Pushover Analysis of Multistorey Building with Soft Story

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Abstract— The project work deals with the Reinforced Concrete Special Moment Frame that are used as a part of seismic force-resisting systems in buildings that are designed to resist earthquake. Beams, columns, and beam-column joints in moment frames are proportioned and detailed to resist flexural, axial and shearing actions that result as a building sways through multiple displacement cycles during strong earthquake ground shaking. Special proportioning and detailing requirement results in a frame capable of resisting strong earthquake shaking without significant loss of stiffness or strength. These moment-resisting frames are called "Special Moment Resisting Frames" because of these additional requirements, which improve the seismic resistance in comparison with less stringently detailed Intermediate and Ordinary Moment Resisting Frames. The design criteria for SMRF buildings are given in IS 13920 (2002). In this study, the buildings are designed both as SMRF and OMRF, and their performance is compared. For this, the buildings are modeled and pushover analysis is performed in SAP2000. The pushover curves are plotted from the analysis results and the behavior of buildings is studied for various support conditions and infill conditions. The behavior parameters are also found for each building using the values obtained from pushover curve and is investigated.

Key words: Open Ground Storey, Multistorey Building with Soft Story

I. Introduction

Open ground storey (also known as soft storey) buildings are commonly used in the urban environment nowadays since they provide parking area which is most required. This type of building shows comparatively a higher tendency to collapse during earthquake because of the soft storey effect. Large lateral displacements get induced at the first floor level of such buildings yielding large curvatures in the ground storey columns. The bending moments and shear forces in these columns are also magnified accordingly as compared to a bare frame building (without a soft storey). The energy developed during earthquake loading is dissipated by the vertical resisting elements of the ground storey which resulting the occurrence of plastic deformations which transforms the ground storey into a mechanism, in which the collapse is unavoidable. The construction of open ground storey is very dangerous if not designed with proper care.

Modern seismic codes just neglect the effects of nonstructural infill walls during analysis. Many urban multistory buildings in India today consist of an open first storey as an unavoidable feature. This is primarily being practiced and adopted to the accommodate parking or reception lobbies in the first stories. The upper stories consist of brick infilled wall panels. The draft Indian seismic code classifies a soft storey as one whose lateral stiffness is less than *50%* of the storey above or below [Draft IS:1893,1997].

Interestingly, this classification renders most Indian buildings, with no masonry infill walls in the first storey, to be "buildings with soft first storey." Total seismic base shear as experienced by a building during an earthquake is dependent on its natural period whereas the seismic force distribution is dependent on the distribution of stiffness and mass along the height. In buildings with soft first storey, the upper storey's being stiff is subjected to smaller inter-storey drifts. However, the inter-storey drift in the soft first storey is large. The strength demand on the columns in the first storey is also large since the shear in the first storey is maximum. For the upper storey's, however, the forces in the columns are effectively reduced due to the presence of the Buildings with abrupt changes in storey stiffness's have uneven lateral force distribution along the height, which is likely to locally induce stress concentration. As a result, the performance of buildings is adversely affected during ground shaking.

II. Methodology

For seismic performance evaluation, a structural analysis of the mathematical model of the structure is required to determine force and displacement demands in various components of the structure. Several analysis methods, both elastic and inelastic, are available to predict the seismic performance of the structures. (sermin, 2005)

A. *Elastic Methods of Analysis*

The force demand on each component of the structure is obtained and compared with available capacities by performing an elastic analysis. Elastic analysis methods include code static lateral force procedure, code dynamic procedure and elastic procedure using demand-capacity ratios. In code static lateral force procedure, a static analysis is performed by subjecting the structure to lateral forces obtained by scaling down the smoothened soil-dependent elastic response spectrum by a structural system dependent force reduction factor, "R". In this approach, it is assumed that the actual strength of structure is higher than the design strength and the structure is able to dissipate energy through yielding.

The dynamic analysis may be either a response spectrum analysis or an elastic time history analysis. Sufficient number of modes must be considered to have a mass participation of at least 90% for response spectrum analysis. In demand/capacity ratio (DCR) procedure, the force actions are compared to corresponding capacities as demand/capacity ratios. Demands for DCR calculations must include gravity effects. The seismic force reduction factor "R" is utilized to account for inelastic behavior indirectly by reducing elastic forces to inelastic.

Elastic methods can predict elastic capacity of structure and indicate where the first yielding will occur, however they don't predict failure mechanisms and account for the redistribution of forces that will take place as the yielding progresses.

