# Study of Soft story response of typical building of NBC

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**Research Article**

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# Abstract

Construction of building omitting an infill wall mostly in ground floor and other floors has led a building to face a soft story failure mechanism. This omission of infill wall is for commercial purposes and parking of vehicles in ground floor. In this study, study on the behavior of the structure is done when a soft story happens in different floor levels. A building explained as per NBC 201 and NBC 205 is taken into consideration. Soft story is assigned in all floors to study the responses separately. An equivalent diagonal strut is assigned to the structure to account the consideration of infill wall. Non-linear hinges are assigned to structural members. Different parametric study is performed in terms of displacement, story drift, time period, formation of hinges, performance point, and capacity curve to compare the behavior of the structure. Linear static and non-linear static (Pushover analysis) analysis is performed to evaluate 4 different models. Modal analysis is performed to obtain time period of different models. The time period of bare frame, ground floor soft story, first floor soft story and second floor soft story using modal analysis is 0.65, 0.49, 0.47 and 0.29 respectively. Pushover analysis is performed to obtain pushover curve of different models forming different non-linear hinges in multiple steps of analysis. Step 1, 4, 7 and 10 were analyzed and hinges from basic to collapse prevention has formed. Story drift of bare frame of all story has been compared to the story drift of buildings having soft story in ground, first and second floor. Comparing variation of story drift for ground, first and second floor between bare frame and ground floor soft story model, the values show 13%, 82% and 85%. The variation of same between bare frame and first floor soft story shows 78%, 20%, 81% while the variation between bare frame and second floor soft story shows 97%, 97%, 21%.

Additional, a multiplication factor has been introduced to compare the value of factor provided by IS 1893:2002. According to IS 1893:2002, the value should have been 2.5, but the value varies for 3 different cases. It varies from 1 to 1.16.


# 1. Introduction

A soft story can be defined as the condition in which the lateral stiffness of lower story is less than 70% of that in the story immediately above or less than 80% of the combined stiffness of the three stories. (IS 1893 (Part 1): 2002, 2002).This is the reason for the deficiency in lateral stiffness and cause a weak story. A soft story building is caused due to spaces being remained opened where masonry works are excluded and large glasses are replaced instead for commercial works. Generally in the commercial areas, ground story are made open for parking or placing of rolling shutters for commercial purposes. Similarly, above the ground floor, on first and second floor too, the masonry works are removed and made open. This are the causes for soft story on the particular floor. Building configuration should not only be regular in plan but should also be regular in vertical direction. Abruptly variation in story stiffness along the vertical direction cause vertical irregularities. Such irregularities and variation in story stiffness causes “Soft story mechanism”. Development of plastic hinges at column ends accompanied by excessive story drift in such soft story are the typical failure mechanism (Lalitha Chandrahas & Polu Raju, 2017).

Behavior of structure with and without infill wall is different. In an earthquake event, the infill walls contribute in the strength and lateral stiffness to the structure. The presence of infill walls in the upper floor and absence in lower story, the stiffness is obviously higher compared to lower story. In this situation, the story with infill wall act as a single block and move together increasing lateral displacement of building in soft story. In such, the upper story above soft story swings like an inverted pendulum during ground force excitation.

A structure should withstand its inertial mass during earthquake. The increase in mass of building increases the inertia forces on the building. The infill walls being non-structural component are generally neglected for their stiffness and strength contribution during earthquake. However the effect of such elements under seismic action has considerable effect on building, by increasing both structural stiffness and strength when compared to bare frame buildings. Lots of evidences from damage in RC building with soft story located at active seismic zones showed that many buildings failed at soft story leads to potential loss (Ghobarah, Saatcioglu, & Nistor, 2006). It is because of large deflection, drift ratio, large story shear in the soft story floor resulting to the local stress concentration accompanied by large plastic deformations at end of column.

This study is intended to find out the behavior of soft story building in ground floor, first floor and second floor as provision provided by NBC 201 and NBC 205. Comparison of different dynamic characteristics of theses configuration has been done. IS 1893:2002 have suggested to design a column members after using a multiplication factor of 2.5 in the story shear. This study is intended to find out the appropriate multiplication factor to be used for soft story floor for low-rise building. BCDBSS (1987) suggests that the beams and columns of the ground story building frame shall be designed for three times the design seismic force corresponding to regular bare frame with an addition of 50% increment in the base shear.SEAOC (1994) recommends a multiplication factor of 3R/8 (average value of response reduction factor, R = 8) for OGS buildings, Scarlet (1997). This will result a value of MF of around three. It is also clear from the above expression that the MF is completely independent and is no related with that of the amount of irregularity present in the building(Haran et al, 2016) concluded that the building with open ground story designed with multiplication factor 1 is vulnerable than bare frame and fully infilled frame. Similarly he also concluded that the scheme of applying MF only to the ground story proposed by Indian codes is found to lead to satisfactory performance only for two story frames. This scheme is found to be not effective for four and six story frames as these frames cannot match the reliability of a corresponding fully infilled frame.

# 2. Nbc 201 And 205

NBC 201 is mandatory rules of Thumb (MRT) code developed for construction for non-engineered buildings. This code prepared for ready to use dimension and detailing of structural elements and non-structural elements for up to three-story reinforced concrete with masonry walls. The objective of the code is to solve the preliminary challenges of mid-level technicians who are not trained to undertake independently the structural design of buildings (Planning & Development, 1994).

NBC 205 is also a mandatory rules of thumb (MRT) code developed for construction for non-engineered buildings. This code is prepared for ready to use dimension and detailing of structural and non-structural elements for up to three story reinforced concrete without masonry infill. But to use these codes, some limitations have to be taken care of (To et al., 2012).Some are illustrated as:

- Neither A nor B shall exceed 6 bays in length nor 25 m. Each bay shall not exceed 4.5 m, as shown in Fig. 4.1.
- A shall be not greater than 3 B nor less than B/3.
- Neither H/A nor H/B shall exceed 3.
- The maximum height of a structure is 11 m or 3 story, whichever is less (To et al., 2012).

# 3. Modelling Of Wall

Modelling of infill wall on numerical analysis can be done by using two techniques, micromodel and macro model (G. Asteris, 2012)(Morbiducci, 2003). Micromodel techniques provides the accurate and precise computation of stress analysis of masonry wall. This method uses FEM technique which precisely predicts the interaction of infill wall with the structure. Micromodel method is time consuming and cost consuming. It requires a lots of computational cost. In macro modelling infill walls are simulated as equivalent single strut or multi-struts whichever is more suitable for the study. Some past papers suggested that single strut model is incapable for detailed analysis like infill structures interactions (Morbiducci, 2003)(Hopkins, 1992)(Smith, 1962)(Polyakov, 1960).

# 4. Pushover Analysis

Pushover analysis is a simplified non-linear static technique used to estimate the seismic structural deformations. As the components of the structure fails or yields during the seismic loading, the dynamic loading on the building are shifted to other components, thus need to check the level of damage and location of damage of the components (Khan, 2013). Pushover analysis is as described is static nonlinear analysis where a structure is subjected to the gravity loading and monotonic displacement controlled lateral load pattern which continuously increases through elastic range to inelastic behavior until an ultimate condition is reached (Khan, 2013). The capacity curve or Pushover curve is formed by Pushover analysis for any structure which represents the nonlinear behavior of the structure and is a load deformation curve of the base shear force versus horizontal roof displacement of the building (“ATC-40 Seismic Evaluation and Retrofit of Concrete Buildings by APPLIED TECHNOLOGY COUNCIL (z-lib.org),” n.d.). Performance point is obtained by intersecting pushover curve and demand curve which shows the actual performance of the structure at that point. Pushover analysis is commonly used to evaluate the seismic capacity of existing structures and perform retrofitting measures if required. Also is used for performance base design of new buildings that rely on ductility or redundancies to resist earthquake forces. Pushover load cases have been assigned to two orthogonal direction. The monitored displacement of 500 mm have been assigned for pushover loading to obtain a pushover curve. Demand curve for design based earthquake has been assigned matching of response spectra to IS 1893:2002.The performance point is obtained intersecting pushover curve and demand curve for 4 different models.

