CHAPTER 7
SEISMIC EVALUATION OF RC FRAMES WITH T-SHAPED COLUMNS

7.1 NUMERICAL MODEL

In this chapter, a G+6, 6m x 6m plan building with a 3m x 3m grid and having rectangular columns of size 230mm x 450mm at all panel points is considered for the analysis. All the columns are oriented such that their longer side is parallel to the global Y direction and the shorter side is parallel to the global X direction of the building. The height of the columns in the global Z direction is considered as 3m for each floor level and the columns extend for 3m below plinth level up to the foundation. From practical point of view, the sizes of columns below plinth level are considered 50mm more in both the lateral directions. The slab is modeled as a shell element which accounts for a rigid diaphragm action in the analysis. The columns are considered to be fixed at the foundation level.

All the beam members are considered rectangular in cross section of size 230mm x 450mm deep. Plastic hinges are defined at 5% span length from either end of all beams and columns. The default PMM hinges are defined at the ends of all beams and columns and default M3 hinge is considered at mid-span of all beams to consider the effect of possible hinge formation due to gravity loads. Keeping all the above geometric features as same, another model is developed with columns having equivalent tee (T) shaped cross section of size 340mm x 340mm x 230mm keeping the projection of all columns parallel to global X axis as shown in **Fig. 7.1**. Also another set of models with all the above features as same and with brick infill walls considered in the peripheral frames as diagonal struts are considered for the analysis.

The response of the building with rectangular columns is compared with that having equivalent tee shaped columns with and without infill walls modeled in both the lateral directions.

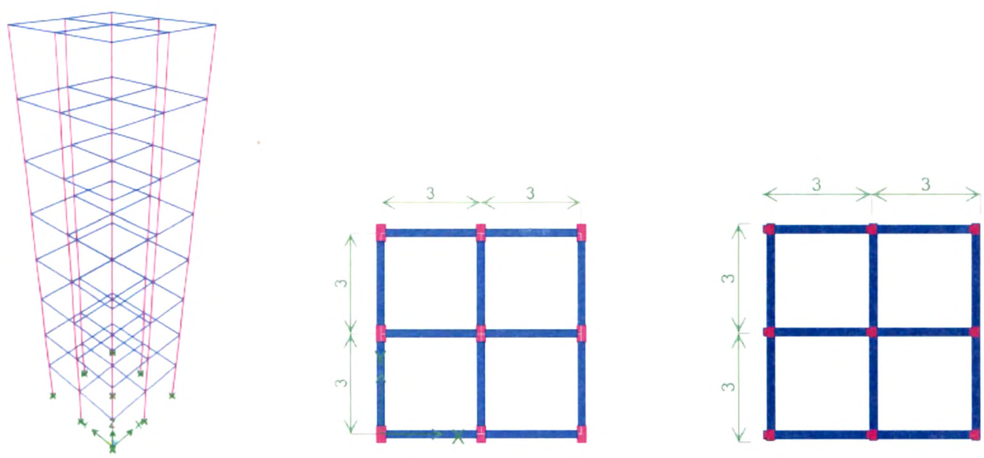


Fig. 7.1 Buildings with Rectangular Columns and Tee Columns

7.2 LOADS CONSIDERED FOR ANALYSIS

Each of the above eight structural models are subjected to gravity loads in the form of floor loads considered as dead load of intensity 5 kN/sq.m. on all typical floors and 6 kN/sq.m. on terrace floor. The live load is considered as 2 kN/sq.m. on all typical floors with 1.5 kN/sq.m. on terrace floor. All external peripheral beams are subjected to a uniformly distributed load of 13 kN/m on typical floors and 6 kN/m on the terrace floor to account for parapet walls. The effect of infill walls is considered as equivalent strut as per Das and Murty **[23]**. The seismic loads in the two lateral directions are applied as per response spectrum method as per IS:1893 Part 1, 2002 **[24]**. Thus, following four basic load cases are considered: 1. Dead Load, 2. Live load, 3. Earthquake load in X direction, 4. Earthquake load in Y direction.

For carrying out design, in all 13 load combinations based on the four basic load cases as defined in IS 1893, Part 1, 2002 are attempted. ETABS V8 is used to do the analysis as well as design of the 3D frame.

ETABS is the software which has all the provisions of ATC 40 document for performing the push over analysis. There are four types of default plastic hinges available in the software which can be assigned to any frame element at the desired location. The software monitors the stress level developed in the defined hinge and reports the same by colour coded hinges graphically as well as in tabular format when a push is given to the structure in predefined steps. The software has the facility to push the structure by applying load control as in the case of gravity push and the displacement control as in the lateral push case. The software also reports number of important parameters like effective damping, effective time period, base shear and roof displacement which changes progressively with push at each step. The facility of plotting the demand and capacity curves in ADRS format and the reporting of the performance point makes ETABS a unique software for easy implementation of the push over analysis.