B. Inelastic Methods of Analysis

Structures suffer significant inelastic deformation under a strong earthquake and dynamic characteristics of the structure change with time so investigating the performance of a structure requires inelastic analytical procedures accounting for these features. Inelastic analytical procedures help to understand the actual behavior of structures by identifying failure modes and the potential for progressive collapse. Inelastic analysis procedures basically include inelastic time history analysis and inelastic static analysis which is also known as pushover analysis.

The inelastic time history analysis is the most accurate method to predict the force and deformation demands at various components of the structure. However, the use of inelastic time history analysis is limited because dynamic response is very sensitive to modeling and ground motion characteristics. Inelastic static analysis, or pushover analysis, has been the preferred method for seismic performance evaluation due to its simplicity. It is a static analysis that directly incorporates nonlinear material characteristics. Inelastic static analysis procedures include Capacity Spectrum Method, Displacement Coefficient Method and the Secant Method. (sermin, 2005)

Building performance levels and ranges (act, 1997a)

- Performance Level: the intended post-earthquake condition of a building; a well-defined point on a scale measuring how much loss is caused by earthquake damage.
- Performance Range: a range or band of performance, rather than a discrete level.
- Designations of Performance Levels and Ranges: performance is separated into descriptions of damage of structural and nonstructural systems; structural designations are s-1 through s-5 and nonstructural designations are n-a through n-d.
- Building Performance Level: the combination of a structural performance level and a nonstructural performance level to form a complete description of an overall damage level.

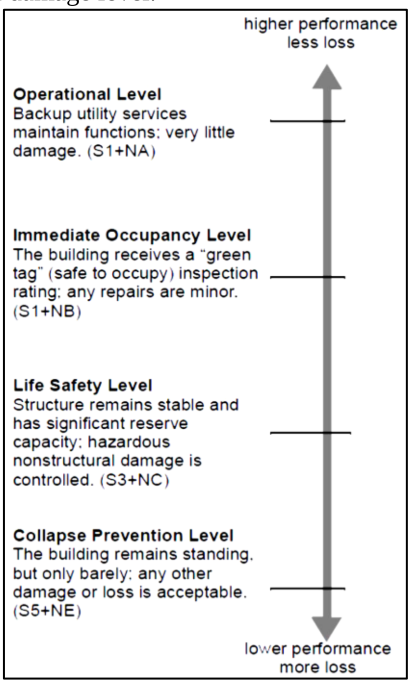

Fig. 1: Building Performance Levels (ATC, 1997a)

The four Building Performance Levels are Collapse Prevention, Life Safety, Immediate Occupancy, and Operational.

The three Structural Performance Levels and two Structural Performance Ranges consist of:

- S-1: Immediate Occupancy Performance Level (the post-earthquake damage state in which only very limited structural damage has occurred)
- S-2:Damage Control Performance Range (the continuous range of damage states that entail less damage than that defined for the Life Safety level, but more than that defined for the Immediate Occupancy level)
- S-3: Life Safety Performance Level (the post-earthquake damage state in which significant damage to the structure has occurred, but some margin against either partial or total structural collapse remains)
- S-4: Limited Safety Performance Range (the continuous range of damage states between the Life Safety and Collapse Prevention levels.)
- S-5:Collapse Prevention Performance Level (the building is on the verge of experiencing partial or total collapse)

The four Nonstructural Performance Levels are:

- N-A: Operational Performance Level (the post-earthquake damage state of the building in which the nonstructural components are able to support the building's intended function)
- N-B: Immediate Occupancy Performance Level (the post-earthquake damage state in which only limited nonstructural damage has occurred)
- N-C: Life Safety Performance Level (the post-earthquake damage state in which potentially significant and costly damage has occurred to nonstructural components but they have not become dislodged and fallen)
- N-D: Hazards Reduced Performance Leve (the post-earthquake damage state level in which extensive damage has occurred to nonstructural components)

C. Equivalent Diagonal Strut Method

The infill in each panel behaves somewhat like a diagonal strut as shown in Fig. below.

