2	RMu3	RPu	RMu2	RMu3
4	1.31	1.08	1.31	1.212	1.076	1.2	1.21	1.081	1.21	1.096	1.071	1.096
4.2	1.31	1.08	1.318	1.212	1.07	1.2	1.21	1.08	1.21	1.096	1.068	1.096
4.4	1.32	1.084	1.32	1.2	1.081	1.26	1.222	1.074	1.222	1.096	1.068	1.095
4.6	1.32	1.096	1.345	1.203	1.092	1.22	1.235	1.085	1.253	1.096	1.065	1.111
4.8	1.32	1.079	1.324	1.204	1.076	1.187	1.247	1.069	1.249	1.094	1.063	1.094
5	1.32	1.079	1.32	1.218	1.067	1.182	1.237	1.068	1.237	1.094	1.063	1.094

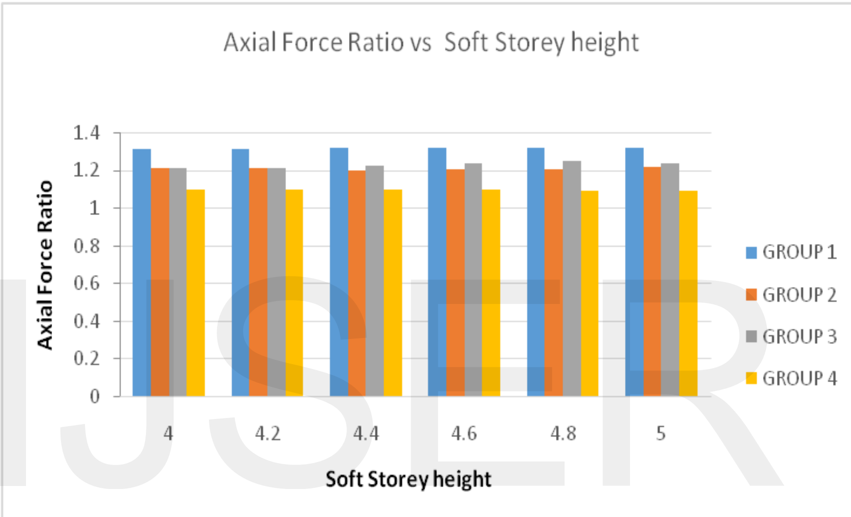

Fig 4.11: Variations of Axial Force for different soft storey heights and column groups

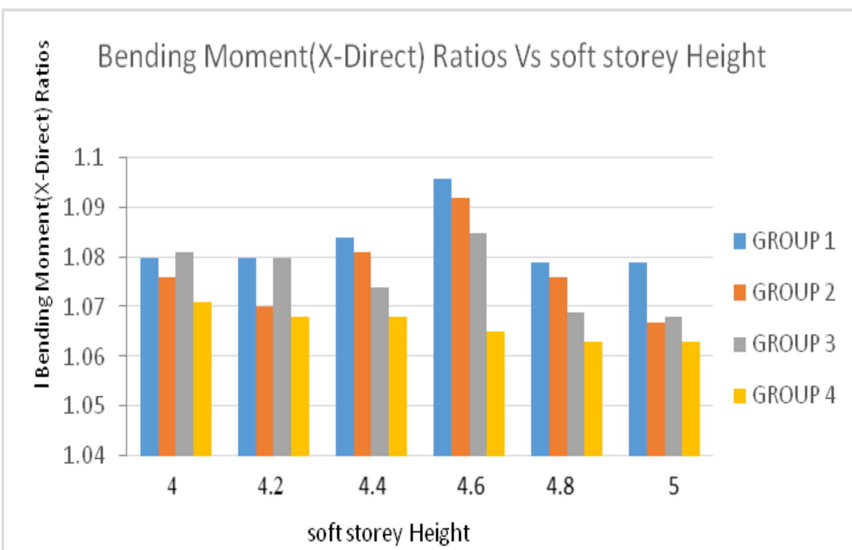

Fig 4.12: Variations of Bending moment(X-direct.) for different soft storey heights and column groups

