CHAPTER 15
SEISMIC PERFORMANCE OF RC FRAMES UNDER TIME HISTORY ANALYSIS

15.1 PREAMBLE

Time history analysis is considered to be one of the most reliable and exact methods of dynamic analysis. In the present chapter, the linear dynamic response spectrum and time history analysis is adopted to evaluate the response of RC space frames. For undertaking a time history analysis the recorded data of the time history which is available online from the cosmos website is utilized here. Time-history analysis is a step-by-step analysis of the dynamical response of a structure to a specified loading that may vary with time. The analysis may be linear or nonlinear. Time-history analysis is used to determine the dynamic response of a structure to arbitrary loading. The other type of dynamic analysis performed is the response spectrum analysis as per the 5% damped IS 1893 **[24]** spectrum considered for medium soil and building lying in zone 3. The response spectrum due to Bhuj time history is also generated for 5% damping and a scale factor of 0.102 to convert the time period versus spectral acceleration in units of g. This spectrum is utilized here to define another response spectrum case and the building is analyzed.

15.2 THE MATHEMATICAL MODELS CONSIDERED

15.2.1 Geometry

Five space frames of G+3 to G+7 storey are considered with an overall plan dimensions of 6m x 6m having four panels of 3m x 3m. Nine columns are considered at the panel points having a cross sectional dimension of 230mm x 450mm throughout. The column height in each storey is considered as 3m and it extends below the plinth level upto 3m where the foundation level is considered. The size of the column below plinth level is considered as 280mm x 500mm. Another set of five similar models having equivalent square column cross section of 322mm x 322mm is also considered for comparison. The beam size is considered as 230mm x 450mm. A rigid diaphragm is considered for each storey to account for the slab stiffness when subjected to lateral loads. The M25 grade of concrete and Fe 415 grade steel reinforcement is considered. A typical isometric view and the typical plan views of a G+7 storey frame are shown in **Fig. 15.1**. All the joints are considered to be fixed at the foundation level.

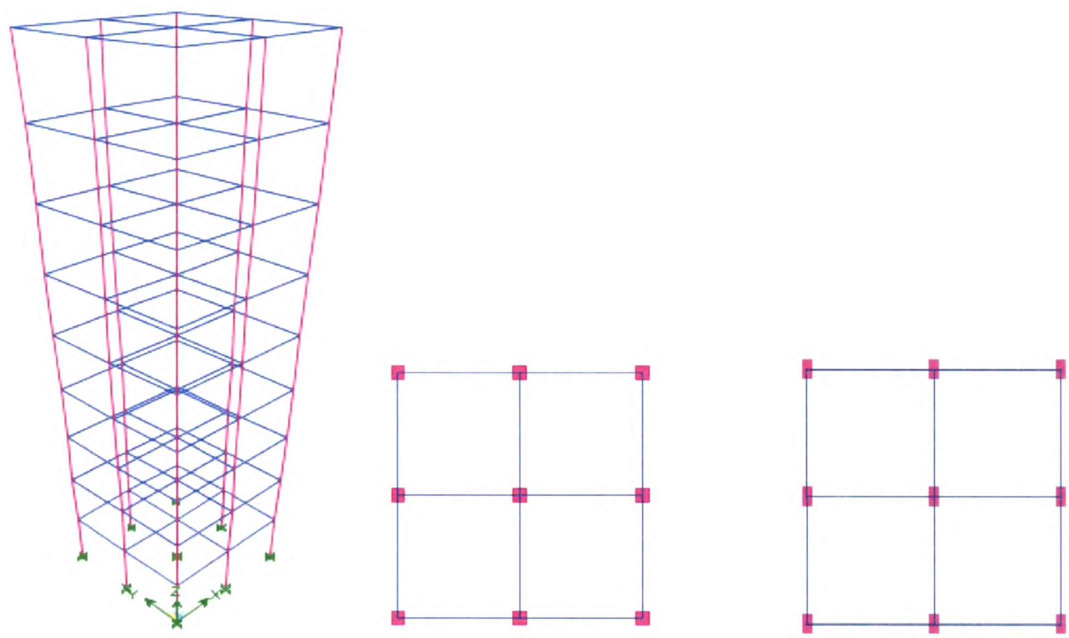

Fig. 15.1 Typical Isometric and Plan Views of the G+7 Frame

15.2.2 Static Load Cases

Following are the four static load cases considered for the models :

1. **Dead load** : This load consists of a uniformly distributed area load of 2 kN/sqm on terrace and 1.5 kN/sqm on all floors along with a uniformly distributed line load of 6 kN/m at terrace level and 13 kN/m on all peripheral beams at typical floor level to account for 230mm thick brick walls. Self weight is automatically calculated by the program for all beams and columns.

2. **Live load** : An area load of 3 kN/sqm on all floors is considered except for the terrace floor where the load considered is 1.5 kN/sqm.

3. **Earthquake load EQX** : This load case is a static load calculated as per the Indian code IS1893 **[24]** for 5% damping with seismic zone factor z = 0.16 and medium soil with importance factor of 1 and a response reduction factor of 5. It is calculated as per the seismic parameters for the frame. The load direction being considered is global X. The loads are applied at the diaphragm centre. The mass considered for generating the lateral load is total dead load + 25% of the live load lumped at diaphragm centre.

4. **Earthquake load EQY** : This load case is exactly similar to the load EQX except for the fact that it is applied in the lateral Y direction.

15.2.3 Dynamic Load Cases

1. Time History Analysis

In the time history analysis, a typical time history for the Bhuj Earthquake of January 26, 2001 at 08:46:42.9 I.S.T. Mag: 7.0 mb, 7.6 Ms recorded at Ahmedabad Station having Latitude and Longitude as 23 02 N, 72 38 E Component : N 78 E is used. Accelerogram Bandpass filtered between 0.07 Hz and 27.0 Hz having an Initial Velocity of -0.1411E-02 m/s, Initial Displacement = 3.970 mm and Peak Acceleration = -1.0382 m/s/s at 46.940 sec is utilized. A total record of 133.53 sec is used having 26706 acceleration data points (in m/s/s) at .005 sec. The plot of acceleration versus time used for the time history is shown in **Fig. 15.2**