7.3 DEFINITION OF PUSHOVER CASES

For all the models, the first push PUSH1 is considered in the gravity direction due to dead and live loads. The stresses developed in the defined hinges are monitored step wise till the full magnitude of gravity loads is applied. Thus, PUSH1 is the push in the gravity direction with load control.

Next, the second push PUSH2 is applied in the lateral X direction, which is the weaker direction for rectangular columns, and its initial condition is considered as the end of the gravity direction push i.e. PUSH1. Thus, the stresses in the hinges which developed due to gravity push are retained and are added to those developed due to the lateral push. The X displacement of the roof level node is monitored up to the target displacement of 4% of the total height of the building, when push is given as per mode 1 (the fundamental mode) profile of the space frame. Thus, the lateral push defined by PUSH2 is displacement controlled, monitored by the displacement of the selected roof level node of the model. This displacement is monitored and applied in a stepwise manner by the software till the structure collapses or the target displacement is achieved.

A third push PUSH3 is the push applied in the lateral Y direction and its initial condition is considered as the end of the gravity direction push i.e. PUSH1. The Y displacement of the roof level node is monitored when push is given as per corresponding mode shape in the Y direction. The non linear static push over analysis is carried out for all the models as per ATC 40 **[1]** guidelines considering Seismic Zone Factor Z as 0.16 and for stiff soil.

7.4 MODELING ASPECTS

For carrying out push over analysis in ETABS, the geometry of the space frame is generated using the templates. Next, the properties like cross sectional dimensions, material and other parameters are defined for beam and column elements. A rigid diaphragm is defined for connecting all the nodes at a particular storey level. This diaphragm acts as a rigid link and emulates the effect of a rigid slab which is not modeled. The restraints at the foundation level nodes are defined and the basic load cases like dead loads and live loads are defined. Using the mass data generated due to dead load and proportionate live load, the static earthquake loads are defined in the two lateral directions. The plastic hinge properties are also defined as given in section 7.2 but for the default hinge properties to be defined, one has to analyze the structure and concrete design is to be carried out in order to determine the reinforcement required. Once, the design check is run for the model the plastic hinges are defined as per ATC 40 provisions. A typical hinge properties generated for PMM type of hinge by ETABS is shown in **Fig. 7.2** and the corresponding interaction curve is shown in **Fig. 7.3**. One can run the static push over analysis and display the results or can print them using the features of the software.

Point	Moment/SF	Rotation/SF
E-	-0.2	-0.025
D-	-0.2	-0.015
C-	-1.1	-0.015
B-	-1	0.
A	0.	0.
B	1.	0.
C	1.1	0.015
D	0.2	0.015
E	0.2	0.025

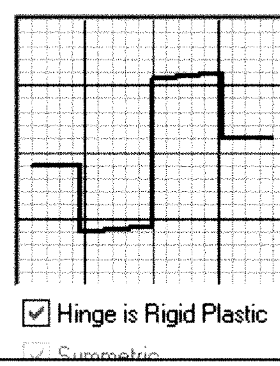


Fig. 7.2 Typical PMM Plastic Hinge Property Generated by ETABS

	Axial Load	M
	P	Curve 1
		Angle 0
1	-1	0
2	-0.8438921	0.1877289
3	-0.7369746	0.2922591
4	-0.6300401	0.3649247
5	-0.5114806	0.4156499
6	-0.3806086	0.4396028
7	-0.3035891	0.4342735
8	-0.2262761	0.3913677
9	-0.1312885	0.3172692
10	-3.643293E-04	0.1903692
11	0.1584131	0

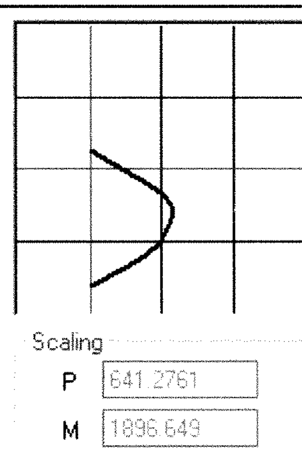


Fig. 7.3 Typical PMM type Platic Hinge Interaction Surface in ETABS

7.5 RESULTS OF THE ANALYSIS

The results obtained are extracted in a graphical form as a pushover curve for each of the cases. In order to get the relevant data for all the models, the pushover analysis is carried out in two steps. Once, a performance point is obtained in a particular analysis, the target displacement for the next analysis is specified as that obtained from the performance point. Thus, in the second run, the analysis will stop just near the performance point. Each figure consists of the final deformed shape of the frame showing colour coded hinges developed at the performance point. These are shown in **Figs. 7.4, 7.6, 7.8 and 7.10**. The colour legend for the hinge level is indicated below each of the figures.

The results also include the superimposed capacity and demand spectrum in the ADRS format along with a family of demand spectra for 5, 10, 15 and 20% damping. These are denoted by the red coloured lines. The plots for rectangular and T columns are shown in **Figs. 7.5, 7.7, 7.9 and 7.11**. The graphs also include a single demand spectrum with variable damping on the same axis. These are shown by magenta lines in the figures. The capacity spectrum is shown in blue coloured line. The graph shows grey radial lines representing the constant period lines.