## 5. Non-linear Hinges

Plastic hinges are formed at the ends of the structural components when subjected to loads. These plastic hinges are formed at both ends of beams and columns. The plastic hinges being formed are defined at number of levels of hinges. Plastic hinges modelling for pushover analysis is done by forces-displacement relationships or moment curvature relationship of member defining different performance criteria of members. In beams, plastic hinges are formed due to uniaxial bending moments (M3) whilst in columns plastic hinges are formed due to both axial load and biaxial bending (P-M-M).(Manual, 2000). In SAP 2000, flexural default hinges (M3) have been assigned to beams at both ends. The interacting (P-M-M) hinges have also been assigned to column at both ends. M3 hinge is used to simulate the plastic hinge caused by uniaxial moment and similarly in columns, PMM hinges are used to simulate the plastic hinge due to axial load and biaxial bending moments. Similarly masonry infill wall has been modelled as equivalent diagonal strut using two node frame element using pinned jointed frame element to release the moment at both ends.

## 6. Lateral Load Pattern

Lateral load pattern is the distribution of design base shear in each floor. In this study seismic coefficient method which is a static linear analysis is used provided by IS 1893:2002. The distribution of the lateral load is parabolic in nature for this method.

## 7. Building Description

In this study a typical reinforced concrete (RC) framed building as per guidelines provided by NBC 201 and NBC 205 is taken into study. A building model with 3 bays of center to center dimension 3.9m is taken along x-direction and 2 bays of center to center dimension 3.4 m is taken along y-direction. The slab area is so selected that its area is not greater than 13.5 sq.m.(Planning & Development, 1994). The building is modelled as a moment resisting frame having soft story at ground floor, first floor and second floor. A symmetric building plan is considered in both X and Y direction to avoid eccentricity.

Table 7:1
Building Model Details

| No. of Story | G + 3 |
|---|---|
| Story height | 2.8m |
| Bays in X-direction | 3 |
| Bays in Y-direction | 2 |
| Type of Soil | II |
| Seismic Zone | V |
| Importance factor | 1 |
| Response Reduction factor | 5 |

Table 7:2
Material Properties

| Material | Grade | Unit Weight | Modulus of elasticity |
|---|---|---|---|
| Concrete | M20 | 25KN/$m^3$ | 22360 N/$mm^2$ |
| Rebar | Fe415 | 78Kn/$m^3$ | 200000 N/$mm^2$ |
| Masonry | First class brickwork with 1:4 c/s | 18.85 KN/$m^3$ | 3000 N/$mm^2$ |

Table 7:3
Section Properties

| Section | Size |
|---|---|
| Beam | 230mm X 355mm |
| Column | 300mm X 300mm |
| Slab | 125mm |
| Strut along x-direction | 508 mm with 230mm thick |
| Strut along y-direction | 495 mm with 230 mm thick |

Table 7:1 above shows the building model details like story number, story height, length and breadth of building plan, seismic zone factor. Table 7:2 shows the material properties and sectional details are provided in Table 7:3. The numerical modelling of the building model has been prepared in SAP 2000 version 14. SAP 14 provides the static and dynamic methods of analysis and similarly provides the linear and non-linear techniques of analysis.

Generally to incorporate the effect of masonry-infill walls, two methods are proposed, one being macro modelling (Polykov) and other micro modelling (Morbiducci). The micro modelling approach gives good results in understanding the local and global responses. However it is rarely used because of its complexity, computational cost and simulation difficulty. Macro modelling is widely used method despite of its disadvantages in equivalent diagonal strut method (macro modelling method) in its accuracy in modelling of openings. However, the effect of opening can be created using less number of struts in less infill story (Asterus 2003, Puglisi and Uzcategui 2008). In this study, the infill wall is modelled as equivalent diagonal compression strut of suitable width based on the equation in Eq. 1. The strut is modelled as two nodded pin jointed frame element. The thickness and modulus of elasticity of the strut are equivalent to infill masonry walls.

# 8. Equivalent Diagonal Strut

Consideration of infill wall is done by converting the infill wall into equivalent diagonal strut. It is required to assign the geometrical and material properties of the equivalent diagonal strut for conventional braced frame analysis. The width and thickness of diagonal strut is the geometrical properties to be assigned. The thickness of strut and material properties of strut is similar to the properties of infill wall. Only the width of equivalent diagonal strut has to be determined. Width of diagonal strut has been proposed by different writers. At first Polyakov (1956) proposed that the width of diagonal strut depends on the length of contact between wall and column frame, αh and between wall and beam, αL. Later Stafford Smith (1966) proposed αh and αL on the basis if elastic foundation. He further proposed a relation to determine the constants which depends upon the geometry and material properties of infill wall and frame. The following is the relation,

$$\alpha h = \frac{\pi}{2}\sqrt[4]{\frac{4Ef*Ic*h}{Em*t\sin 2\theta}} \qquad \textbf{Equation 8-1}$$

$$\alpha L = \pi\sqrt[4]{\frac{4Ef*Ib*L}{Em*t\sin 2\theta}} \qquad \textbf{Equation 8-2}$$

Hendry (1998) further proposed the relationships assuming that the strut is uniformly subjected to compressive stress.

$$w = \frac{1}{2}\sqrt{\alpha l^2 + \alpha h^2} \qquad \textbf{Equation 8-3}$$

Where,

Em and Ef = Elastic modulus of masonry wall and frame respectively

T,h,L = Thickness, height, and length of infill wall respectively

Ic, Ib = Moment of Inertia of the column and the beam of the frame, respectively

Θ = tan-1(h/L)

# 9. Results And Discussion

Natural Time Period Comparison

Table 9:1
Time Period of model for soft story in ground floor

| Fixed end | Empirical formula | | Modal Analysis | |
|---|---|---|---|---|
| | Without infill | With infill | Without infill | With infill |
| Tx (s) | 0.46 | 0.28 | 0.65 | 0.49 |
| Ty (s) | 0.46 | 0.38 | 0.65 | 0.49 |
| (Sa/g)x | 2.50 | 2.50 | 2.11 | 2.50 |
| (Sa/g)y | 2.50 | 2.50 | 2.11 | 2.50 |

Table 9:2
Time period of model for soft story in first floor

| Fixed end | Empirical formula | | Modal Analysis | |
|---|---|---|---|---|
| | Without infill | With infill | Without infill | With infill |
| Tx (s) | 0.46 | 0.28 | 0.65 | 0.47 |
| Ty (s) | 0.46 | 0.38 | 0.65 | 0.47 |
| (Sa/g)x | 2.50 | 2.50 | 2.11 | 2.50 |
| (Sa/g)y | 2.50 | 2.50 | 2.11 | 2.50 |

Table 9:3
Time period of model for soft story in second floor

| Fixed end | Empirical formula | | Modal Analysis | |
|---|---|---|---|---|
| | Without infill | With infill | Without infill | With infill |
| Tx (s) | 0.46 | 0.28 | 0.65 | 0.29 |
| Ty (s) | 0.46 | 0.38 | 0.65 | 0.29 |
| (Sa/g)x | 2.50 | 2.50 | 2.11 | 2.50 |
| (Sa/g)y | 2.50 | 2.50 | 2.11 | 2.50 |

Table 9:1, 9:2, 9:3 shows that time period of bare frame model is high compared to other model which has effect of infill wall. Time period gradually decreases as soft story shifts at upper floors. The time period of model having soft story on ground floor is higher than model having soft story in first and second floor. It is because the lateral stiffness of second floor soft story model has high due to struts in ground as well and first floor but the lateral stiffness of ground floor soft story is low in base of the building. This shows that the lateral displacement is low for the model having high stiffness at base like soft story on second and first story whereas the displacement is high for bare frame model and soft story in ground floor.