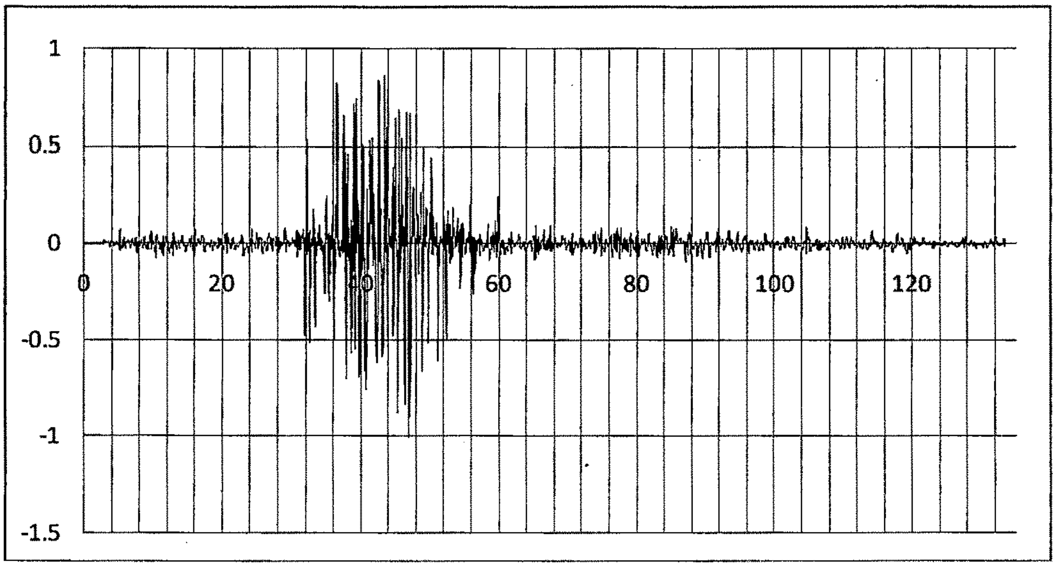

Figure 15.2 Time versus Acceleration Record for Bhuj Earthquake

This file is used as the input for time history function. As the file is having values of acceleration in m/sec^2, the time history load case is defined as acceleration in the X direction with a scale factor of 1. After running the analysis, the response spectrum curve of the ground level node is extracted for time period versus pseudo spectral acceleration as ordinate in the arithmatic scale for 5% damping and X direction is extracted from the time history traces display in the form of a text file. The response spectrum extracted for the central node at the base for each of the models is presented in **Fig. 15.3**. The response spectra are plotted for model with square columns and that with rectangular columns along with the IS 1893 code specified response spectrum on the same plot. This gives a comparative plot of the response of building to the time history of the Bhuj earthquake for 5% damping. The values of this response spectrum are input as a response spectrum function for the response spectrum dynamic analysis. The output of the results is obtained at a time step of .04 sec giving 25 output steps per sec.

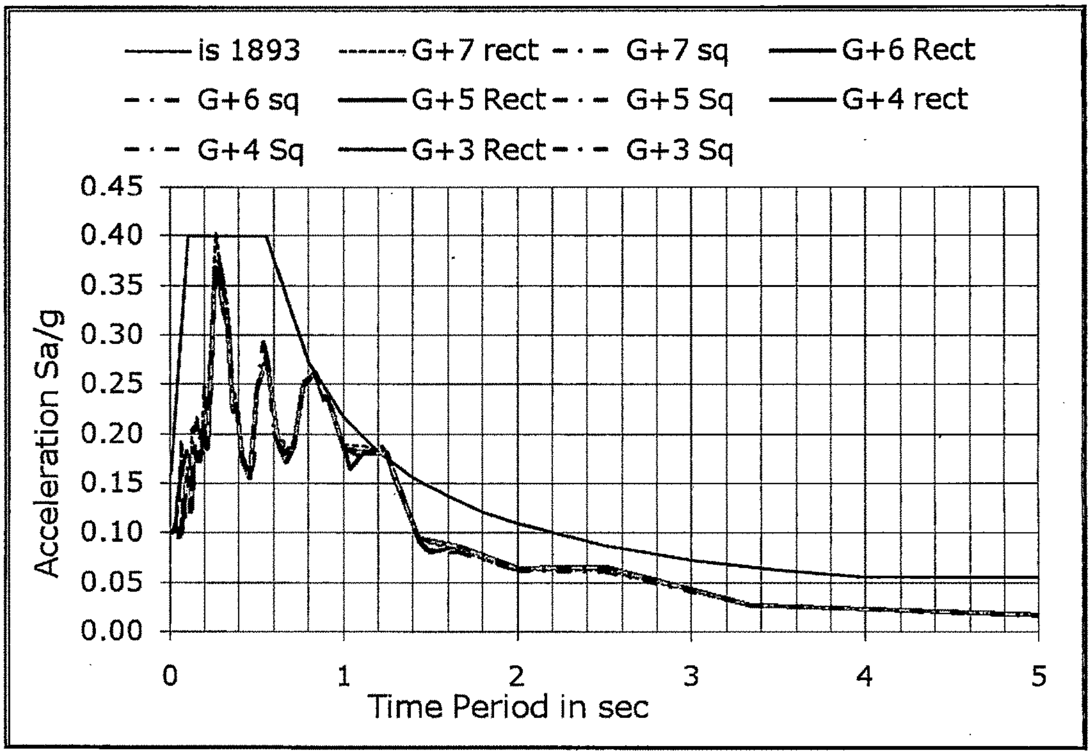

Fig. 15.3 Response Spectra for Models for Bhuj Earthquake

2. Response Spectrum Analysis

First a response spectrum function is defined to carry out the linear dynamic analysis. For the current mathematical models, following two response spectrum functions are defined: i) IS 1893 specified response spectrum for zone factor z = 0.16 having medium soil and 5% damping. This is defined by using the in built function of the software for the Indian code and ii) Response spectrum generated from the time history analysis under Bhuj earthquake for each model which is read from a text file containing the values as shown in **Fig. 15.3**.

Next, the Response spectrum load cases are defined wherein again two separate cases are specified for IS 1893 specified spectrum and the response spectrum function defined for Bhuj earthquake. For both the response spectrum cases, the structural and functional damping considered is 5% which gets modified in the analysis as per the structural properties. The CQC method is used for modal combinations and the SRSS method is used for directional combination. Input response spectrum is defined in the U1 (corresponding to X) direction with a scale factor of 9.81 to convert the acceleration in m/sec^2 units from units of g. The results of the analysis are obtained by running the analyze command of the ETABS software.