The result is also presented in a tabular format which lists the number of hinges developed at the performance point along with the stress level of the hinges representing the severity of the hinges. These are shown in **Tables 7.1** to **7.4**. The tables also show the roof displacement and the base shear at the performance point for comparison purposes.

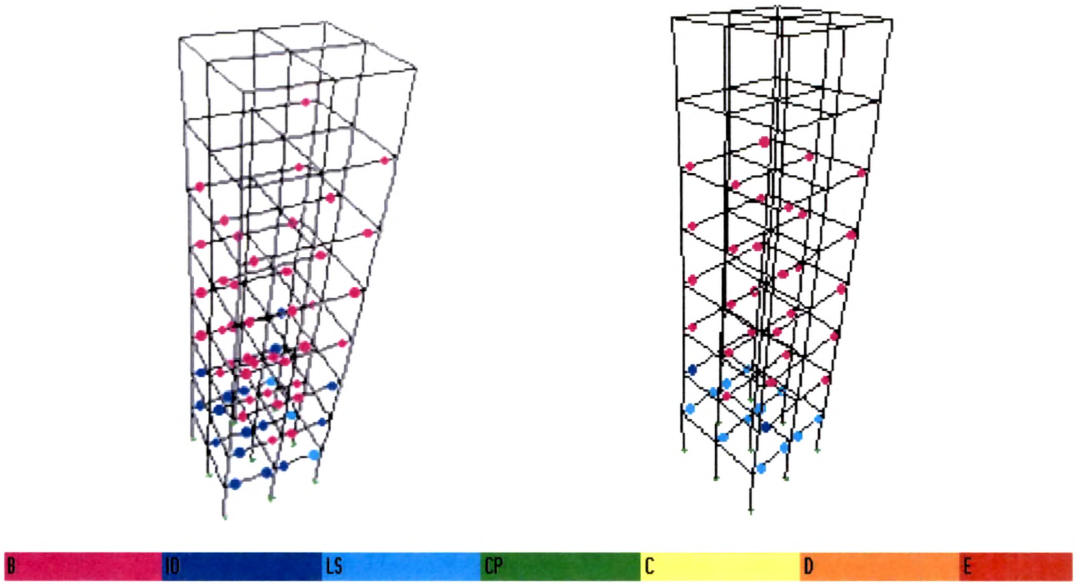
The results presented here are used to plot a number of important charts which gives a clear idea about the relative performance of frames modeled. There are in all, eight RC space frames which are modeled with and without infill walls. **Figure 7.12** shows the number and category of hinges developed in the models. It may be noted here that it is not only the number of plastic hinges developed at performance point which matters but the stress level it reaches at performance point is also important. This is indicated in the figure as colour coding corresponding to the stress level. In pushover analysis, it is also important to note weather the hinges develop in a beam member or a column member. In fact, **Fig. 7.12** is a graphical representation of the **Tables 7.1** thru **7.4**.

Figure 7.13 depicts the effective damping at performance point for various mathematical models. The initial damping in all RC frames is considered as 5% but as the plastic hinges develop in the models, the effective damping goes on increasing. The values of effective damping presented in **Fig. 7.13** are at performance point which, in a way, is also an indication of the damage sustained by the structure under lateral push.

The base shear and roof displacement are compared at performance point for 3m x 3m panel size models for all the eight mathematical models considered in **Fig. 7.14** and **7.15** respectively. The higher value of base shear resisted at a smaller roof displacement is indicative of a better seismic performance of a structure under pushover analysis. Thus, the plots of base shear and roof displacement at performance point for various mathematical models are important in the present parametric study.

The storey drift at performance point are presented for the models without struts representing the infill walls is shown in **Fig. 7.16** and that with infill walls modeled as struts is presented in **Fig. 7.17**. In the same figures, the permissible storey drift as per IS:1893 [24] is represented as dashed line.