Comparison of Displacement

Table 9:4
Maximum Joint Displacement along X-direction

| Story No. | Bare Frame(mm) | Ground floor soft story(mm) | First floor soft story(mm) | Second floor soft story(mm) |
|---|---|---|---|---|
| 4 | 19.8 | 8.9 | 9.8 | 7.0 |
| 3 | 17.0 | 6.6 | 7.5 | 4.2 |
| 2 | 12.2 | 5.9 | 6.6 | 0.4 |
| 1 | 5.4 | 4.7 | 1.2 | 0.2 |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |

Table 9:5
Maximum joint displacement along Y-direction

| Story No. | Bare Frame(m) | Ground floor soft story(m) | First floor soft story(m) | Second floor soft story(m) |
|---|---|---|---|---|
| 4 | 18.8 | 9.7 | 10.6 | 7.2 |
| 3 | 15.8 | 7.3 | 8.2 | 4.2 |
| 2 | 11.4 | 6.2 | 6.9 | 0.7 |
| 1 | 5.1 | 4.5 | 1.6 | 0.3 |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |

Referring to Figs. 2 and 3 shows that displacement of floor for bare frame model gradually increases from bottom and further rises up parabollically but model considering the infill wall and soft story, the floor having soft story have a significant displacement and other floor with infill wall has no tremendous displacement. The floor having soft story on ground floor has huge displacement in ground floor and other floors have less displacement, while first floor has remarkable displacement than other floors for model in first floor soft story. Similarly in model having soft story in second floor has significant displacement in second story can be seen and negligible displacement is noticed in ground floor and first floor. The displacement is high only in the story without infill walls because in other floors the lateral stiffness is high due to diagonal strut of masonry. This made a floor with soft story a flexible which caused a sway frame thus forming a huge displacement than other floors.

**Comparison of Story Drift**

Table 9:6
Drift ratio along X and Y direction

| Story No | Bare frame | | Ground floor soft story | | First floor soft story | | Second floor soft story | |
|---|---|---|---|---|---|---|---|---|
| | Along-x | Along-y | Along-x | Along-y | Along-x | Along-y | Along-x | Along-y |
| 4 | 0.101 | 0.105 | 0.082 | 0.085 | 0.082 | 0.085 | 0.102 | 0.106 |
| 3 | 0.170 | 0.157 | 0.026 | 0.039 | 0.033 | 0.046 | 0.134 | 0.125 |
| 2 | 0.243 | 0.227 | 0.043 | 0.061 | 0.193 | 0.189 | 0.008 | 0.015 |
| 1 | 0.193 | 0.181 | 0.168 | 0.162 | 0.043 | 0.058 | 0.007 | 0.011 |
| 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Table 9:7
Variation of drift of bare frame and ground floor soft story

| Story No | Bare frame | | Ground floor soft story | | Varitation | |
|---|---|---|---|---|---|---|
| | Along-x | Along-y | Along-x | Along-y | Along-x | Along-y |
| 4 | 0.101 | 0.105 | 0.082 | 0.085 | 19% | 19% |
| 3 | 0.170 | 0.157 | 0.026 | 0.039 | 85% | 75% |
| 2 | 0.243 | 0.227 | 0.043 | 0.061 | 82% | 73% |
| 1 | 0.193 | 0.181 | 0.168 | 0.162 | 13% | 11% |
| 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0% | 0% |

Table 9:8
Variation of drift of bare frame and first floor soft story

| Story No | Bare frame | | First floor soft story | | Varitation | |
|---|---|---|---|---|---|---|
| | Along-x | Along-y | Along-x | Along-y | Along-x | Along-y |
| 4 | 0.101 | 0.105 | 0.082 | 0.085 | 19% | 19% |
| 3 | 0.170 | 0.157 | 0.033 | 0.046 | 81% | 71% |
| 2 | 0.243 | 0.227 | 0.193 | 0.189 | 20% | 17% |
| 1 | 0.193 | 0.181 | 0.043 | 0.058 | 78% | 68% |
| 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0% | 0% |

Table 9:9
Variation of drift of bare frame and second floor soft story

| Story No | Bare frame | | Second floor soft story | | Varitation | |
|---|---|---|---|---|---|---|
| | Along-x | Along-y | Along-x | Along-y | Along-x | Along-y |
| 4 | 0.101 | 0.105 | 0.102 | 0.106 | -2% | -1% |
| 3 | 0.170 | 0.157 | 0.134 | 0.125 | 21% | 20% |
| 2 | 0.243 | 0.227 | 0.008 | 0.015 | 97% | 94% |
| 1 | 0.193 | 0.181 | 0.007 | 0.011 | 97% | 94% |
| 0 | 0.000 | 0.000 | 0.000 | 0.000 | 0% | 0% |

Drift is difference between displacements two consecutive floor normalized with height of the story. Generally it is seen that drift ratio is minimum at lower floor and rises maximum at middle floor and again lowers at top story but it can be observed that considering the effect of infill wall, the drift ratio is not remarkable whereas at the location of soft story, drift ratio increases significantly. As seen in Figs. 4 and 5, the drift for bare frame is 0 at the base and it parabolically varies from first story and up to roof. The drift is maximum at story 2 rising from base and reduces on story 3 and roof. In Fig. 5 (i),(ii),(iii), drift ratio for model which is soft story on ground floor, first floor and second floor is shown. In Fig. 5 (i), the drift of model having soft story on ground floor is shown where the drift isn maximum for ground floor only and no tremendous drifts in other floor. Table 9 – 7 shows that the drift ratio of ground floor of bare frame model and model with soft story on ground floor has nearly similar type of drift having only variation to be 13%. But on other floor there is huge variation of drift about 82–85% which means there is no huge drift due to infill walls. In Fig. 5 (ii) the drift of model having soft story on first floor is shown where the drift is maximum for first floor only and no tremendous drifts in other floor. Table 9-8shows that the drift ratio of first floor of bare frame model and model with soft story on first floor has nearly similar type of drift having only variation to be 20%. But on other floor there is huge variation of drift about 78–81%. In Fig. 5 (iii) the drift of model having soft story on second floor is shown where the drift is maximum for second floor only and no tremendous drifts in other floor. Table <link rid="tb16">9</link>–9 shows that the drift ratio of second floor of bare frame model and model with soft story on second floor has nearly similar type of drift having only variation to be 21%. But on other floor there is huge variation of drift about 97%.

## Multiplication factor

Table 9:10
Calculation of Multiplication factor for different forms

| MULTIPLICATION FACTOR | | | |
|---|---|---|---|
| Ground floor soft story | Column shear | 1.016 | 59%<2.5 |
| | Column moment | 1.1 | 56%<2.5 |
| First floor soft story | Column shear | 1 | 60%<2.5 |
| | Column moment | 1.16 | 54%<2.5 |
| Second floor soft story | Column shear | 1 | 60%<2.5 |
| | Column moment | 1 | 60%<2.5 |

According to IS 1893:2002, the members of soft story have to be designed for 2.5 times the story shear and moments obtained without considering the effects of masonry infill in any story. This value of 2.5 is specified to incorporate the extent of irregularities. It is quite conservative and empirical method and have to be modified for different scopes of improvement.

$$\mathrm{M.F} = \frac{\mathrm{Memberforcesofinfilledframes}}{\mathrm{Memberforcesofbareframes}}$$

From the above, Table 9:10 The multiplication factor for column shear and column moment varies accordingly for ground, first and second floor soft story. Values of multiplication factor does not increase 1.2 either. Hence no multiplication factor of 2.5 should be implied for low rise building.