15.3 THE RESULTS OF ANALYSIS

For the lateral load analysis, the important parameters like base shear, roof displacement and storey drift are noted from the analysis results. Five different methods are applied for evaluating these parameters for the ten RC space frame models under lateral loads. The methods employed are: i) The linear static method (EQX), ii) The non linear static method (Push Over), iii) The linear dynamic response spectrum method (as per IS 1893 response spectrum), iv)The response spectrum method for Bhuj earthquake response spectrum and v) The linear dynamic time history analysis as per Bhuj earthquake strong motion data. These parameters are reported for G+7 storey frame in the form of **Table 15.1**. The results noted down for the time history analysis are time dependent and the maximum results may occur at different times. However, they are presented here for comparison.

Table 15.1 Comparison of Seismic Parameters for a G+7 Frame

Parameter	Analysis Type	Linear Static	Non Linear Static (Push Over)	Response Spectrum		Time History Bhuj	
	Column			1893	Bhuj	Min	Max
Base Shear kN	Square	147	827	822	531	-987	1010
	Rect	147	708	695	455	-1493	1461
Roof Displ. in m	Square	0.023	0.169	0.101	0.068	-0.102	0.102
	Rect	0.034	0.192	0.123	0.079	-0.155	0.157
Max. Drift in m	Square	0.0011	0.0102	0.0052	0.0034	-	0.0060
	Rect	0.0016	0.0198	0.0068	0.0044	-	0.0125

The graphical comparison of Base Shear Variation in the G+7 storey RC space frame is presented in **Fig. 15.4.** A similar comparison for roof displacement is shown in **Fig. 15.5** whereas **Fig. 15.6** shows the variation in maximum storey drift.