3m x 3m Panel Models without Infill Walls under Push X



T-shaped columns　　　　Rectangular columns

Fig. 7.4 Performance Point Deformed Shape with Developed Hinges

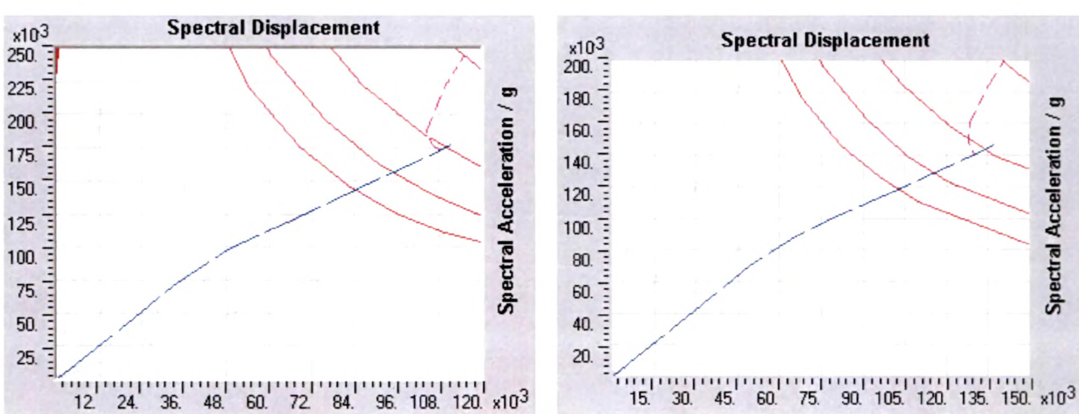
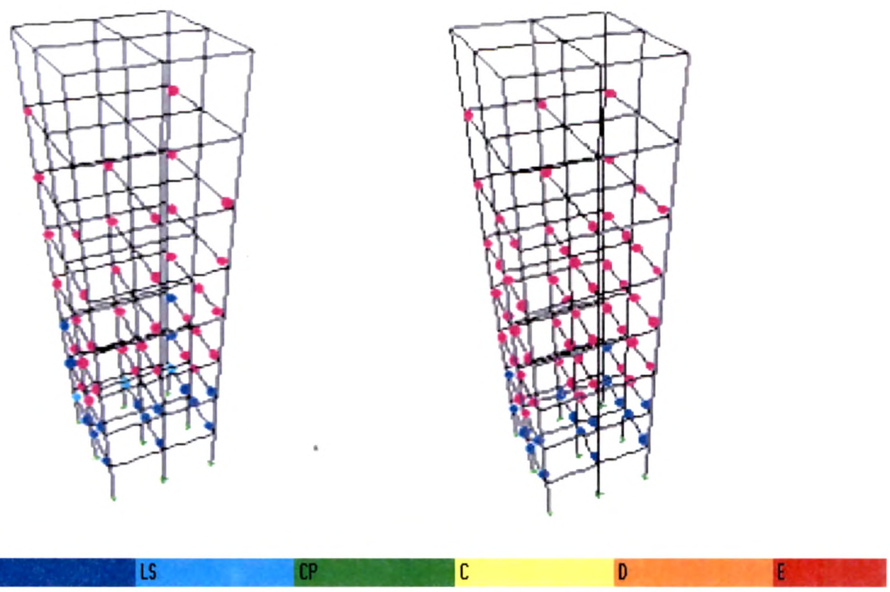


Fig. 7.5 Demand Capacity Spectra at Performance Point

Table 7.1 Number of Hinges with Roof Displacement and Base Shear

Column Type	Roof Disp in m	Base Force in kN	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E
T-shaped	0.129	777.38	372	41	16	3	0	0	0	0
Rect.	0.165	672.33	390	28	2	12	0	0	0	0

3m x 3m Panel Models without Infill Walls under Push Y



T-Shaped columns Rectangular columns

Fig. 7.6 Performance Point Deformed Shape with Developed Hinges

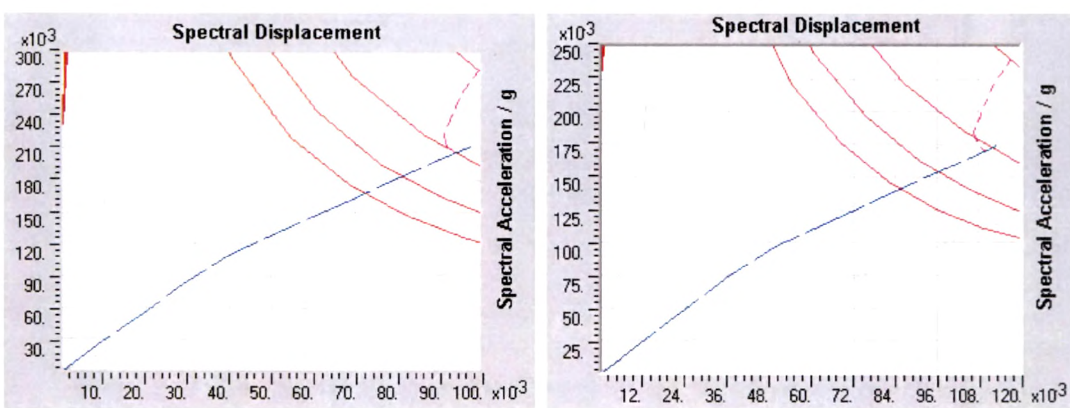
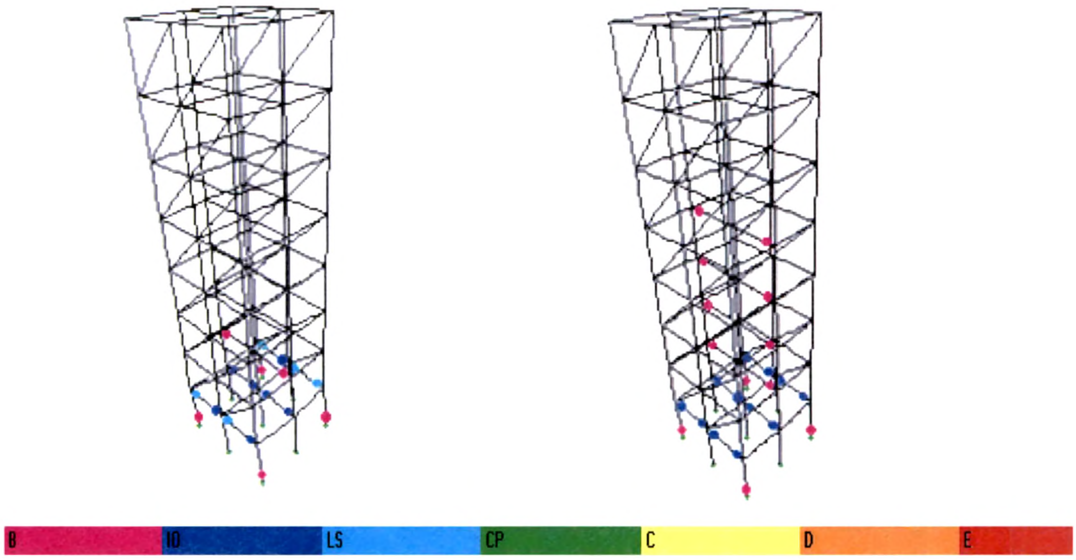