## Comparison of Performance Point

Table 9:11
Comparison of Performance point along X-direction

| Model | Base Shear KN | Displacement mm |
|---|---|---|
| Bare Frame | 1021.57 | 48 |
| Ground floor soft story | 1066.5 | 25 |
| First floor soft story | 1212.6 | 20.51 |
| Second floor soft story | 633.24 | 4.9 |

Table 9:12
Comparison of Performance point along Y-direction

| Model | Base Shear KN | Displacement mm |
|---|---|---|
| Bare Frame | 1002.78 | 49 |
| Ground floor soft story | 1064.41 | 29 |
| First floor soft story | 1226.28 | 24.3 |
| Second floor soft story | 790.5 | 6.9 |

**Comparison of Displacement at Performance Point**

Table 9:13
Comparison of Displacement at Performance point

| Story No | Bare frame mm | | Ground floor soft story mm | | First floor soft story mm | | Second floor soft story mm | |
|---|---|---|---|---|---|---|---|---|
| | Along-x | Along-y | Along-x | Along-y | Along-x | Along-y | Along-x | Along-y |
| 4 | 54.66 | 48 | 22.91 | 24.99 | 19.96 | 21.02 | 11.25 | 12.36 |
| 3 | 51.5 | 44.71 | 20.78 | 22.68 | 17.72 | 18.77 | 7.73 | 8.57 |
| 2 | 42.75 | 36.8 | 19.68 | 20.96 | 16.15 | 16.61 | 1.28 | 2.29 |
| 1 | 23.68 | 19.66 | 16.96 | 16.97 | 3.71 | 4.86 | 0.69 | 1.2 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Formation of Hinges**

Figure 5,6,7,8 shows the sequential steps for the formation of Non-linear linear hinges in the structural elements. In first step of pushover analysis, bare frame model has formed 10 basic level hinges from base to second story but ground floor soft story has formed one basic hinge in column, first floor soft story has no hinges formed and second floor soft story has formed one basic hinge in beam. Similarly in fourth step, bare frame model has formed 15 basic level hinges in beam and column from base to second floor while ground floor soft story has formed 8 basic hinges in column in ground floor, first floor soft story has formed 11 basic hinges in first floor column and beam and second floor soft story has formed 12 basic hinges in second story columns and beams. Similarly in seventh step, bare frame model has formed 21 hinges in which 8 immediate occupancy hinge is formed in ground floor column whereas 13 basic hinges at upper floor levels while ground floor soft story has formed 9 hinges in which 8 immediate occupancy hinges are formed column in ground story and one basic hinge in beam level, in first floor soft story has formed 12 hinges out of which 5 hinges are beyond collapse hinges at level “D” hinge 3 is life safety hinge in first floor column 4 is basic hinge in beam and in second floor soft story has formed 14 hinges out of which 1 is life safety and 7 immediate occupancy hinge in second floor column 6 basic hinges in beam. Comparing step 10, bare frame model has formed 22 hinges in which 1 hinge is beyond collapse hinge at level “D” hinge 2 hinge is life safety hinge 5 immediate occupancy hinge is formed in ground floor column whereas 14 basic hinges at upper floor levels while ground floor soft story has formed 11 hinges in which 4 hinge is beyond collapse hinge at level “D” hinge 3 hinge is life safety hinge 1 immediate occupancy hinges are formed column in ground story and 3 basic hinge in beam level, in first floor soft story has formed 12 hinges out of which 5 hinges are beyond collapse hinges at level “D” hinge 3 is life safety hinge in first floor column 4 is basic hinge in beam and in second floor soft story has formed 22 hinges out of which 1 is beyond collapse prevention hinge at level “D” hinge 4 life safety and 3 immediate occupancy hinge in second floor column 6 basic hinges in second floor beam level while 2 life safety and 2 basic hinge at top story column and 2 basic hinges at roof level beam.

## Conclusion

- The infill wall inside a frame has a tremendous effect increasing the lateral stiffness of entire structure. Consideration of infill wall affects the global response and behavior of structure.
- The effect of soft story goes on decreasing as increasing in the story height.
- Time period goes on decreasing as soft story gets increased to upper floor. Bare frame exhibits its flexible characteristics having high time period. Building having soft story on ground floor has higher time period. The open ground story behaves flexible. The soft story in upper floor exhibits a stiffer characteristics because of high stiffness at base.
- The deflections is only high on the story having the soft story and effect in story drift accordingly.
- Drift is high for the bare frame model. If infill wall is considered, then the drift is very low compared to the drift of bare frame model. Only the fact that, the story having soft story effect has drift similar to the bare frame otherwise there is huge variation on drift for other stories.
- The design multiplication factor on story shear and overturning moment ranged from 1 to 1.2 only for the building type as prescribed by NBC 201 and NBC 205.
- Different levels of hinges is formed for bare frame model for all the story but the hinges are only formed on the story where soft story has occurred for soft story models. Different levels of hinges

are formed in ground story only for the model in which ground floor has soft story effect similarly is the case for first story soft story and second story soft story models.

# Limitation

- Regular and symmetrical building is considered to avoid geometric eccentricity.
- Masses are considered evenly distributed and symmetrical to avoid mass irregularities.
- Soil structure interaction has been neglected
- Considerations of openings for strut modelling is not done.
- Varying building plan could provide more variable results.

# References


1. ATC-40 Seismic Evaluation and Retrofit of Concrete Buildings by APPLIED TECHNOLOGY COUNCIL (z-lib.org). (n.d.).
2. G. Asteris, P. (2012). Modeling of Infilled Frames With Openings. The Open Construction and Building Technology Journal, *6*(1), 81–91. https://doi.org/10.2174/1874836801206010081
3. Ghobarah, A., Saatcioglu, M., & Nistor, I. (2006). The impact of the 26 December 2004 earthquake and tsunami on structures and infrastructure. Engineering Structures, *28*(2), 312–326.
4. Haran Pragalath, D. C., Avadhoot, B., Robin, D. P., & Pradip, S. (2016). Multiplication factor for open ground storey buildings–a reliability based evaluation. Earthquake Engineering and Engineering Vibration, *15*(2), 283–295. https://doi.org/10.1007/s11803-016-0322-4
5. Hopkins, D. C. (1992). *Seismic design of reinforced concrete and masonry buildings. Bulletin of the New Zealand Society for Earthquake Engineering* (Vol. 25). https://doi.org/10.5459/bnzsee.25.4.362
6. IS 1893 (Part 1): 2002. (2002). IS 1893 (Part 1): 2002 Indian Standard Criteria for Earthquake Resistant Design of Structures Part 1 General Provisions and Buildings (Fifth Revision). *Indian Standard*, *1*(5).
7. Khan, M. A. (2013). *Seismic Design for Buildings. Earthquake-Resistant Structures*. https://doi.org/10.1016/b978-1-85617-501-2.00010-9
8. Lalitha Chandrahas, B., & Polu Raju, P. (2017). Behaviour of soft storey RC framed building under seismic loading. International Journal of Civil Engineering and Technology, *8*(4), 265–277.
9. Manual, C. D. (2000). Computers and Structures, Inc. Berkeley, California, USA, (May).
10. Morbiducci, R. (2003). Nonlinear parameter identification of models for masonry, *40*, 4071–4090. https://doi.org/10.1016/S0020-7683(03)00170-7
11. Planning, P., & Development, U. (1994). N e p a l n a t i o n a l b u i l d i n g c o d e, (October).
12. Polyakov, S. V. (1960). On the interaction between masonry filler walls and enclosing frame when loaded in the plane of the wall. Translations in Earthquake Engineering, *2*(3), 36–42.