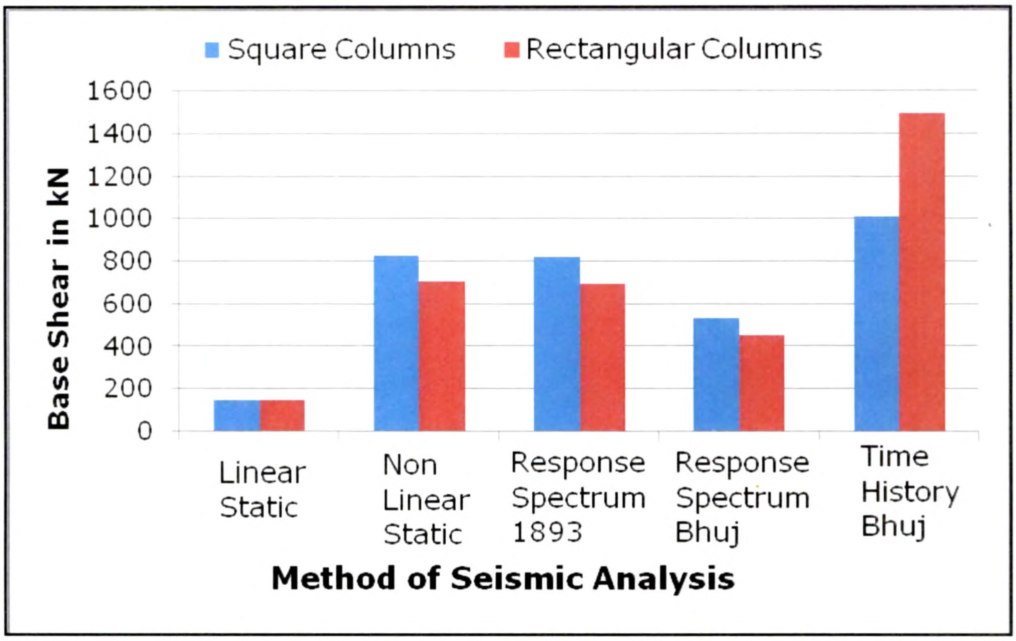

Fig.15.4 Base Shear Comparison for a G+7 Storey RC Frame

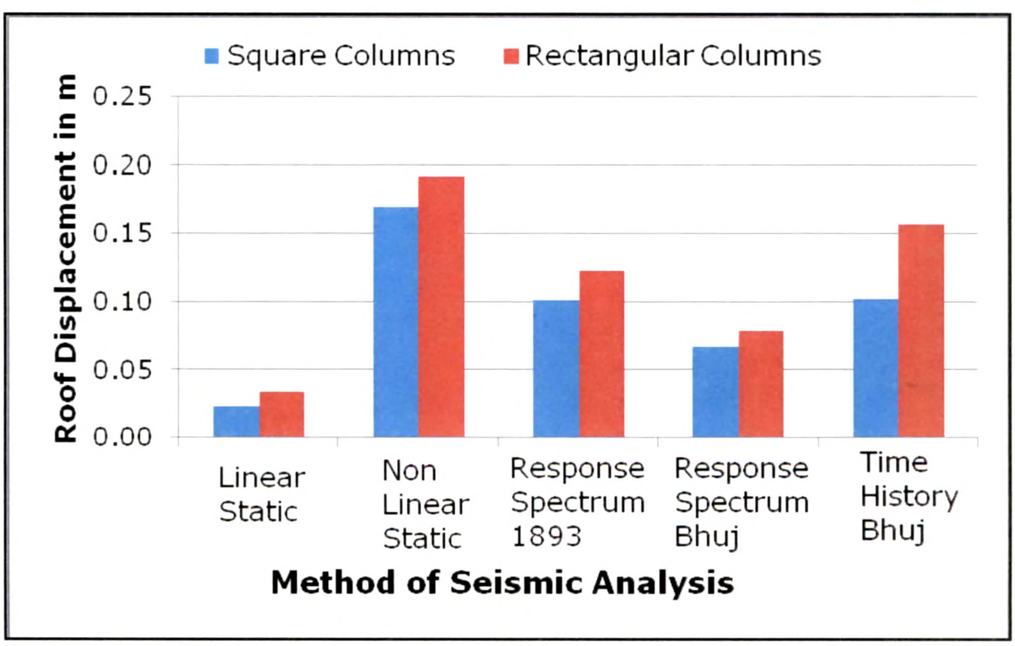

Fig.15.5 Roof Displacement Comparison for a G+7 Storey Frame

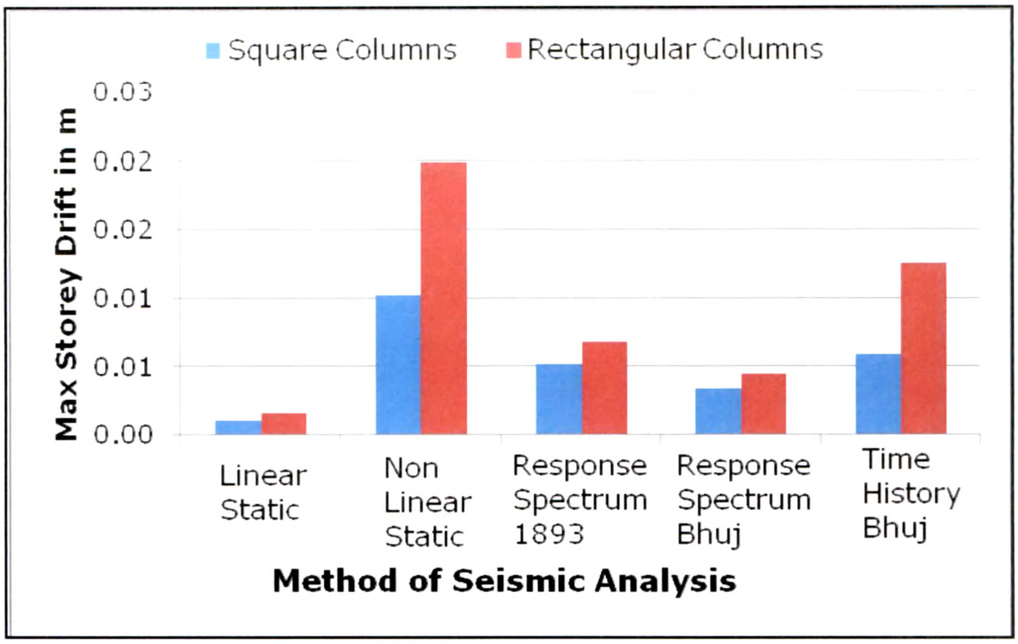

Fig.15.6 Storey Drift Comparison for a G+7 Storey Frame

The two important parameters of comparison for structures under lateral loads are the base shear and the roof displacement. These two parameters evaluated by five different methods for all the ten models are presented in **Table 15.2**. The variation in base shear for all the models is graphically presented in **Fig. 15.7** and that for roof displacement is shown in **Fig. 15.8**.

The variation in storey drift over the height of the structure is also a parameter which gives an insight into the seismic performance of a structure. The storey drift values for all the above five methods are noted for the G+7 storey space frame. The storey drifts for all the five cases of lateral load in the global X direction for frames with square and rectangular columns are presented in **Table 15.3** which are also plotted in **Fig. 15.9** for all the methods on a single plot for comparison. It may be noted here that the values of storey drift for non linear static (push over) case are the drift values at performance point when the space frame is pushed in the X – direction. For rectangular columns, the X direction is the weak direction for lateral load resistance.

Table 15.2 Base Shear and Roof Displacement Comparison by Various Methods of Analysis

Model	Parameter	Column Shape	Linear Static	Non Linear Static (Push Over)	Response Spectrum		Time History Bhuj	
					1893	Bhuj	Min -ve	Max
G+7	Base Shear in kN	Square	147	827	822	531	987	1010
		Rect	147	708	695	455	1493	1461
	Roof Displ. in m	Square	0.023	0.169	0.101	0.068	0.102	0.102
		Rect	0.034	0.192	0.123	0.079	0.155	0.157
G+6	Base Shear in kN	Square	85	818	826	825	1755	1791
		Rect	69	685	691	381	894	905
	Roof Displ. in m	Square	0.011	0.145	0.087	0.091	0.187	0.185
		Rect	0.014	0.161	0.107	0.058	0.089	0.087
G+5	Base Shear in kN	Square	84	812	834	712	1595	1596
		Rect	68	664	687	606	1277	1265
	Roof Displ. in m	Square	0.010	0.123	0.077	0.068	0.127	0.145
		Rect	0.012	0.145	0.091	0.084	0.140	0.137
G+4	Base Shear in kN	Square	82	799	842	816	2192	2182
		Rect	67	643	687	590	1350	1362
	Roof Displ. in m	Square	0.008	0.102	0.061	0.062	0.164	0.160
		Rect	0.009	0.124	0.077	0.068	0.149	0.166
G+3	Base Shear in kN	Square	79	780	868	521	1525	1493
		Rect	64	616	688	655	1957	1938
	Roof Displ. in m	Square	0.006	0.082	0.052	0.031	0.076	0.077
		Rect	0.007	0.103	0.063	0.061	0.149	0.149