The strut area *as* was given by the following equation.

$$A_e = W\ t$$

$$W = 0.175\ (\lambda\ H)^{-0.4}\ D$$

$$\lambda = \sqrt[4]{\frac{E_i\ t\ \mathrm{Sin}(2\theta)}{4\ E_f\ I_c\ h}}$$

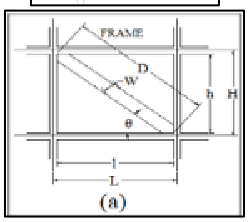

Fig. 1(a): Strut area

Where,

Ei = the modules of elasticity of the infill material, N/mm^2

Ef= the modules of elasticity of the frame material, N/mm^2

Ic= the moment of inertia of column, mm4
t = the thickness of infill, mm
H =the centre line height of frames
h = the height of infill
L =the centre line width of frames
l = the width of infill
D = the diagonal length of infill panel
θ = the slope of infill diagonal to the horizontal.

III. MODELLING ON SAP2000

The building considered in the present report is G+5 storied R.C framed building of symmetrical rectangular plan configuration. Complete analysis is carried out for dead load, live load & seismic load using SAP2000. Nonlinear method (Pushover analysis) of seismic analysis is used. All combinations are Considered as per IS 1893:2002. Typical plan of building is shown in Fig.2

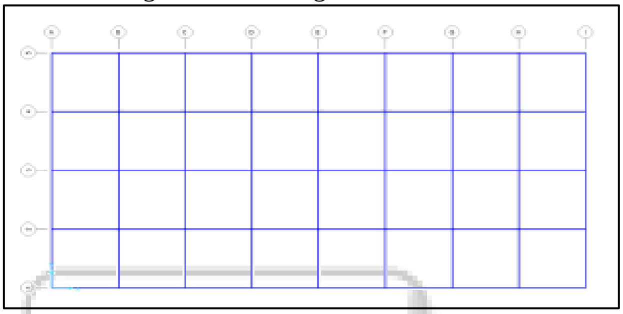

Fig. 2: Plan of the considered building

A. *Building Properties*

1) *Site Properties*

- Details of building: G+5
- Plan Dimension: 40m x 20m, 5m span in each direction.
- Outer wall thickness: 230mm
- Inner wall thickness: 230mm
- Floor height: 3 m
- Parking floor height: 3m

2) *Seismic Properties*

- Seismic zone: IV
- Zone factor: 0.24
- Importance factor: 1.0
- Response Reduction factor R: 3
- Soil Type: medium

3) *Material Properties*

- Material grades of M30& Fe415 were used for the design.

4) *Loading on structure*

- Dead load: self-weight of structure
- Weight of 230mm wall: 13.8 kN/m²
- Live load: For G+5: 2.5kN/m²
- Roof: 1.5 kN/m²
- Wind load: Not considered
- Seismic load: Seismic Zone IV

5) *Preliminary Sizes of members*

- Column: 600mm x 400mm
- Beam: 300mm x 500mm
- Slab thickness: 120mm

6) *Calculation of diagonal strut*

Strut direction	along X	along Y
length of strut D = $\sqrt{(H^2+L^2)}$	5385.164807	5385.16
$\lambda = (Emt\sin 2\theta/4EcIch)^{1/4}$	0.00081	0.00066
Width of strut W = $0.175(\lambda H)^{0.4}$ D	1144.376082	1055.24
thickness of strut	230.00	230.00
A= w*t	263206.4988	242705
Stiffness of strut = AE/l	94086.72313	86758.1

Table 1: Calculation

The models created are as follows:

- Case 1: G+5 storey infilled wall frame building.
- Case 2: G+5 storey with ground floor soft storey.
- Case 3: G+5 storey with first floor soft storey.
- Case 4: G+5 storey with second floor soft storey.
- Case 5: G+5 storey with third floor soft storey.
- Case 6: G+5 storey with fourth floor soft storey.
- Case 7: G+5 storey with fifth floor soft storey.

B. *Load Combinations*

Load combinations that are to be used for Limit state Design of reinforced concrete structure are listed below.