13. Smith, B. S. (1962). Lateral stiffness of infilled frames. Journal of the Structural Division, *88*(6), 183–226.
14. To, R., Guideline, U. S. E., Detailings, F. O. R., Low, O. F., Reinforced, R., Buildings, C., & Masonry, W. (2012). Ready To Use Guideline for Detailings of Low Rise Reinforced Concrete Buildings.
15. Stafford, S. B. (1966). Behavior of square infilled frames. J. Struc. Div. ASCE, 92(1), 381–403.
16. Hendry, A. W. (1998). Structural masonry. Macmillan International Higher Education.

# Figures

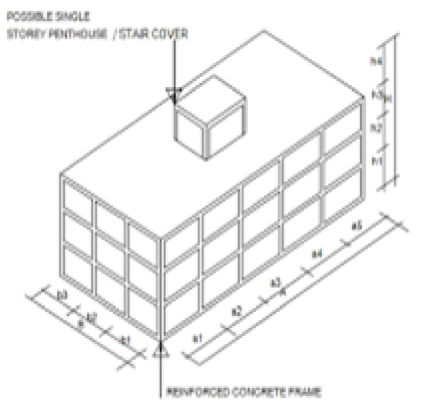



**Figure 1**

Typical building configuration (NBC 201 and NBC 205)

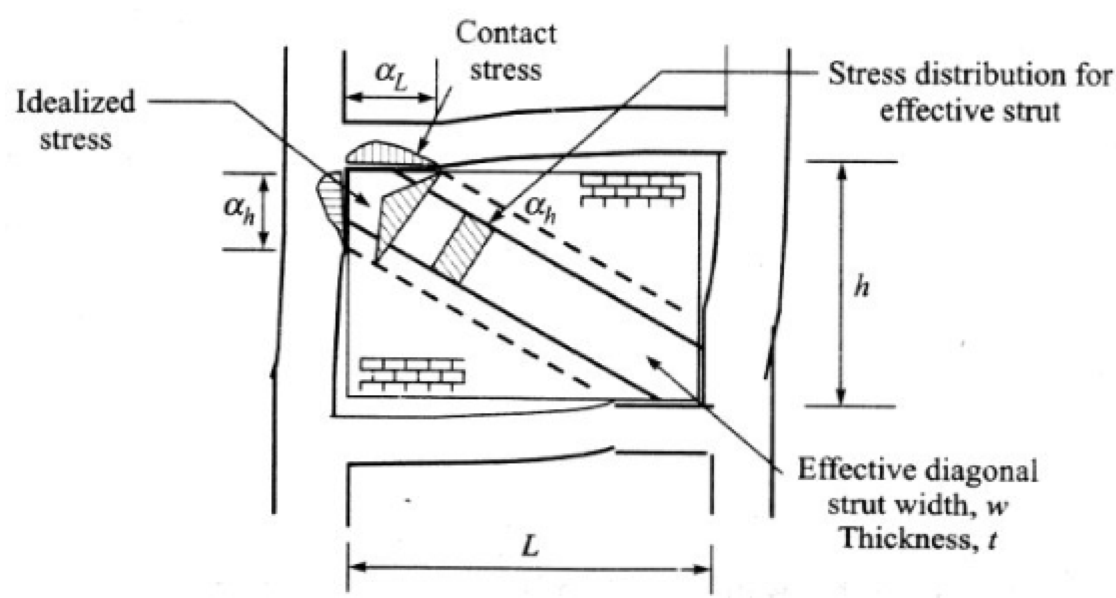


**Figure 2**

Equivalent Diagonal Strut (Drydale,Hamid and Baker,1994)

**Figure 3**

Maximum joint displacement along X-direction

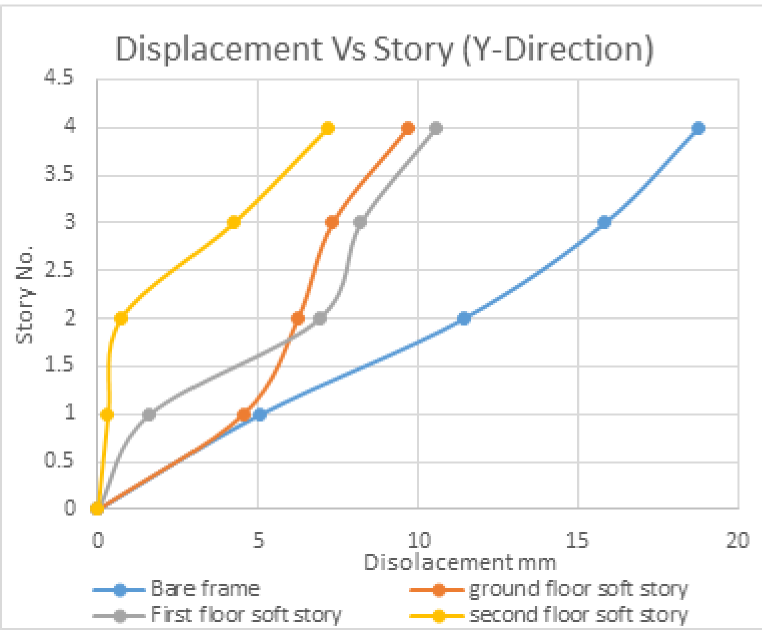
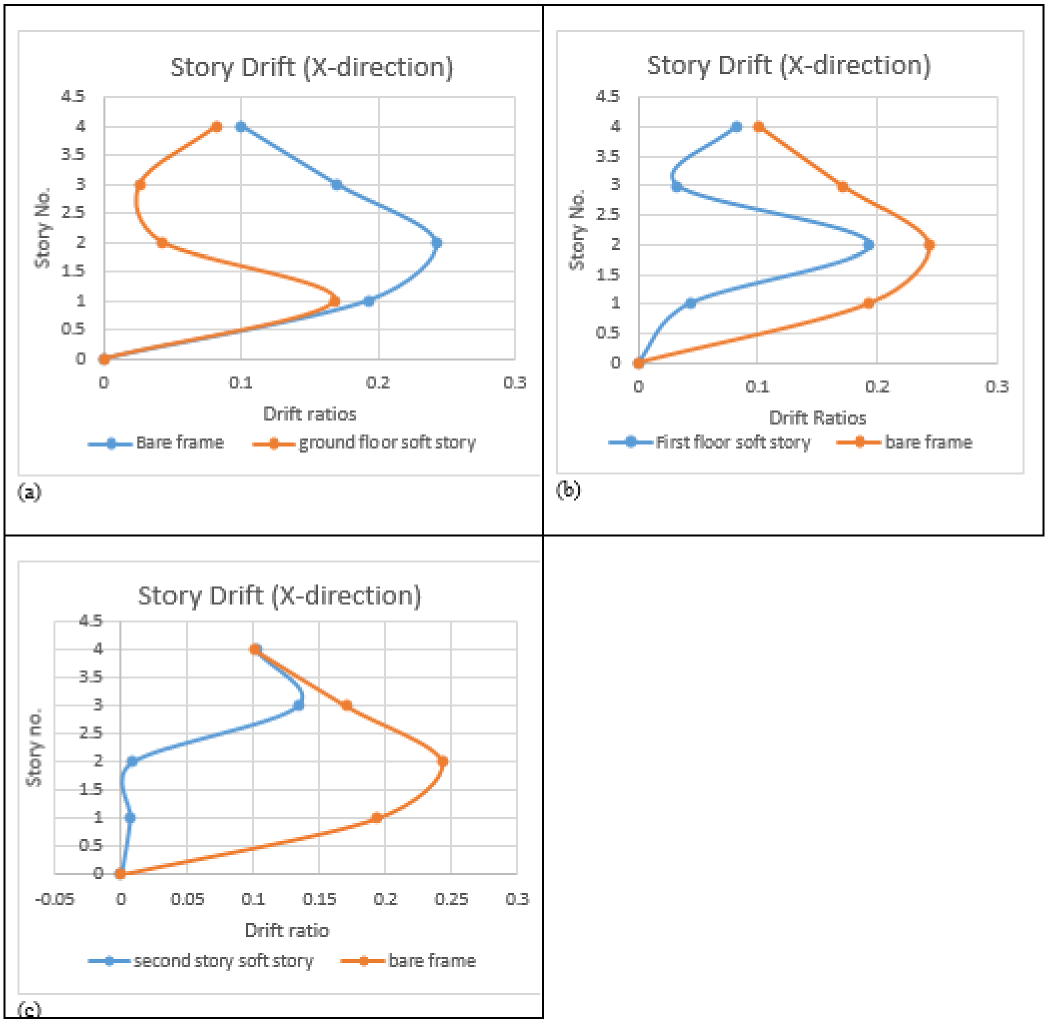