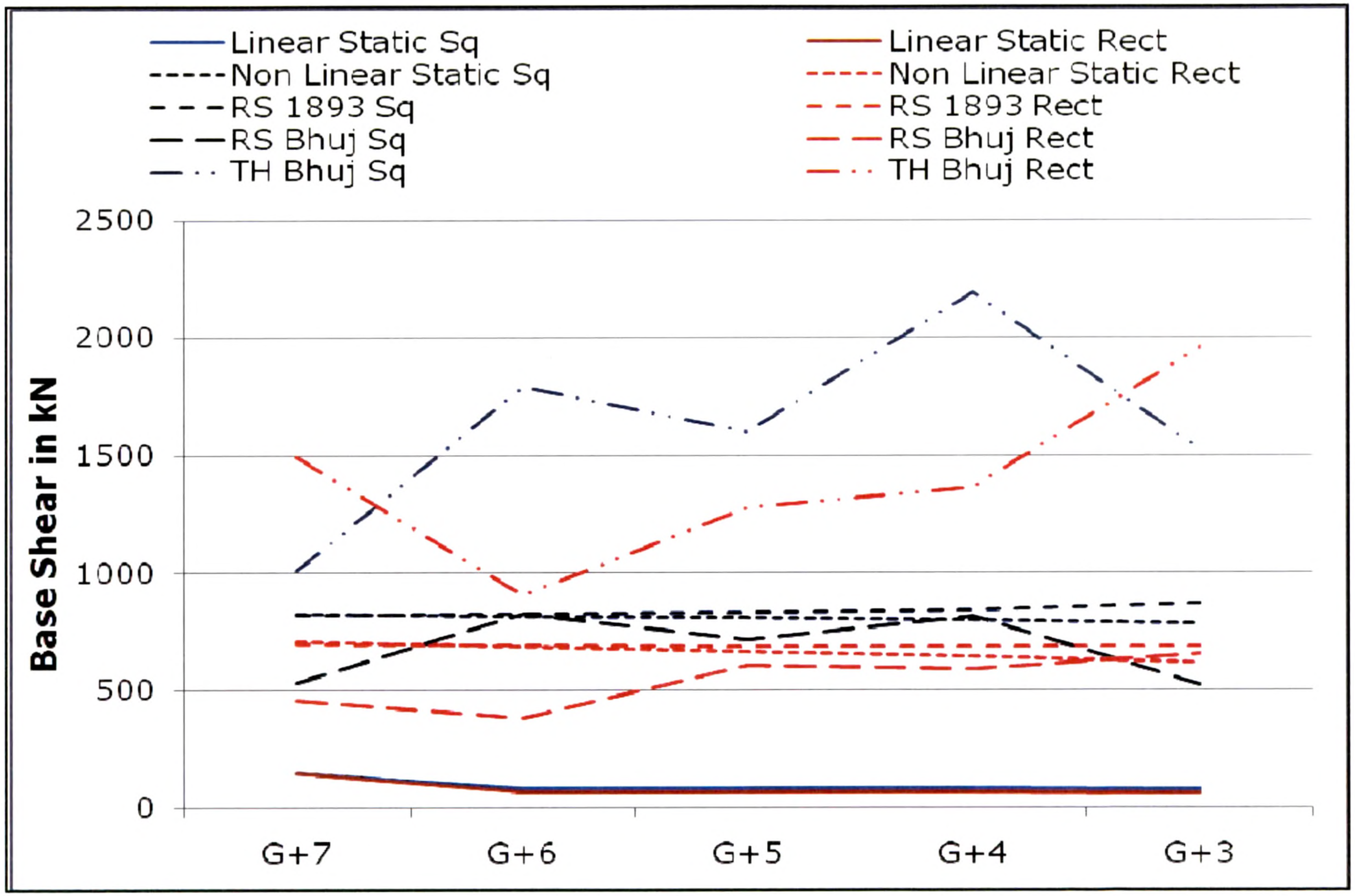

Fig. 15.7 Base Shear Variation for the Models under X Direction Force by Various Methods

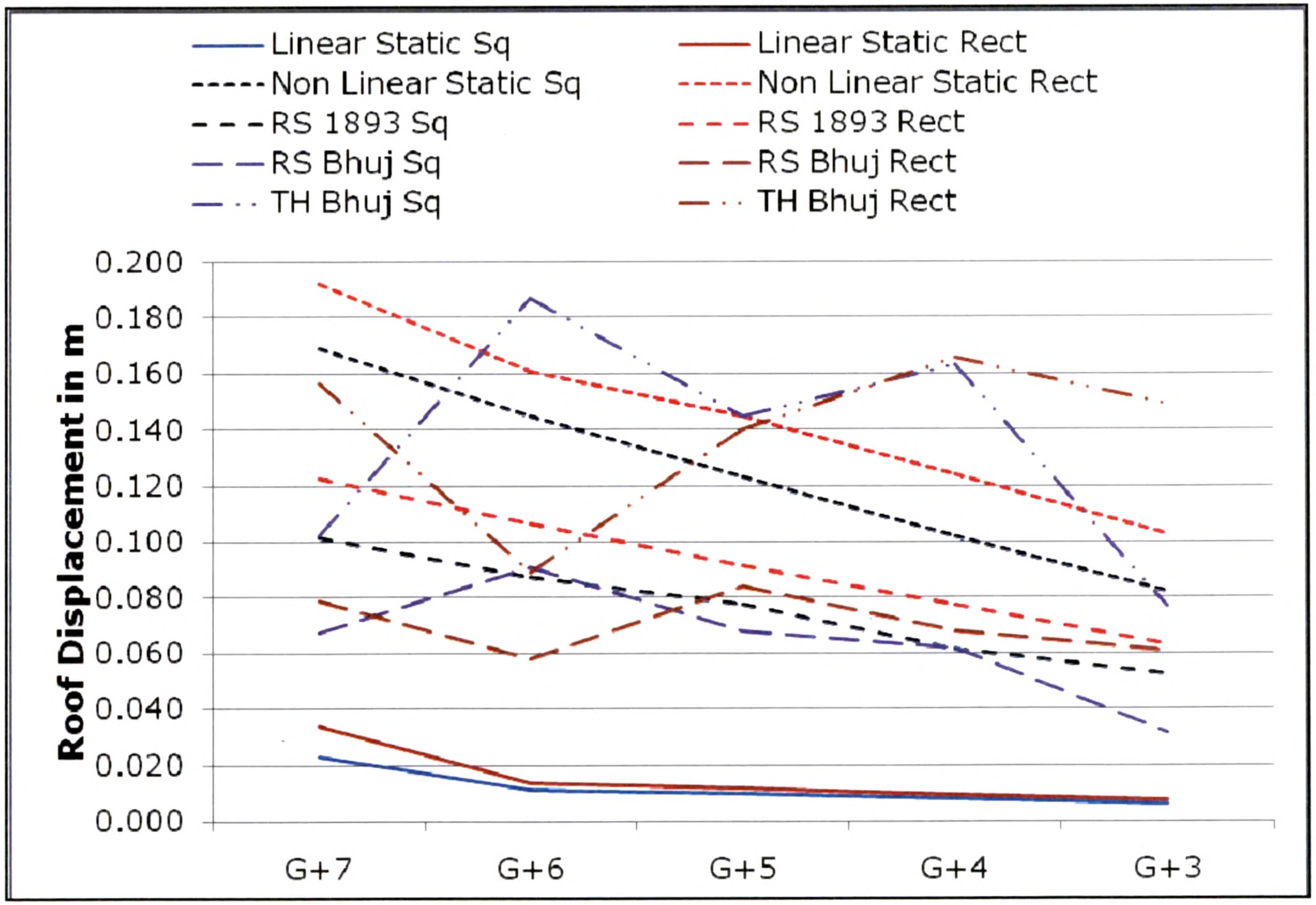

Fig. 15.8 Roof Displacement Variation for the Models under X Direction Force by Various Methods

