International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

Seismic Performance Evaluation of RC Frames with Semirigid Joints using Storey Drift as a Criterion

Dr. B. A. Shah
Associate Professor, Applied Mechanics Department,
Faculty of Tech. & Engg., M S Univ of Baroda
Vadodara, India

***Abstract*—A set of G+3 to G+7 RC space frames having an overall plan dimension of 6m x 6m with four panels of 3m x 3m and having a column at each panel point is considered in the present study. The mathematical models developed have been considered to have four variations in the beam column joint rigidity varying from pinned to fixed and two variations in column cross section i.e. rectangular and equivalent square cross section. A combination of rigid and semi rigid joints have been used to define a frame called hybrid frame for analysis under seismic loads. The storey drift values noted for all the mathematical models at performance point under push over analysis, carried out by using commercially available ETABS software, is used as a basis of seismic performance. It is observed that the square shaped columns exhibit less drift as compared to the rectangular shaped columns. It is also found that the hybrid frames with internal beam column joint having an intermediate rigidity perform almost like a frame having all joints as fully rigid.**

Keywords*—Seismic Performance; RC Frames; Semi rigid joints; pushover analysis; storey drift; hybrid frame

I. INTRODUCTION

The 2001 Bhuj earthquake of India was an eye opener. It made thousands of people lose their lives and rendered millions to lose their houses. The effect was so wide spread that it not only affected the people in the vicinity of the epicenter but also those living in a metro city Ahemdabad, about 250 km away from the epicenter were badly affected. A major damage was observed in RC framed structures which were in the range of G+3 to G+ 7 storeys. Further, most of the buildings were having a normal grid of 3m x 3m column spacing with a standard storey height of 3m.

One important parameter concerned with the seismic behavior is the storey drift which should not exceed a permissible value. This fact is evident from the inclusion of a clause related to specifying a permissible value of storey drift in all country codes related to earthquake engineering including the Indian code IS 1893, 2002 [1]. The current work aims to report the seismic performance of G+3 to G+7 storey RC space frames from the point of view of storey drift observed under push over analysis.

The effect of beam column joints on seismic performance in precast concrete frames has been studied by Joshi et al [2]. The importance of the rigidity of the beam column joint has also been reported by Uma and Jain [3] in their paper related to the comparison of provisions of aseismic design of RC moment resisting frames of American, New Zealand and European country codes. This fact has been utilized here to study the effect of introducing semi rigid joints in various combinations in an RC space frame. It has been pointed out by Shah et al [4-5] that the joint rigidity plays an important role in seismic performance of RC plane and space frames. The same concept has been used here to define RC space frame having all internal joints as semi rigid and the beam column joints in the peripheral frames as fully rigid to develop a hybrid frame concept.

II. MATHAMATICAL MODELS CONSIDERED

Three types of mathematical models are developed to study the RC space frame models on the concept of following three types of variations.

1. Considering the frames as having all the joints as fully rigid.
2. Considering the frames having all the joints as semi rigid.
3. Considering the internal joints as semi rigid and external joints as fully rigid.

In the case of semi rigid frames, the joint stiffness is taken as 0 kNm/rad representing pinned ends, 7500 kNm/rad representing very low stiffness, 100000 kNm/rad representing intermediate stiffness and 290000 kNm/rad representing a very high value of stiffness corresponding to fixed ends. Rectangular and equivalent square shapes of columns are considered for all variations.

The rigid frame is a moment resisting frame having all the joints as rigid and resists the external load by frame action. A semi rigid frame is a type of frame having all the joints as semi rigid and resists the external load by truss or combined (truss and frame) action. In hybrid frame, all the joints other than external are considered as semi rigid which are expected to contribute to the better post earthquake performance and external joints are considered as rigid which are expected to fulfill the need for higher initial stiffness and better pre earthquake performance. A typical G+7 storey frame with rigid, semi rigid and hybrid joints is shown in Fig. 1. The semi rigid joints are indicated by a dot near the joint. Thus, it can be seen that in a hybrid frame, the combination of a rigid and a semi rigid frame is considered. The rigidity of only beam elements is varied in all the models whereas the column to column connection is considered as rigid.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

III. GEOMETRIC PROPERTIES AND LOADS CONSIDERED

A 3m x 3m panel model giving an overall plan dimensions as 6m x 6m is considered with storey height as 3m and the columns are extended up to foundation level which is assumed to be 3m below the ground level. Five different models comprising of G+3 to G+7 storey buildings are considered for the analysis. The size of beam is considered as 230 x 450 mm for all floors. Columns are considered of 230 x 450 mm size when considering rectangular columns and of 322 x 322 mm for equivalent square sections.