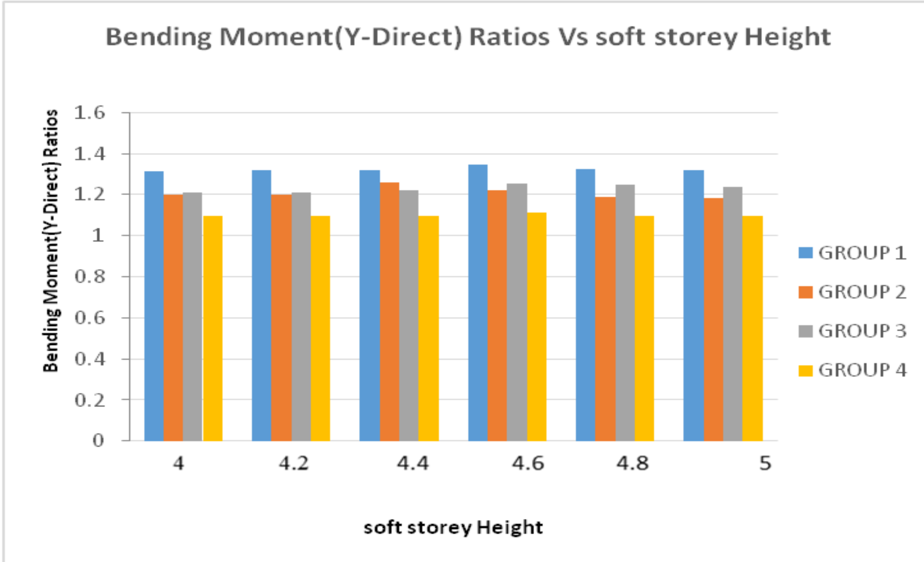

Fig 4.13: Variations of Bending moment(Y-direct.) for different soft storey heights and column groups

TABLE 4.5

RATIOS OBTAINED FOR DIFFERENT GROUPS AND SOFT STOREY HEIGHTS ARE SUMMARIZED FOR FRAME WITH TIE-BEAM.

STOREY	GROUP 1			GROUP 2			GROUP 3			GROUP 4		
HEIGHT	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3
4	1.43	1.153	1.32	1.266	1.085	1.172	1.282	1.139	1.18	1.154	1.025	1.064
4.2	1.44	1.153	1.315	1.268	1.081	1.15	1.282	1.137	1.17	1.153	1.029	1.064
4.4	1.448	1.152	1.3	1.282	1.079	1.139	1.271	1.131	1.143	1.153	1.009	1.054
4.6	1.455	1.149	1.29	1.282	1.072	1.137	1.274	1.128	1.13	1.153	1	1.059
4.8	1.462	1.146	1.27	1.282	1.065	1.12	1.276	1.123	1.116	1.153	0.992	1.044
5	1.485	1.143	1.27	1.29	1.055	1.114	1.29	1.127	1.113	1.153	0.991	1.03

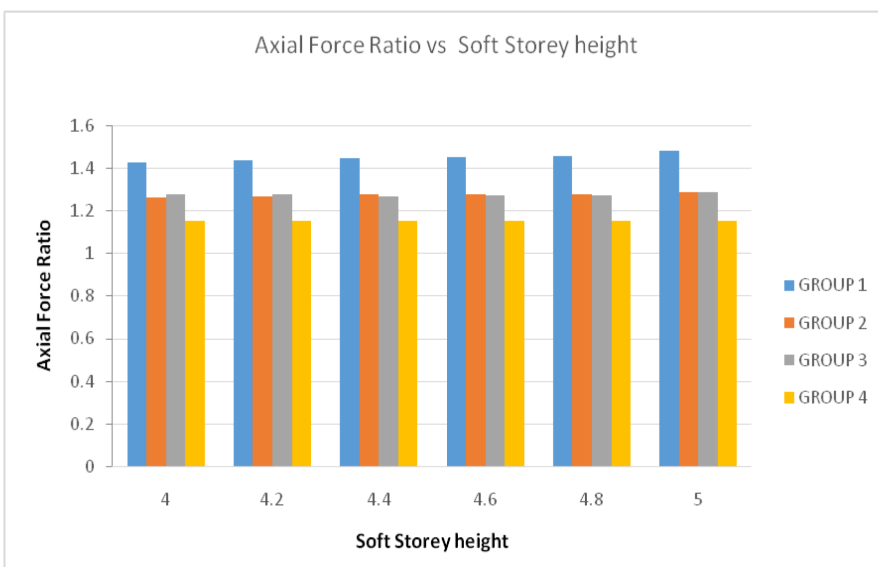

Fig 4.14: Variations of Axial Force for different soft storey heights and column groups