Fig. 7.7 Demand Capacity Spectra at Performance Point

Table 7.2 Number of Hinges with Roof Displacement and Base Shear

Column Type	Roof Disp. in m	Base Force in kN	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	>E
T-Shape	0.138	795.40	376	37	16	3	0	0	0	0
Rect.	0.119	940.64	361	54	17	0	0	0	0	0

3m x 3m Panel Models with Infill Walls as Struts under Push Y



T-Shaped columns Rectangular columns

Fig. 7.10 Performance Point Deformed Shape with Developed Hinges

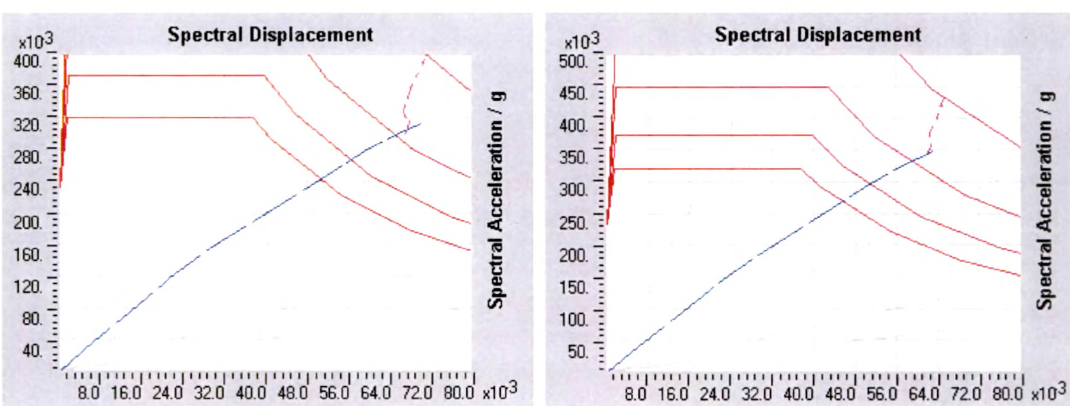


Fig. 7.11 Demand Capacity Spectra at Performance Point

Table 7.4 Number of Hinges with Roof Displacement and Base Shear

Column Type	Roof Disp. in m	Base Force in kN	A-B	B-IO	IO-LS	LS-CP	CP-C	C-D	D-E	> E
T-Shape	0.089	1534.00	411	6	7	5	0	0	0	0
Rect.	0.076	1551.00	405	12	12	0	0	0	0	0