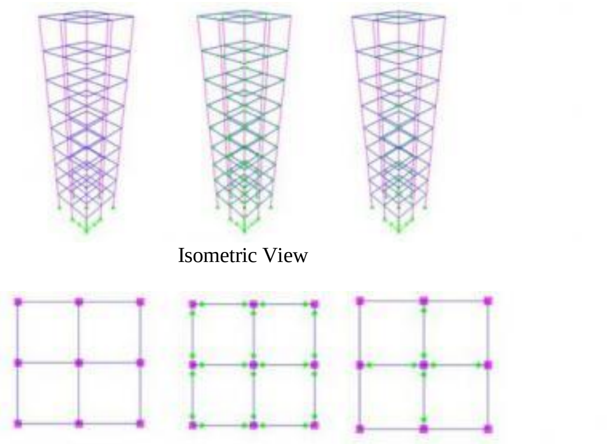

Fig. 1. Views Definig the types of Frames Considered

The column sizes between ground level and foundation level are increased by 50mm in columns in both lateral directions. Thus, for a typical rigid frame, five models with G+3 to G+ 7 storeys are considered with rectangular columns and five models with equivalent square columns. Similarly, ten models for semi rigid frames and ten models with hybrid frames are considered. Again, within each category of semi rigid and hybrid frames, the models are considered having four different variations in joint stiffness as 0, 7500, 100000 and 290000 kNm/rad. Thus, in all there are 90 models which are analyzed, 40 for hybrid frames, 40 for semi rigid frames and 10 for rigid frames. Concrete of grade M25 and reinforcing steel of grade Fe 415 is assumed. A uniformly distributed load of 5 kN/m^2 is considered as dead load on all typical floors with a live load of 2 kN/m^2. On the terrace floor, the dead load of 6 kN/m^2 and a live load of 2 kN/m^2 is considered. A uniform load of 13 kN/m is considered on all perimeter beams of typical floors to account for 230 thick brick wall and the same is considered as 6 kN/m on terrace floor for parapet wall. The earthquake loads are generated as per IS 1893, 2002 [1] considering the mass contribution as 100% from dead load and 25% from live load.

IV. PARAMETERS FOR PUSHOVER ANALYSIS

The mathematical models developed are subjected to push over analysis as per ATC 40 [6] provisions using ETABS software. Default plastic hinges of four types are available in the software. Out of them, P-M-M types of hinges are defined at 5% and 95% of the span for all beam and column elements. Moreover, flexural plastic hinges M3 are defined at the mid span of all beams to capture the possible development of stresses beyond yield point due to gravity loads. The static analysis is carried out under dead, live and earthquake load cases. The members of the frame are designed for standard load combinations as specified in IS 456, 2000 [7] and IS 1893, 2002 [1].

There are three push over cases specified for each model. The first case is PUSH1 which is the push given in the gravity direction up to the full magnitude of dead load and 50% of live load, applied in an incremental manner. Next, the two lateral pushes i.e. PUSH2 in the lateral X direction and PUSH3 in the lateral Y direction are applied to the structure in a step wise manner. The two lateral pushes are displacement controlled in which a designated roof level node is monitored up to the target displacement of 0.04 times the height of the building. The other parameters considered are P-delta effects for incorporating the geometric non linearity. These effects start governing especially when a few plastic hinges are fully developed and they deform the structure considerably. The storey drift at performance point is taken as output to plot the drift parameter as an indicator of the seismic performance of a particular frame.

V. RESULTS OF THE ANALYSIS

The storey drifts obtained at performance point for G+3 to G+7 structures having all joints as rigid are presented in Table I for frames with square and rectangular shaped columns. The comparison is presented for push given in the X direction only which is the weak direction for rectangular columns. The percentage difference between drift value for square and rectangular columns at each storey level is presented in Table II.

From Table II indicating percentage difference in drift values at different storey level between square and equivalent rectangular shaped columns, it is seen that this ratio is minimum for G+5 structure. Hence, further detailed investigations on the variation in storey drift at performance point due to push over analysis is carried out on G+5 structure. It may be noted here that for hybrid and semi rigid frames with joint stiffness as 290000 kNm/rad, the frames behave just like a fully rigid frame. Hence, the drift results are tabulated only for joint rigidity of 100000, 7500 and 0 kNm/rad for hybrid and semi rigid frames with square and rectangular columns. These values of drift under lateral push in X direction at performance point are presented in Table 3. All

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

TABLE I. STOREY DRIFT IN M AT PERFORMANCE POINT FOR FRAMES UNDER PUSHX

Storey	G+3		G+4		G+5		G+6		G+7	
	Square	Rect	Square	Rect	Square	Rect	Square	Rect	Square	Rect
8									0.0027	0.0040
7							0.0026	0.0034	0.0043	0.0066
6					0.0025	0.0028	0.0043	0.0059	0.0056	0.0089
5			0.0027	0.0036	0.0043	0.0049	0.0056	0.0079	0.0066	0.0104
4	0.0026	0.0037	0.0047	0.0065	0.0057	0.0065	0.0065	0.0092	0.0071	0.0115
3	0.0046	0.0067	0.0061	0.0085	0.0065	0.0075	0.0071	0.0100	0.0075	0.0122
2	0.0061	0.0090	0.0071	0.0101	0.0072	0.0084	0.0076	0.0108	0.0078	0.0130
1	0.0094	0.0163	0.0108	0.0172	0.0108	0.0133	0.0110	0.0182	0.0102	0.0198