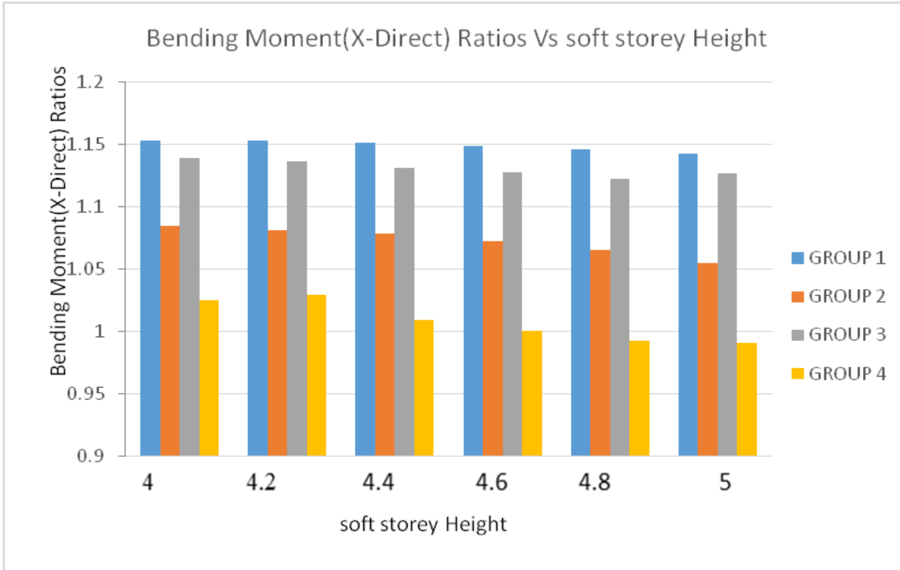

Fig 4.15: Variations of Bending moment(X-direct.) for different soft storey heights and column groups

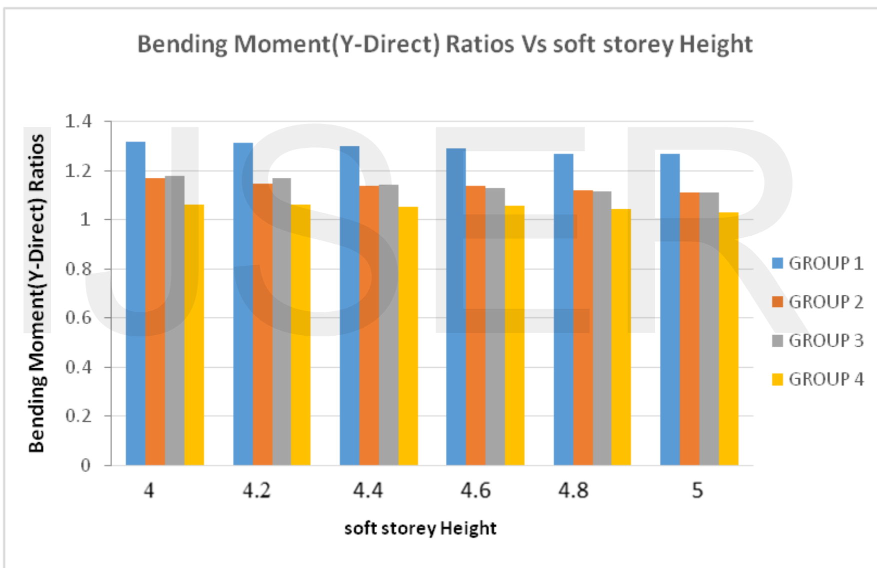

Fig 4.16: Variations of Bending moment(Y-direct.) for different soft storey heights and column groups

TABLE 4.6

RATIOS OBTAINED FOR DIFFERENT GROUPS AND SOFT STOREY HEIGHTS ARE SUMMARIZED FOR FRAME WITH BRACINGS.