- 1.5 (DL + LL)
- 1.2 (DL + LL ± EQ - X)
- 1.2 (DL + LL ± EQ - Y)
- 1.5 (DL ± EQ - X)
- 1.5 (DL ± EQ - Y)
- 0.9DL ± 1.5EQ – X
- 0.9DL ± 1.5EQ - Y

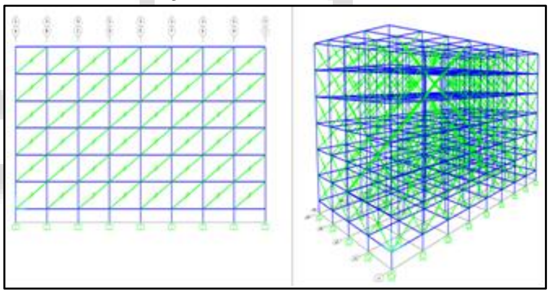

Fig. 3: Elevation & 3D View of G+5 storey infill wall frame building

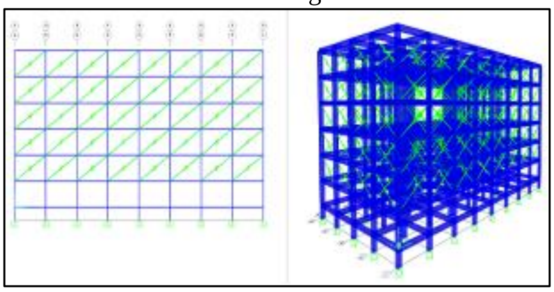

Fig. 4: Elevation & 3D View of G+5 soft storey at ground floor.

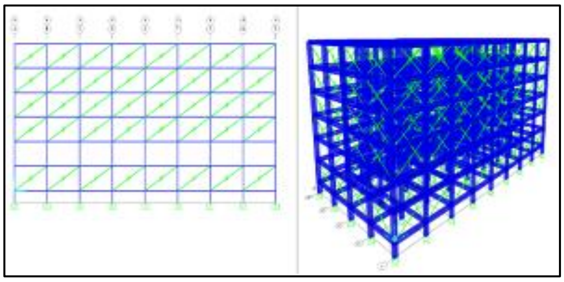

Fig. 5: Elevation & 3D View of G+5 soft storey at first floor.

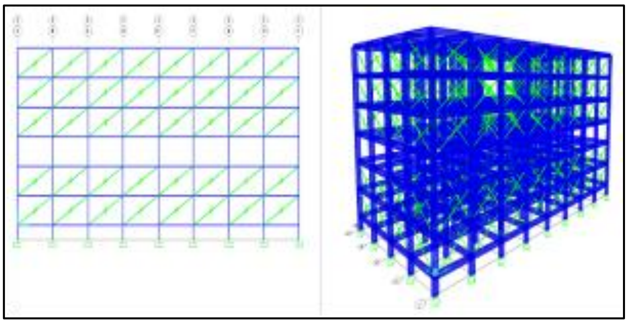

Fig. 6: Elevation & 3D View of G+5 soft storey at second floor.

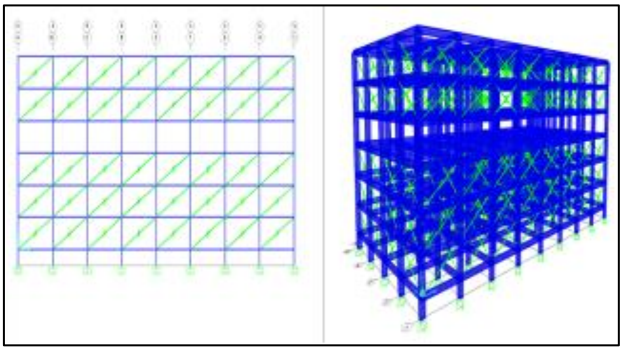

Fig. 7: Elevation & 3D View of G+5 soft storey at third floor.

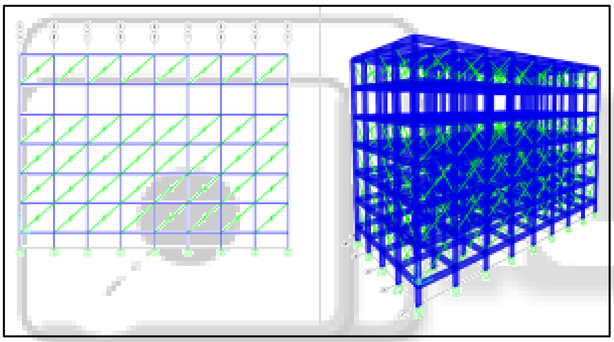

Fig. 8: Elevation & 3D View of G+5 soft storey at fourth floor.