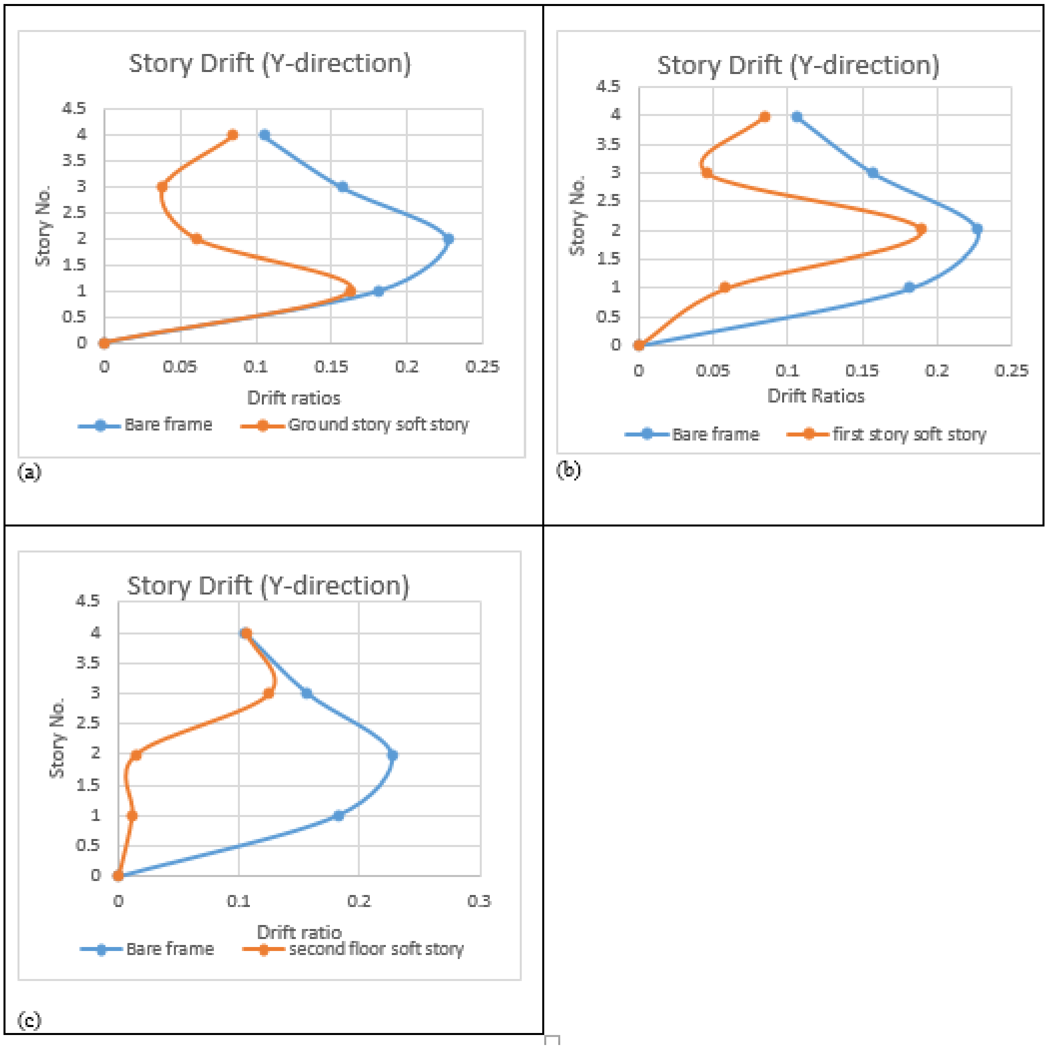

**Figure 4**

Maximum Joint Displacement Along Y-direction



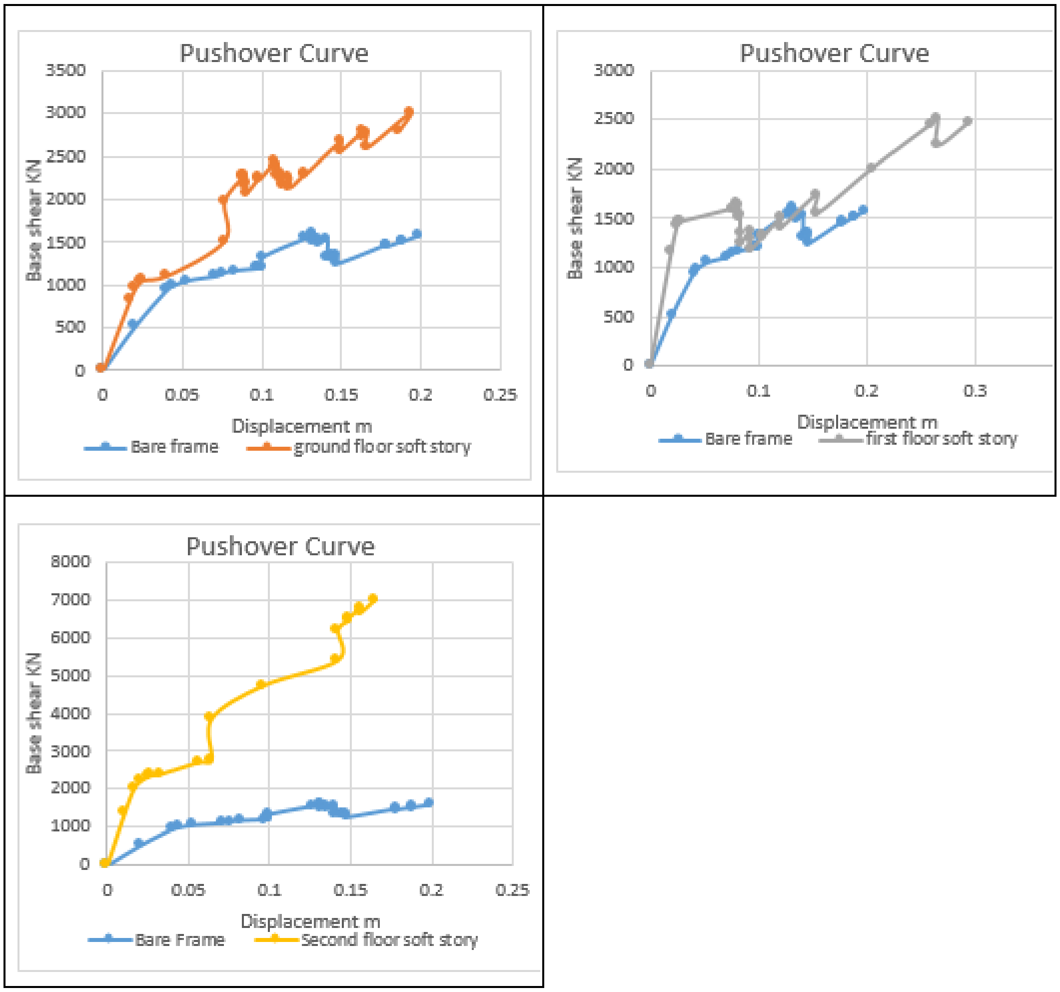

## Figure 5

Comparison of Story Drift for Bare frame with Ground floor, First floor and Second floor Soft story along x-direction