Table 15.3 Storey Drift Values for G+7 Storey RC Frame by Various Methods

Storey	EQX		Push Over		RS 1893 Spectrum		RS Bhuj Spectrum		Time History Bhuj	
	Square	Rect	Square	Rect	Square	Rect	Square	Rect	Square	Rect
9	0.0005	0.0006	0.0027	0.0040	0.0020	0.0022	0.0012	0.0015	0.0028	0.0052
8	0.0007	0.0010	0.0043	0.0066	0.0030	0.0036	0.0019	0.0024	0.0039	0.0080
7	0.0009	0.0013	0.0056	0.0089	0.0037	0.0046	0.0023	0.0030	0.0042	0.0088
6	0.0010	0.0015	0.0066	0.0104	0.0043	0.0052	0.0027	0.0034	0.0046	0.0086
5	0.0011	0.0016	0.0071	0.0115	0.0046	0.0057	0.0031	0.0037	0.0055	0.0089
4	0.0011	0.0016	0.0075	0.0122	0.0049	0.0061	0.0033	0.0039	0.0058	0.0088
3	0.0011	0.0016	0.0078	0.0130	0.0052	0.0065	0.0034	0.0042	0.0055	0.0099
2	0.0010	0.0015	0.0102	0.0198	0.0052	0.0068	0.0034	0.0044	0.0060	0.0125
1	0.0005	0.0008	0.0020	0.0040	0.0028	0.0035	0.0018	0.0023	0.0035	0.0072

EQX -Linear Static Method

Push Over -Non linear Static Method (Values at performance point)

RS i893 Spectrum -Response Spectrum Method with IS 1893 Spectrum

RS Bhuj Spectrum -Response Spectrum Method with Bhuj Earthquake Spectrum

Time History Bhuj -Time History Method of Analysis under Bhuj Earthquake Time History

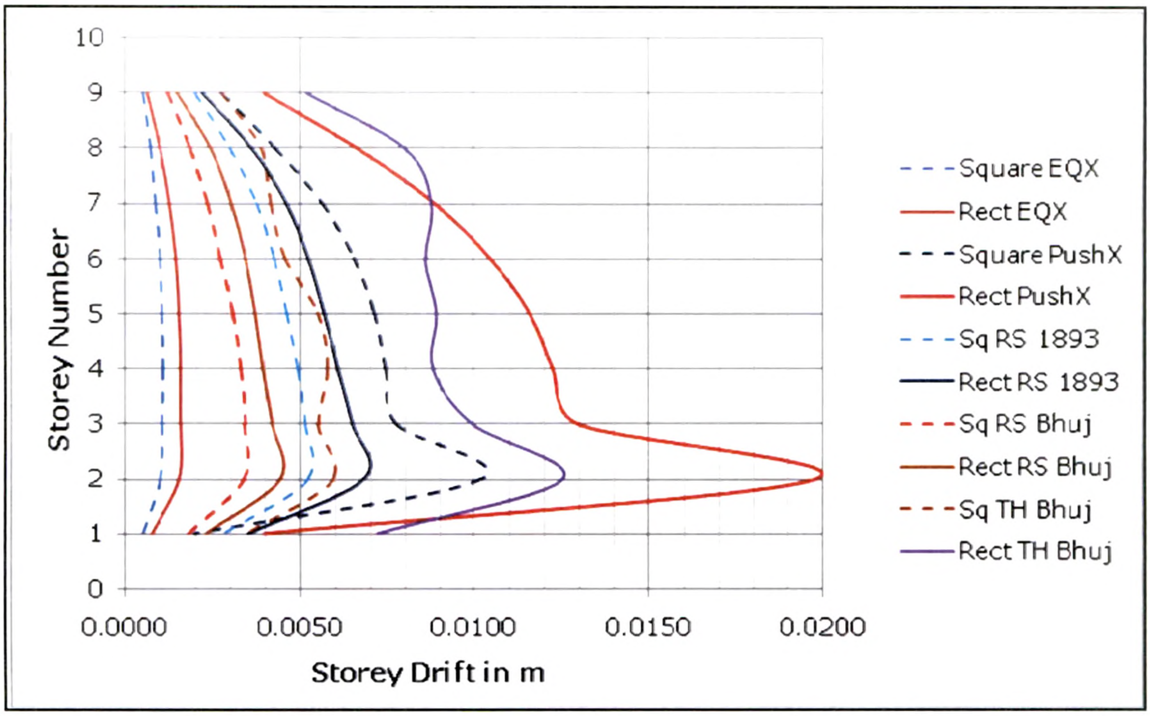

Fig. 15.9 Storey Drift Plot for G+7 Storey Frame in X Direction

The plot of storey drift for the G+6 to G+3 space frame models by all the methods are presented in **Figs. 15.10** to **15.13**.