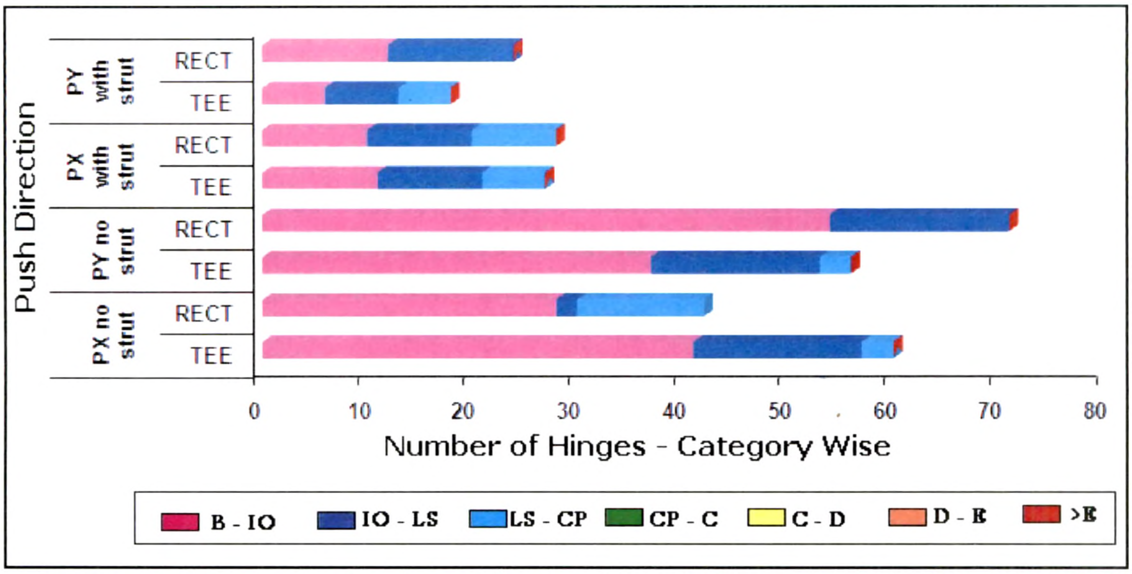


Fig. 7.12 Number and Category of Hinges for 3m x 3m Panel Model

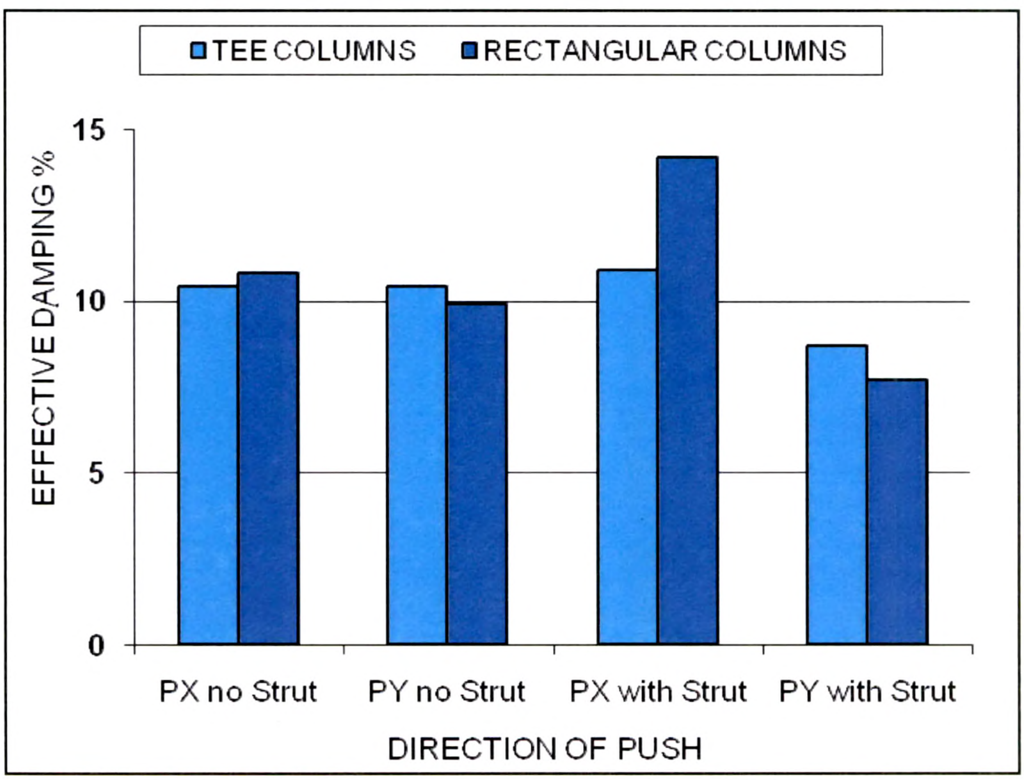


Fig. 7.13 Effective Damping at Performance Point

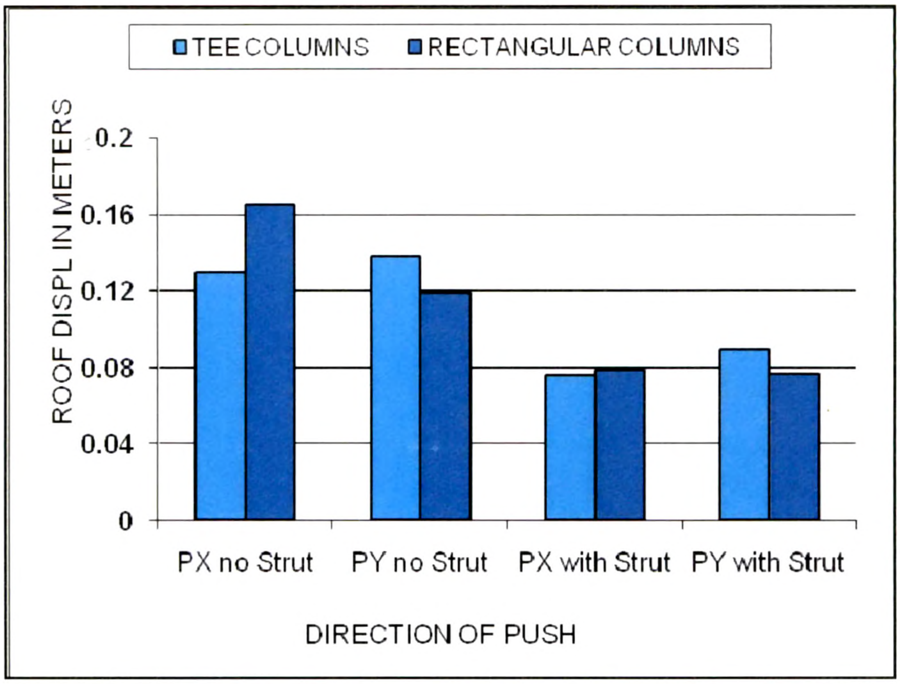


Fig. 7.14 Roof Displacement at Performance Point

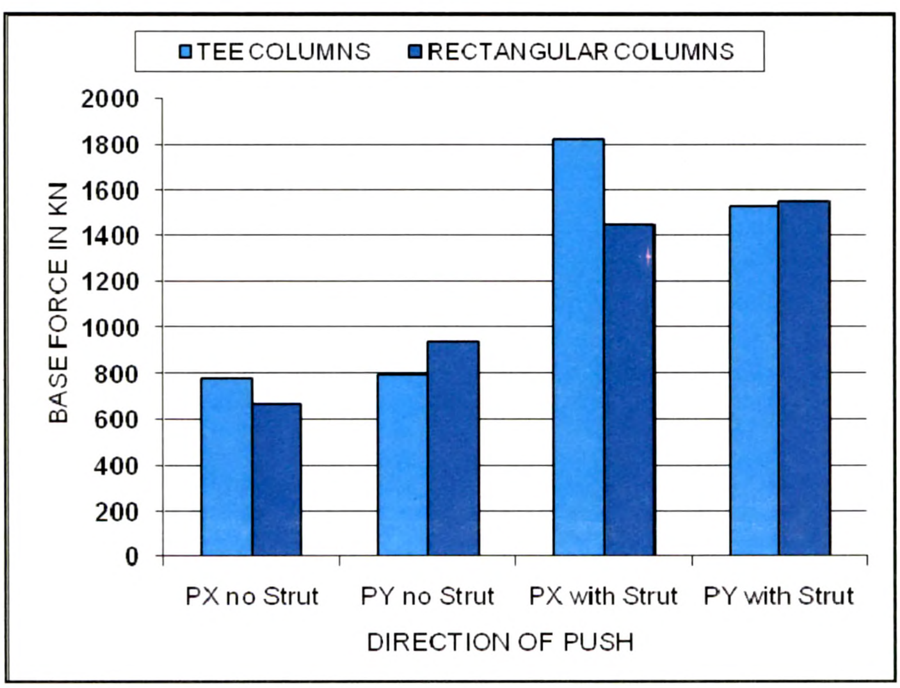


Fig. 7.15 Base Shear at Performance Point

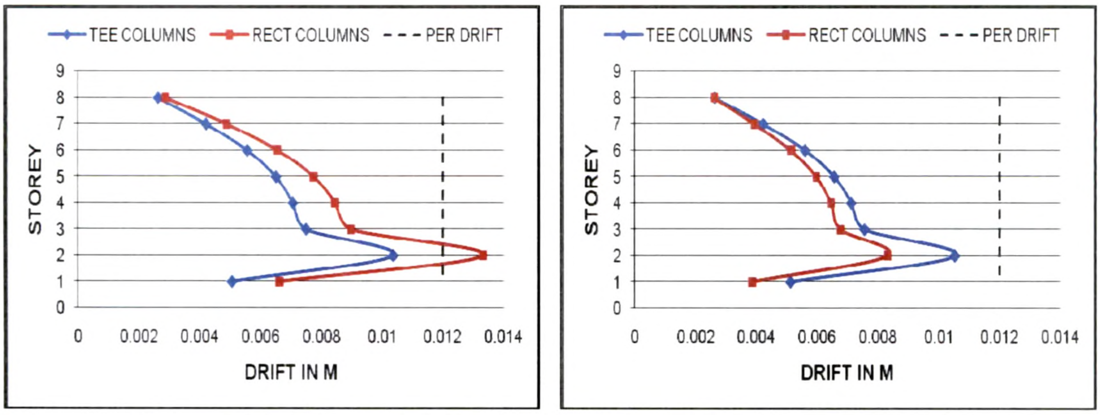


Fig. 7.16 Drift under X and Y Push at Performance Point - No Strut

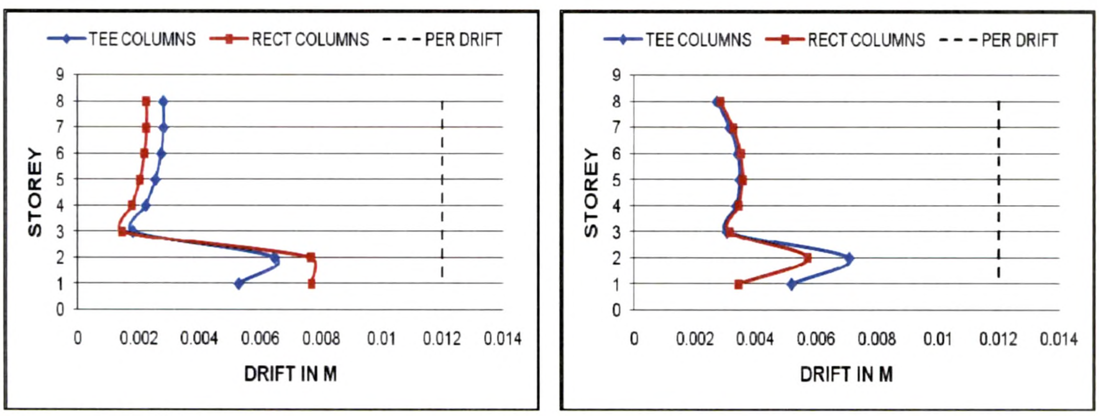


Fig. 7.17 Drift under X and Y Push at Performance Point - With Strut

7.6 OBSERVATIONS AND DISCUSSIONS

- It can be seen from **Fig. 7.4** and **7.6** that tee shaped columns perform better than the rectangular shaped columns for the push in X direction when the infill walls are not considered. Whereas for push in Y direction, the behavior is opposite. This is expected as the rectangular columns are weak in the X direction while T-shaped columns are having almost the same seismic resistance under both X and Y push. This is also indicated by **Tables 7.1** and **7.2** from the number of hinges developed due to these push in various categories.

- **Figure 7.12** shows that for 3m x 3m panel size, the number of plastic hinges developed in T-shaped columns is less for push X as compared to rectangular columns but the situation is reverse in case of push in Y-direction. When the effect of brick infill walls is considered, the performance improves for both the types of column shapes but the result is similar. This behavior is justified from the fact that rectangular columns are weak in X-direction and strong in Y-direction, thus, they show different behavior when pushed in the X and Y direction. As against this, the T-shaped columns are showing almost the same behavior when pushed in either direction which shows a more consistent performance.