IV. RESULTS AND DISCUSSION

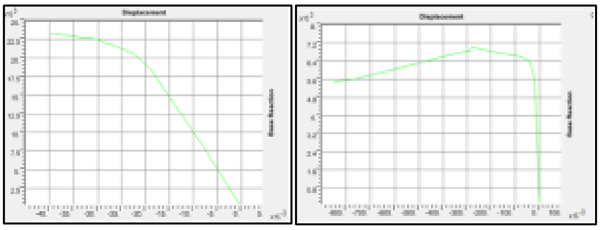

Fig. 9: Base Force Vs Displacement for Full Infill wall (Push X and Push Y)

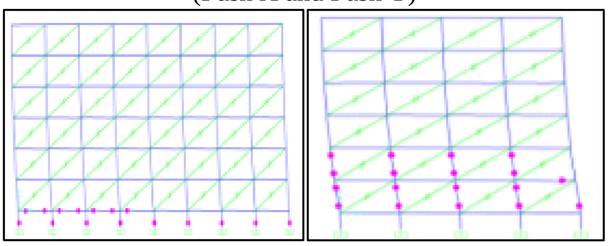

Fig. 10: Deformed shape and plastic hinge formation for performance point Full Infill wall (Push X and Push Y)

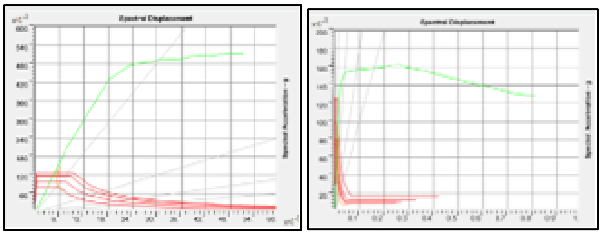

Fig. 11: Performance point as per 440 FEMA Equivalent Linearization Full Infill wall (Push X and Push Y)

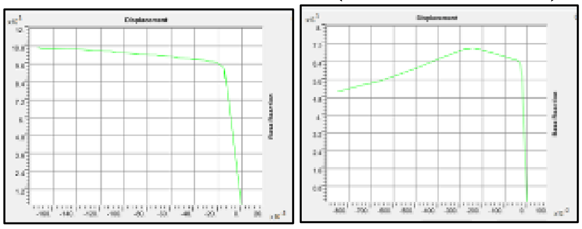

Fig. 12: Base Force Vs Displacement for Soft Storey at Ground Floor (Push X and Push Y)

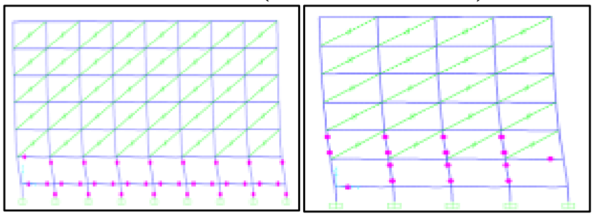

Fig. 13: Deformed shape and plastic hinge formation for performance point Soft Storey at Ground Floor (Push X and Push Y)

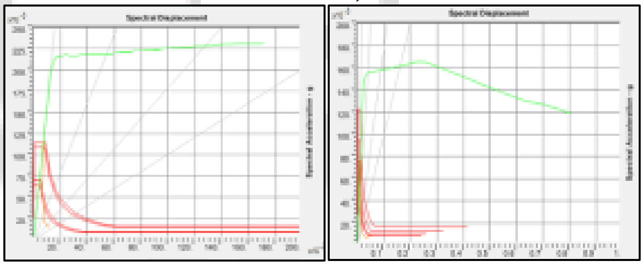

Fig. 14: Performance point as per 440 FEMA Equivalent Linearization Soft Storey at Ground Floor (Push X and Push Y)

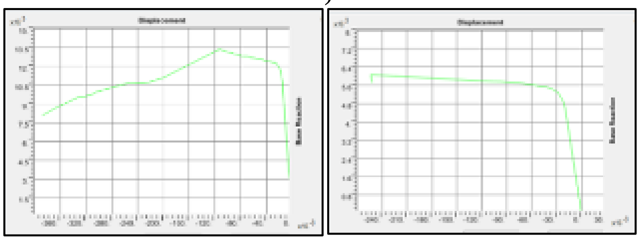

Fig. 15: Base Force Vs Displacement for Soft Storey at First Floor (Push X and Push Y)