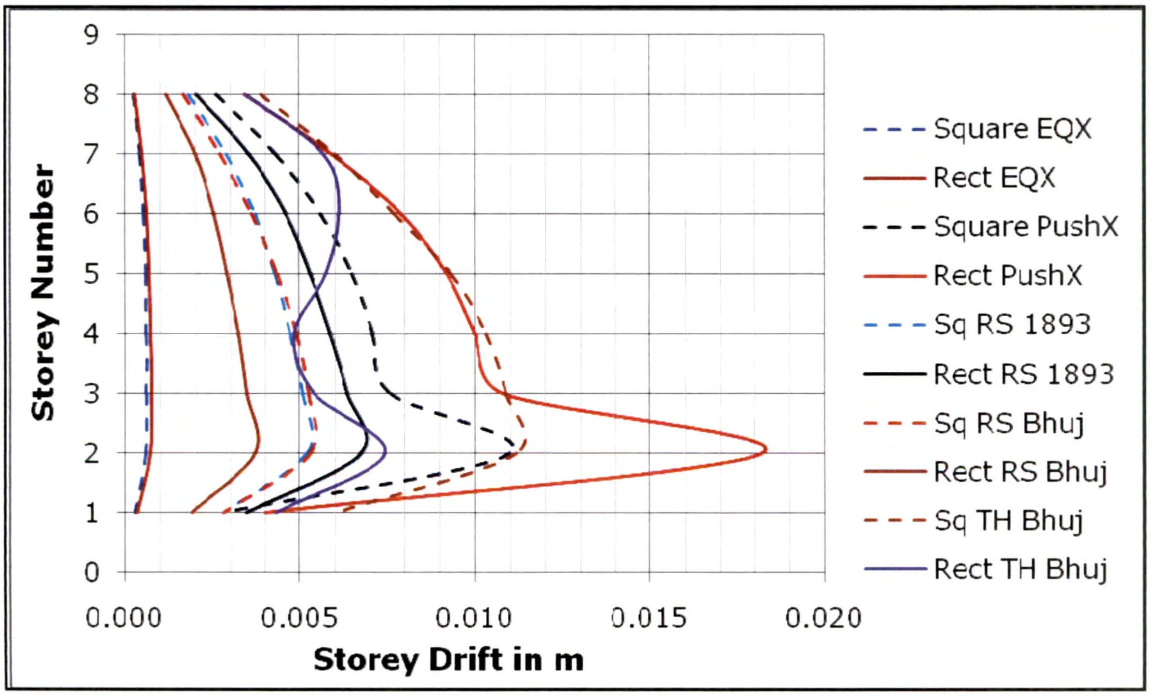

Fig. 15.10 Storey Drift Plot for G+6 Storey Frame in X Direction

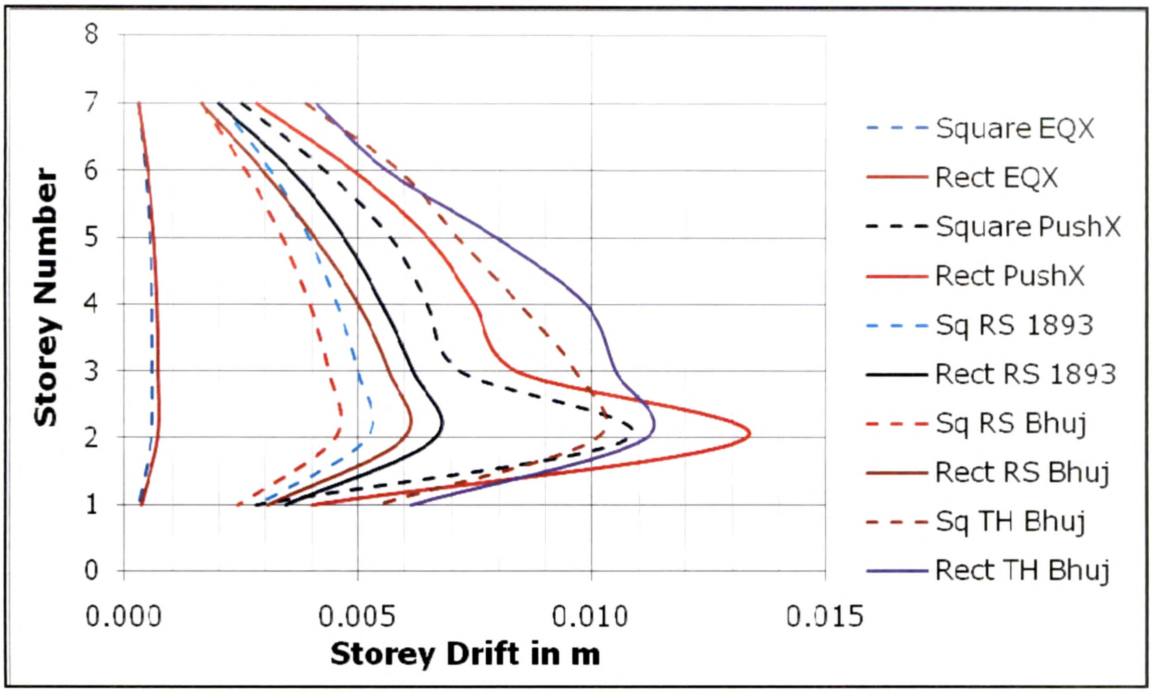

Fig. 15.11 Storey Drift Plot for G+5 Storey Frame in X Direction

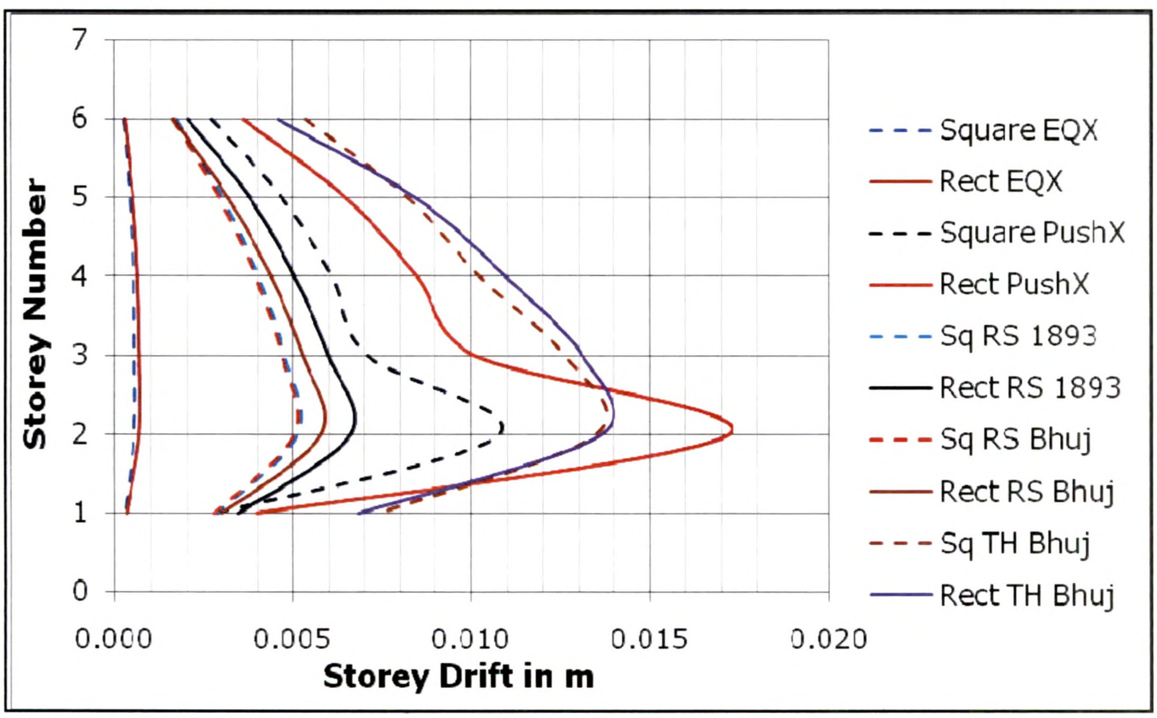

Fig. 15.12 Storey Drift Plot for G+4 Storey Frame in X Direction

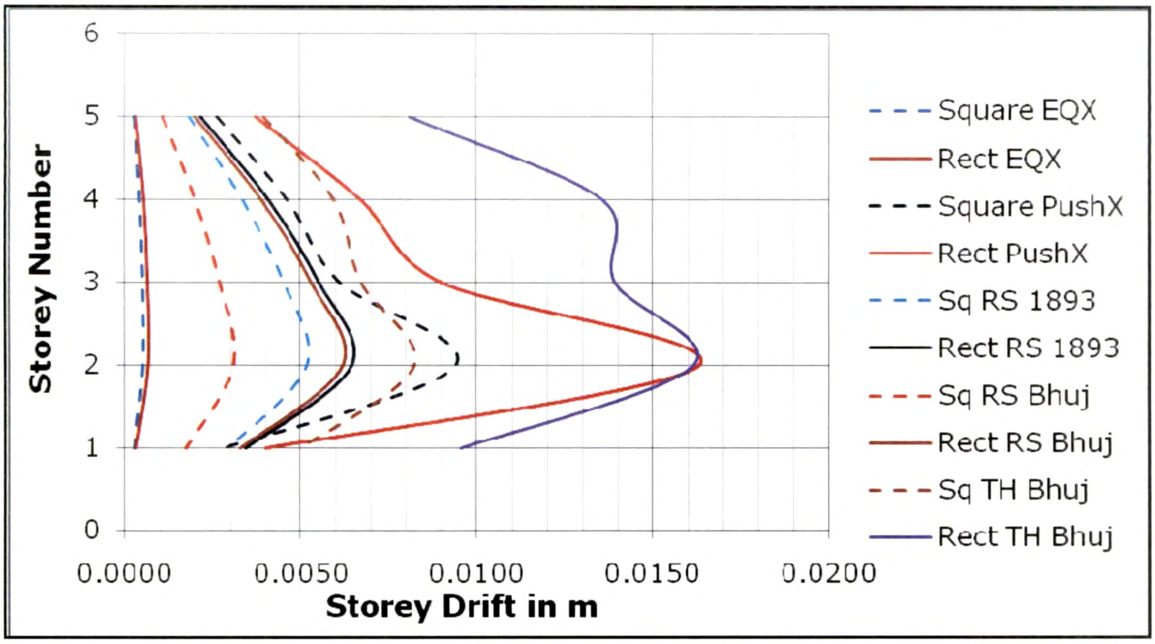

Fig. 15.13 Storey Drift Plot for G+3 Storey Frame in X Direction

15.4 OBSERVATIONS AND DISCUSSIONS

1. **Table 15.1** indicates that the linear static method which is followed to estimate the lateral loads as per the codal provisions is very much on the lower side. The base shear as per time history is 10.15 times that as per linear static method and it is almost 5.6 times in case of response spectrum method. The response spectrum developed for a specific time history will give a value of base shear less than that obtained by the code specified generalized response spectrum. The base shear noted by push over analysis for the same frame at performance point is almost same as that observed for response spectrum as per the codal provisions. However, comparing the forces in frames with square and rectangular columns reveals that the force is higher in square column but at a lower roof displacement.

2. **Table 15.1** indicates that the roof displacement under time history load for square columns is 4.43 times that obtained by linear static method and the same ratio for rectangular columns is 4.61. This indicates that square columns show a less roof displacement as

compared to rectangular columns. Even if we compare the roof displacement of each method, the displacements for frame with square columns are less in comparison to that with rectangular columns.

3. The roof displacement is observed to be maximum in case of push over analysis which is expected because of the formation of plastic hinges. The storey drift is also higher in case of push over analysis because of the plastic hinges. This fact is clearly indicated in **Fig. 15.6**.

4. From **Fig. 15.4** it can be seen that the base shear is highest in case of Time History case followed by that due to push over analysis which is almost same as response spectrum as per IS 1893. The response spectrum developed for specific time history gives a force which is less than that due to code specified spectrum. In general, the base shear due to linear static analysis is 3.6 times smaller than that due to dynamic load due to Bhuj response spectrum for square columns and it is 3.1 times smaller for rectangular columns.

5. **Table 15.2** and **Fig. 15.7** indicates that for the value of base shear obtained by push over analysis and code specified response spectrum are almost same for a specific column shape. For a particular model say G+6 storey frame, square columns are subjected to higher shear force as compared to rectangular columns. The base shear value decreases as the number of storey decrease from G+7 to G+3. For Bhuj time history load case, the base shear variation between square and rectangular columns for different storey structures are quite random. A similar trend is observed for Bhuj earthquake response spectrum analysis, however, the base shear because of Bhuj response spectrum analysis is less as compared to base shear for code specified response spectrum analysis. In general, the base shear response of the structures for G+3 to G+7 frames is quite consistent for code specified response spectrum analysis and push over analysis. The base shear