## Figure 6

Comparison of Story Drift for Bare frame with Ground floor, First floor and Second floor Soft story along y-direction




## Figure 7

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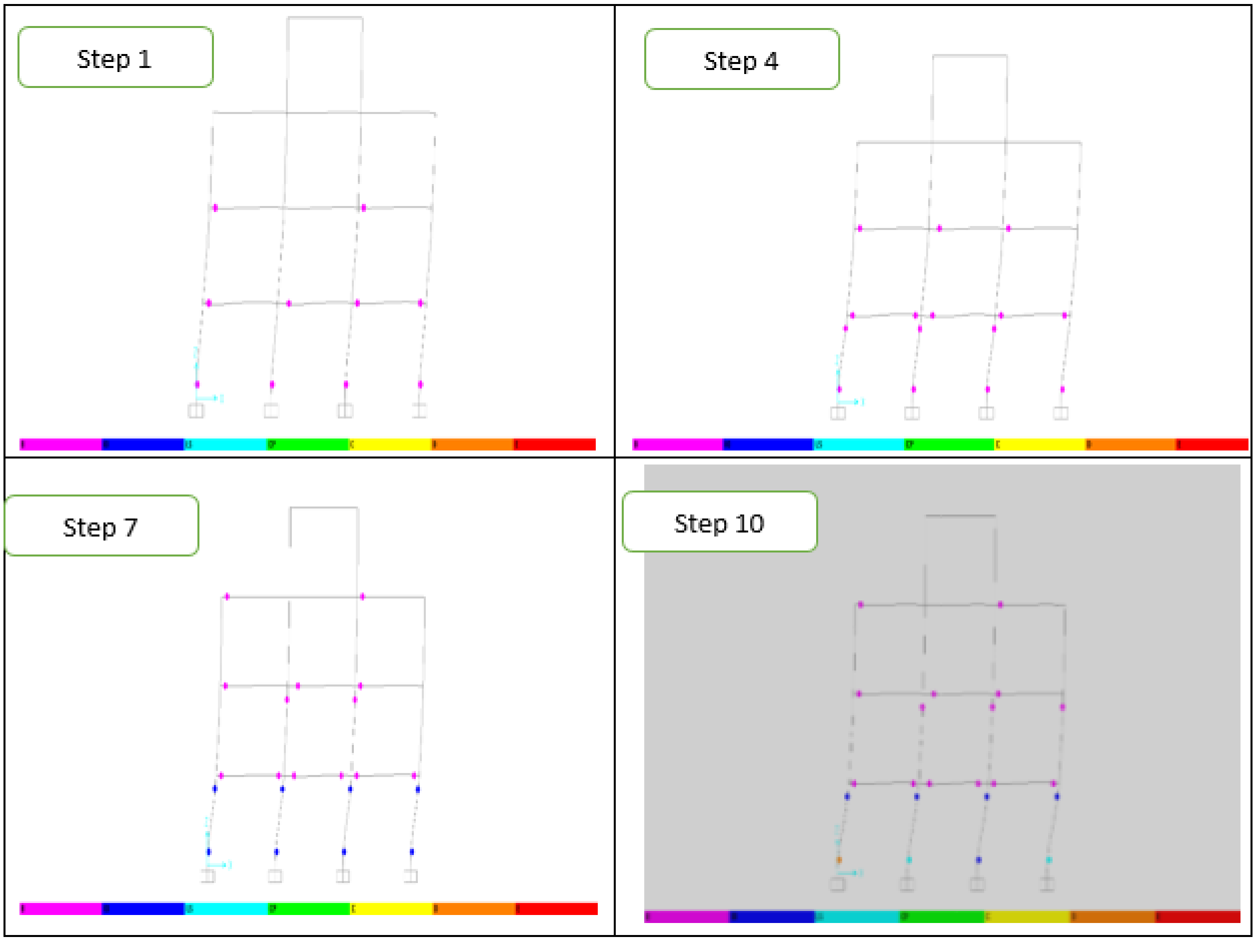