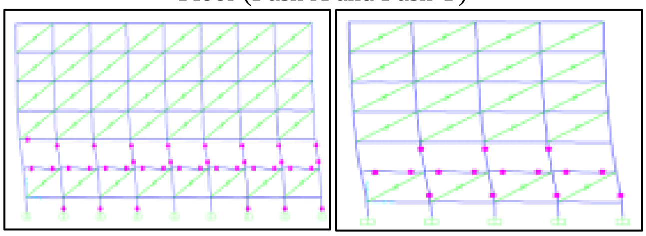

Fig. 16: Deformed shape and plastic hinge formation for performance point Soft Storey at First Floor (Push X and Push Y)

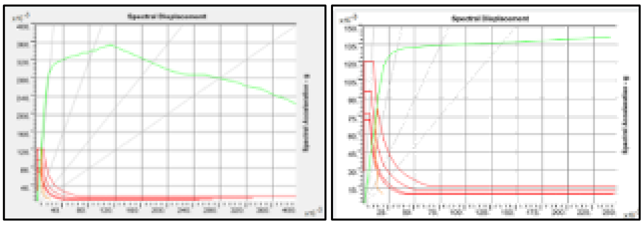

Fig. 17: Performance point as per 440 FEMA Equivalent Linearization Soft Storey at First Floor (Push X and Push Y)

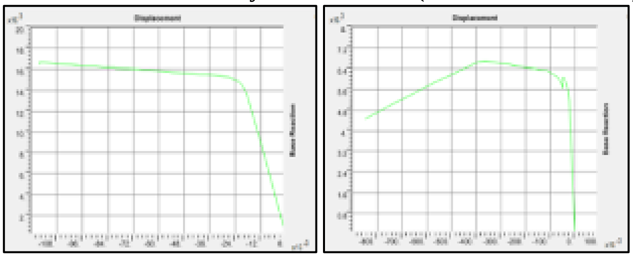

Fig. 18: Base Force Vs Displacement for Soft Storey at Second Floor (Push X and Push Y)

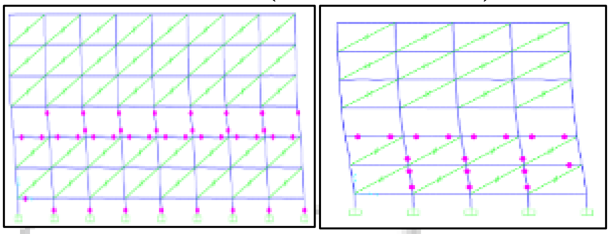

Fig. 19: Deformed shape and plastic hinge formation for performance point Soft Storey at Second Floor (Push X and Push Y)

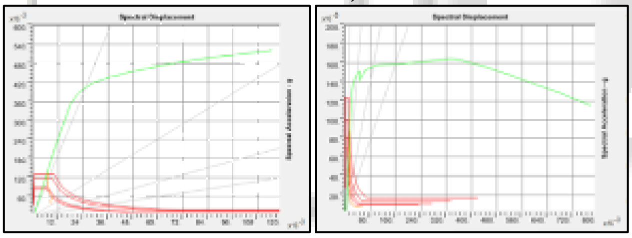

Fig. 20: Performance point as per 440 FEMA Equivalent Linearization Soft Storey at Second Floor (Push X and Push Y)

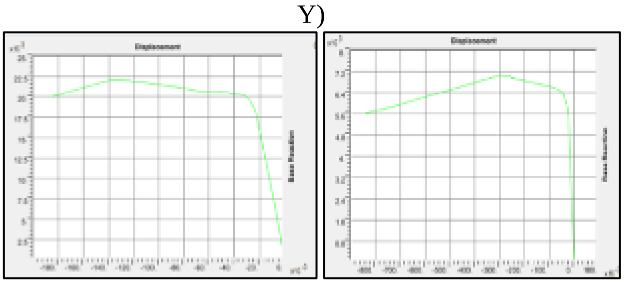

Fig. 21: Base Force Vs Displacement for Soft Storey at Third Floor (Push X and Push Y)

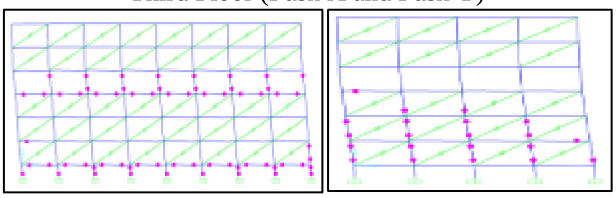

Fig. 22: Deformed shape and plastic hinge formation for performance point Soft Storey at Third Floor (Push X and Push Y)