- From observing the variation in the effective damping at performance point as shown in **Fig. 7.13**, it is seen that T-shaped columns show almost the same behavior under both push when the effect of infill walls is not considered. The seismic performance of rectangular columns is better that T-columns when pushed in Y (stronger) direction but it is inferior to T-columns when pushed in X (weaker) direction when no infill walls are considered. It is also clear that when infill walls are considered, the same behavior becomes more pronounced.
- The roof displacement at performance point is less and the base shear resisted is more for T-shaped columns compared to rectangular columns under push X as is clear from **Figs. 7.14** and **7.15**. The same behavior is seen when infill walls are also considered. These two factors are indicative of the better performance of T-columns for models with or without infill walls under push X. However, the behaviour is exactly opposite when push is given in the Y direction.
- The storey drift is an indication of the seismic performance of a structure under lateral loads. This data which is seen in a graphical form in **Fig. 7.16** for models without struts indicate that for a push in X

direction, Tee shaped columns show less drift compared to rectangular columns but it is the reverse in case of push given in the Y direction, which is the stronger direction for rectangular columns. It is also clear that since majority of hinges develop at the first slab level, there is a considerable drift observed at this particular level. On the other hand, when the effect of infill walls is considered, there is a marked difference in the drift value in both the models under push in X as well as Y direction which is clear from **Fig. 7.17**. It can also be observed that when infill walls are considered, the effect of column shape on the performance becomes negligible as both column shapes show similar drift values. It is worthwhile to note here that at performance point, all the drift values are within the permissible limit specified by IS 1893, Part 1, 2002 **[24]** except for the model with rectangular columns without infill walls under push in X direction.

- It is important to note here that as far as seismic performance is concerned, as the direction of earthquake force is not known, T-shaped columns which gives consistent seismic performance in both the lateral directions is preferred over rectangular columns. Moreover, since T-shaped columns indicate a similar behavior as square columns, they are preferred over square columns from aesthetic point of view as they can be flush with the 230 thick walls in both the directions.
- It may be also noted from the deformed shape of all the models that when the effect of infill walls is not considered, the plastic hinges develop only in the beams. But, when infill walls are modeled as equivalent struts, the hinges develop in the columns for both the models and for push in both the lateral directions. This phenomenon points to the fact that the consideration of the infill walls changes the behavior of the frames to quite an extent.