**Figure 8**

Sequential steps for formation of Hinges for bare frame

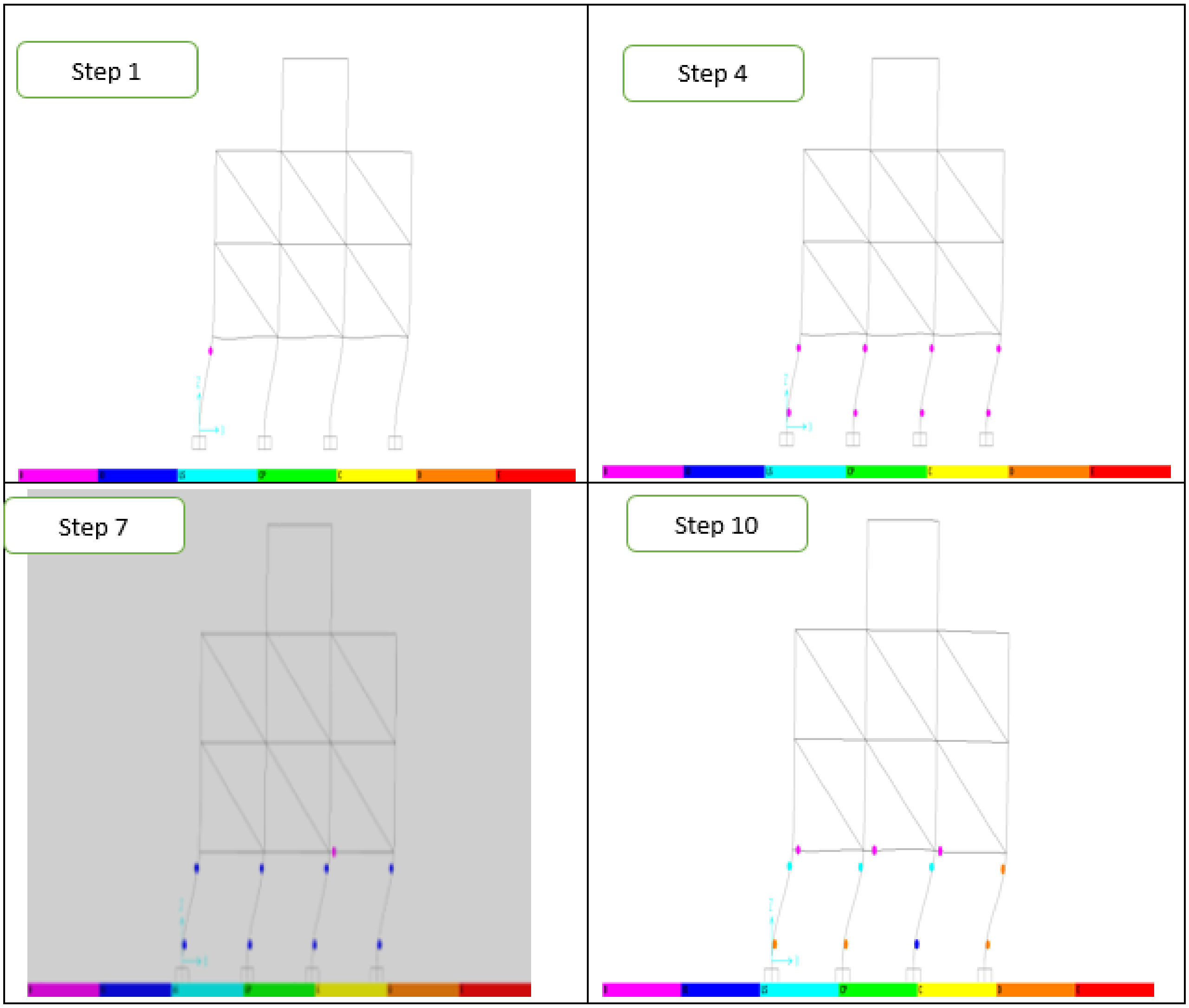


**Figure 9**

Sequential steps for formation of Hinges for Ground floor soft story

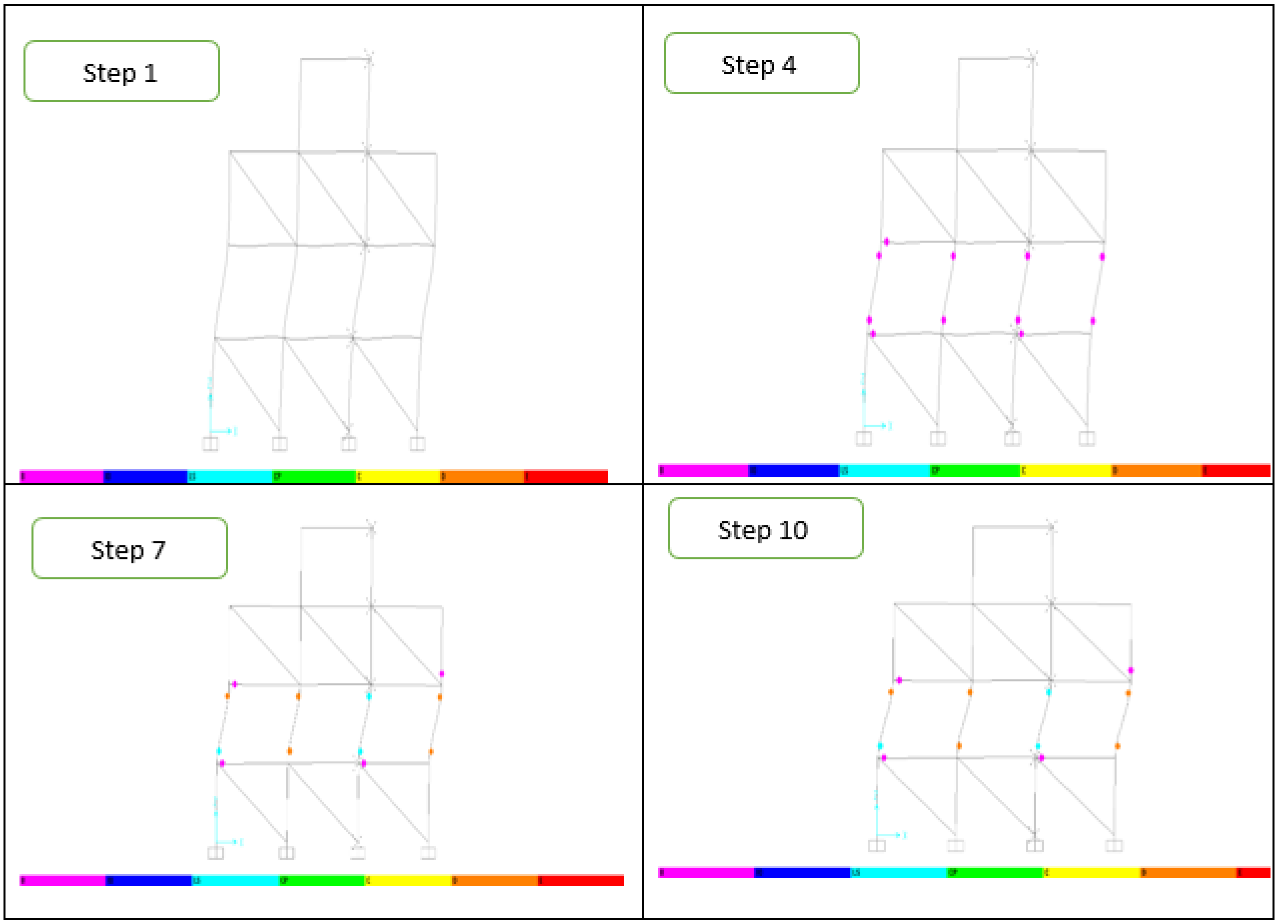


**Figure 10**

Sequential steps for formation of Hinges for First floor soft story

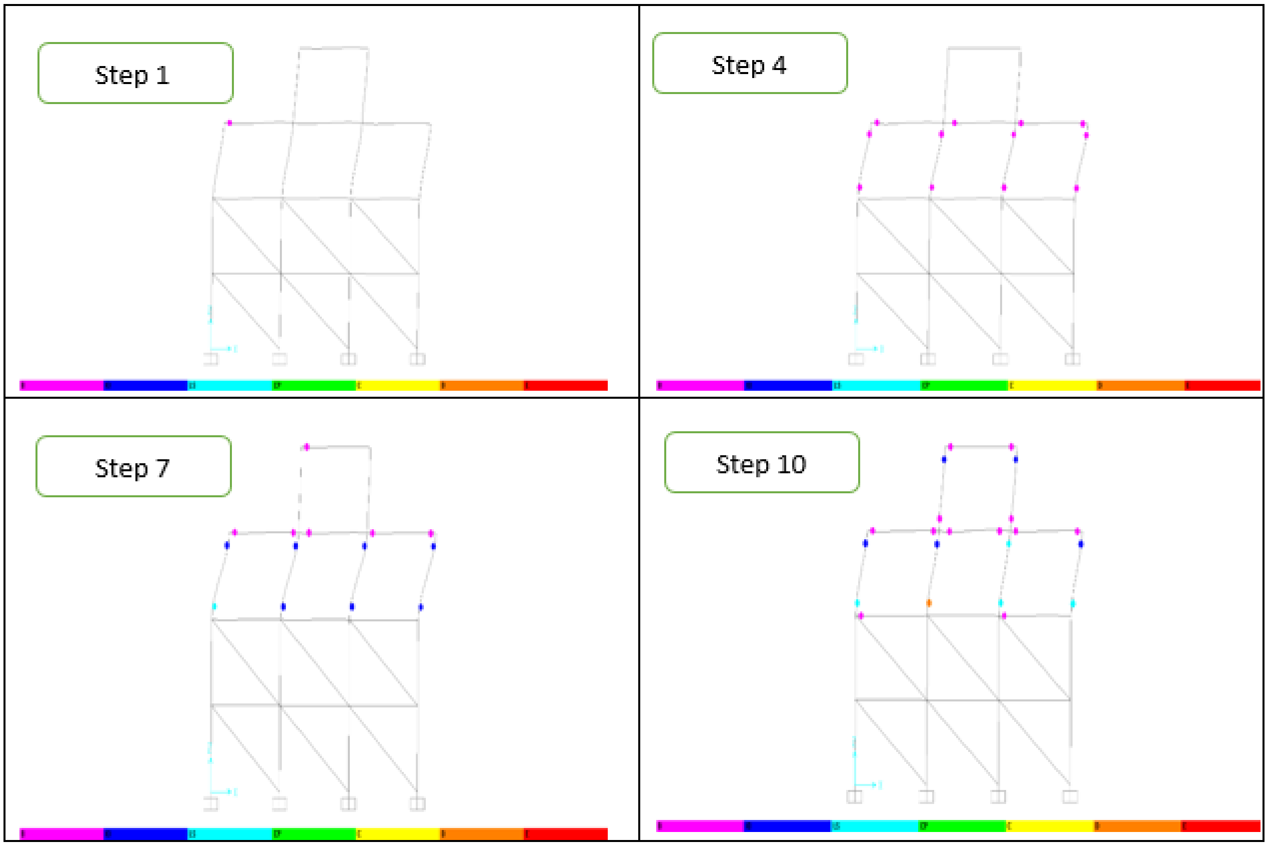


**Figure 11**

Sequential steps for formation of Hinges for Second floor soft story