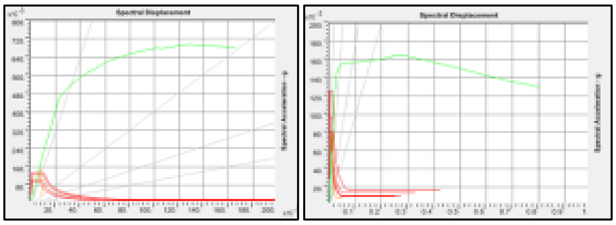

Fig. 23: Performance point as per 440 FEMA Equivalent Linearization Soft Storey at Third Floor (Push X and Push Y)

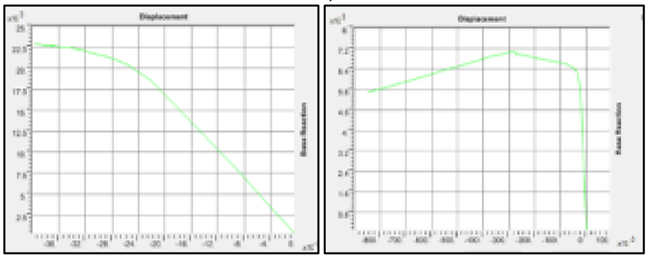

Fig. 24: Base Force Vs Displacement for Soft Storey at Fourth Floor (Push X and Push Y)

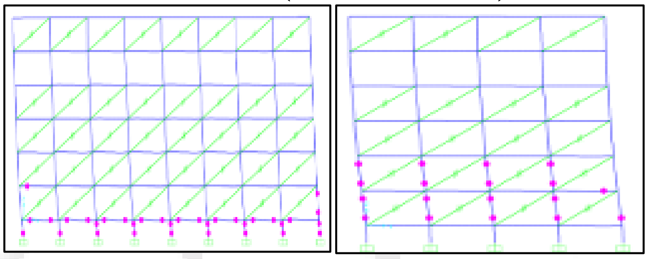

Fig. 25: Deformed shape and plastic hinge formation for performance point Soft Storey at Fourth Floor (Push X and Push Y)

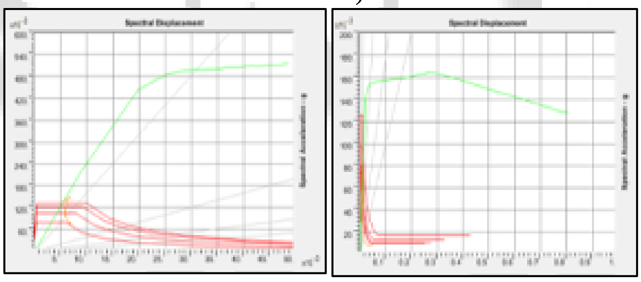

Fig. 26: Performance point as per 440 FEMA Equivalent Linearization Soft Storey at Fourth Floor (Push X and Push Y)

V. CONCLUSION

Following conclusions are made from study are:

1) Modal period is maximum for soft storey at second floor of the considered building.
2) Column moment is maximum for soft storey at second floor of the considered building.
3) Column axial force is maximum for soft storey at fourth floor of the considered building.
4) Shear force in column is maximum for full infill wall.
5) Beam moment is maximum for soft story at second floor of the considered building.
6) Shear force in beams is maximum for soft storey at second floor of the considered building.
7) Comparison of base shear value by response spectrum method and pushover analysis is done in which pushover analysis shows higher values due to hinge formation mechanism.

8) Comparison of lateral displacement by response spectrum method and pushover analysis is done in which pushover analysis shows higher values due to hinge formation mechanism.
9) Building with soft storey at first floor is analyzed upto 0.4m displacement which is high than other types.
10) Building with soft storey at ground floor shows minimum values on Base shear Vs. Displacement curve than other soft storey level. It means that soft storey at ground floor is more susceptible to collapse mechanism.
11) Building with soft storey at fourth floor and full infill wall shows maximum values on Base shear Vs. Displacement curve than other soft storey level. It means that soft storey at fourth floor and full infill wall framesareless susceptible to collapse mechanism.
12) Shear at performance point is greater than base shear due to response spectra method in every model shows safety against ductility and collapse.
13) Performance point is formed in elastic zone in all model shows safety against ductility and collapse.
14) Displacement curves cross target displacement without hinge formation in collapse condition shows safety against ductility and collapse.
15) Hence the studied building doesn't need retrofitting.

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