STOREY HEIGHT	GROUP 1			GROUP 2			GROUP 3			GROUP 4		
	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3	RPu	RMu_2	RMu_3
4	1.259	0.38	1.25	1.59	0.382	1.59	1.601	0.385	1.601	1.092	0.385	1.09
4.2	1.255	0.37	1.25	1.604	0.374	1.604	1.616	0.376	1.616	1.091	0.371	1.09
4.4	1.252	0.365	1.25	1.081	0.368	1.081	1.626	0.383	1.626	1.09	0.368	1.09
4.6	1.249	0.359	1.249	1.072	0.361	1.072	1.634	0.374	1.635	1.09	0.361	1.096
4.8	1.247	0.353	1.247	1.072	0.356	1.064	1.643	0.367	1.643	1.089	0.356	1.089
5	1.247	0.351	1.247	1.049	0.352	1.049	1.64	0.35	1.64	1.088	0.353	1.088

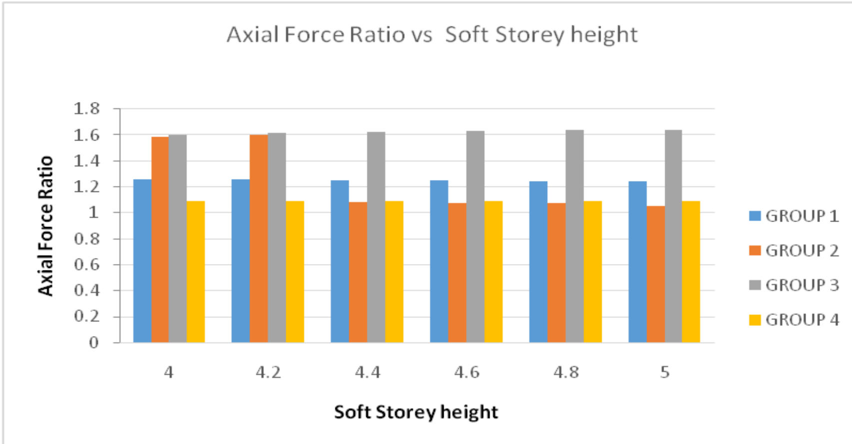

Fig 4.17: Variations of Axial Force for different soft storey heights and column groups

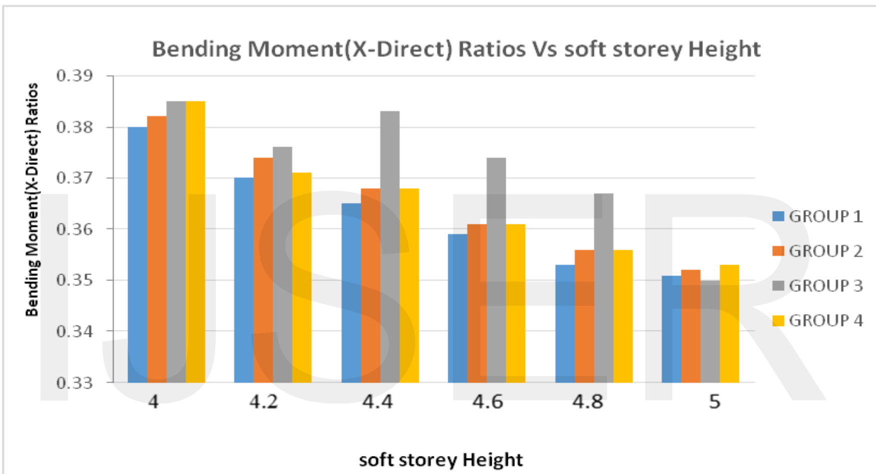

Fig 4.18: Variations of Bending moment(X-direct.) for different soft storey heights and column groups

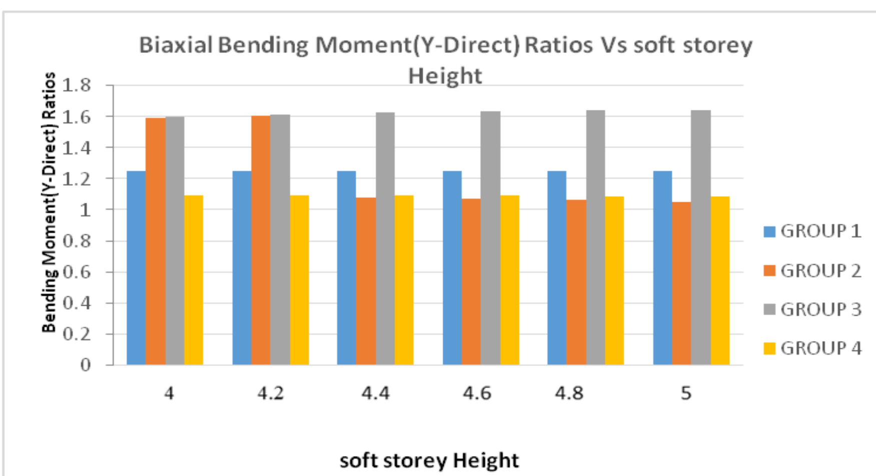

Fig 4.19: Variations of Bending moment(Y-direct.) for different soft storey heights and column groups