response of the same set of structures is quite random for a specific time history data.

6. It can also be observed from **Table 15.2** and **Fig. 15.8** that the roof displacement which is another important response parameter for seismic evaluation is also quite random for time history load due to Bhuj earthquake. The roof displacement for a particular model with square shaped columns is found less than that with rectangular shaped columns. It is also seen that the roof displacement in models analyzed with code specified response spectrum and that due to push over analysis show almost a linear trend for G+3 storey to G+7 storey structure for both square and rectangular shaped columns.

7. The storey drift variation which is presented in **Table 15.3** and plotted in **Fig. 15.9** shows the values for all the analysis methods for both the models in a single graph for G+7 frame. It shows that the highest drift occurs at the first storey slab level for all the methods of lateral load analysis. As per drift criteria, the methods can be classified in the increasing degree of severity as linear static, linear dynamic bhuj response spectrum, linear dynamic IS 1893 response spectrum, linear dynamic time history for Bhuj and non linear static push over analysis.

8. Frames with square columns particularly performed well as compared to those with rectangular columns when the maximum storey drift criterion is considered. It is clear from **Fig. 15.9** that the maximum drift under all cases for square columns is 1.94 times less compared to the maximum drift in frames with rectangular columns for G+7 frame. Also, the maximum drift for frame with square columns under time history dynamic analysis is less than that due to IS 1893 response spectrum analysis for rectangular columns.

9. **Figures 15.10** to **15.13** show that the storey drift due to push over analysis for frames with rectangular columns is particularly very large at the first storey level for G+3 to G+7 frames. For all the models, the storey drift due to time history analysis under Bhuj earthquake for rectangular columns is quite random as compared to models with square columns. The storey drift for rectangular columns for G+6 frame under time history analysis is less which is an exception to the trend. The storey drift of a square column is less than rectangular column regardless of the method of analysis or the size of the frame.

10. As the base shear values for non linear static (push over) analysis is near the value of base shear due to code specified response spectrum analysis, it can be stated that the push over analysis represents the state of the structure in terms of plastic hinges in a more realistic manner for G+3 to G+7 storey space frames.