5 Observations

A. Time period considered for Seismic analysis using Program Calculated.

a) Frame with Masonry Infill.

i. Axial compressive force ratio at bottom storey is increasing in group 1, 2 & 3 as bottom storey height increases. Axial compressive force ratio is constant for group 4 up to 4.6m storey height i.e 1.41. Which is observed to be maximum and then decreases for 4.8m and 5m storey height.

ii. Bending moment ratio in X-direction is in increasing trend for group 1 and 3, where as there is decreasing trend for group 2 for all bottom storey height. For group 4 it decreases up to 4.6m and increases for 4.8m and 5m. Bending moment in X-direction is maximum for group 1 i.e 1.11.

iii. Bending moment ratio in Y-direction for all groups is observed to be in increasing trend and it is maximum for group 1 i.e. 1.29.

b) Frame with Tie-Beam

i. Axial Compressive Force ratio in group 1and 2 increases as bottom storey height increases, whereas it is observed to be decreasing for group 3 and 4. Axial Compressive Force ratio is maximum in group 4 at 4m height i.e 1.51.

ii. Bending Moment ratio in X and Y direction for group 1and 4 is observed to be decreasing and it is maximum for group 1 at 4m storey height i.e 0.69 and 0.92 respectively.

iii. Bending Moment ratio in Y-direction, intensively reduces for group 4 as compared to all other groups.

c) Frame with Bracing.

i. Axial Compressive Force ratio in group 4 remains constant for bottom storey heights 4 to 4.4 m i.e. 1.41 and it decreases for remaining height from (4.6-5m) i.e 1.4.

ii. Bending Moment ratios in X-direction, in group 4 is maximum for bottom storey height 4m which is observed to be 0.34.

iii. Bending Moment ratios in Y-direction, in group 1 remains same for all storey heights which is observed to be 0.87 and for group 2 there is decreasing trend as bottom storey height increases.

B. Time period considered for Seismic analysis using Codal provision.

a) Frame with Masonry Infill.

i. Axial compressive force ratio for group 1 and group 3 is observed to be in increasing trend and it is maximum for group 1 i.e. 1.32.

ii. Bending moment ratios in X-direction and Y-direction for group 1 increases from 4m to 4.6m bottom storey height.

b) Frame with Tie-Beam.

i. Axial compressive force ratio in group 1 is maximum at 5m and is observed to be 1.485

ii. Bending moment ratios in X and Y direction is in decreasing trend in all groups and for all bottom storey heights and it is maximum in group 1 at 4m height which is observed to be 1.153 and 1.32 respectively.

c) Frame with Bracing.

i. Axial Compressive Force ratios in group 1,2 and 3 is in decreasing trend whereas for group 3 it is in increasing trend and is maximum in group 3 at 4.8m bottom storey height which observed to be 1.643.

ii. Bending Moment ratios in X and Y direction is maximum at 4m and 4.8m which is observed to be 0.385 and 1.643 respectively.

6 Conclusion

1. For Axial compressive force, the observed multiplication factor is 1.51 using time period considered for seismic analysis by software (Program Calculated).
2. For Bending moment in X-direction, the observed multiplication factor is 1.11 using time period considered for seismic analysis by software (Program Calculated).
3. For Bending moment in Y-direction, the observed multiplication factor is 1.29 using time period considered for seismic analysis by software (Program Calculated).
4. For Axial compressive force, the observed multiplication factor is 1.643 using time period considered for seismic analysis as per Codal Provisions.
5. For Bending moment in X-direction, the observed multiplication factor is 1.153 using time period considered for seismic analysis as per Codal Provisions.
6. For Bending moment in Y-direction, the observed multiplication factor is 1.643 using time period considered for seismic analysis as per Codal Provisions.

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