TABLE II. PERCENTAGE DIFFERENCE IN STOREY DRIFT BETWEEN SQUARE AND RECTANGULAR COLUMNS

Storey	G+3	G+4	G+5	G+6	G+7
8					30.9
7				23.1	35.3
6			7.9	27.7	36.4
5		24.5	12.2	28.4	37.2
4	29.3	27.3	13.0	28.8	38.1
3	31.3	28.5	13.3	29.4	39.0
2	32.8	29.5	13.4	30.2	40.1
1	42.2	37.0	18.9	39.4	48.5

TABLE III. STOREY DRIFT IN M AT PERFORMANCE POINT FOR G+5 FRAME UNDER PUSH X FOR VARIOUS TYPE OF FRAMES

Type of Column	Storey	Fully Rigid	Hybrid Frame			Semi rigid Frame		
			100000	7500	0	100000	7500	0
Square	6	0.0025	0.0026	0.0026	0.0025	0.0025	0.0041	0.0056
	5	0.0043	0.0044	0.0044	0.0045	0.0042	0.0066	0.0088
	4	0.0057	0.0057	0.0058	0.0059	0.0055	0.0087	0.0117
	3	0.0065	0.0066	0.0068	0.0069	0.0064	0.0103	0.0142
	2	0.0072	0.0073	0.0085	0.0087	0.0072	0.0118	0.0168
	1	0.0108	0.0109	0.0130	0.0135	0.0120	0.0160	0.0223
Rectangular	6	0.0028	0.0028	0.0030	0.0031	0.0030	0.0043	0.0056
	5	0.0049	0.0049	0.0054	0.0057	0.0053	0.0074	0.0095
	4	0.0065	0.0066	0.0072	0.0075	0.0070	0.0099	0.0129
	3	0.0075	0.0076	0.0084	0.0087	0.0081	0.0117	0.0154
	2	0.0084	0.0084	0.0093	0.0097	0.0090	0.0132	0.0181
	1	0.0133	0.0133	0.0135	0.0147	0.0141	0.0175	0.0244

TABLE IV. PERCENTAGE DIFFERENCE IN DRIFT FOR A G+5 FRAME COMPARED TO FULLY RIGID FRAMES

Type of Column	Storey	Hybrid Frame			Semi rigid Frame		
		100000	7500	0	100000	7500	0
Square	**6**	0.4	0.8	0.0	-0.7	37.4	54.2
	5	0.9	2.8	3.3	-2.6	34.6	50.9
	4	1.0	2.3	3.1	-2.7	34.8	51.6
	3	1.3	3.7	4.8	-2.3	36.4	53.8
	2	1.3	14.6	16.6	-0.3	38.5	56.9
	1	0.3	17.0	19.9	9.8	32.5	51.4
Rectangular	**6**	-0.1	7.4	10.2	6.6	35.4	50.5
	5	0.3	9.7	13.4	6.5	33.6	48.4
	4	0.4	9.5	13.3	7.0	34.0	49.3
	3	0.6	9.8	13.7	7.4	35.4	51.1
	2	0.6	9.7	14.2	7.6	36.6	53.8
	1	-0.6	1.3	9.2	5.1	23.9	45.4

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

the results obtained from 7 mathematical models for G+5 storey with square columns and 7 models for rectangular columns are presented in Fig. 2.

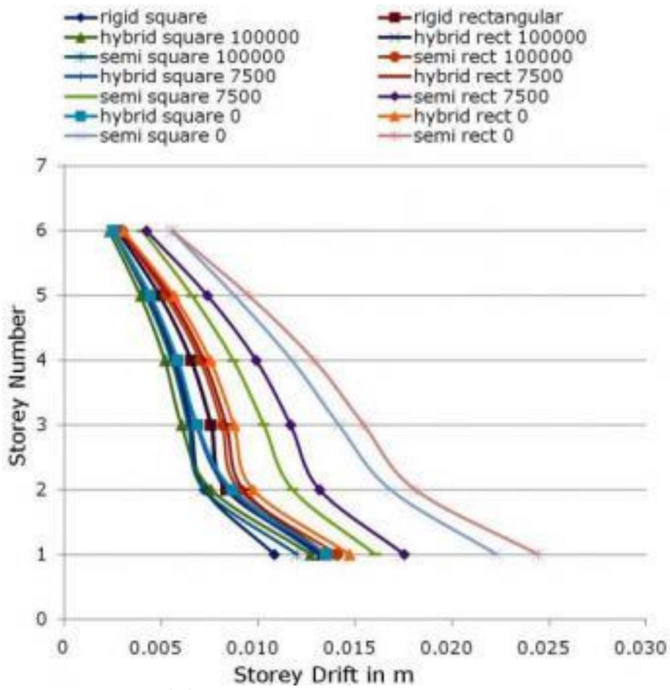

Fig. 2. Drift for G+5 Storey Frame with Square and Rectangular Columns

To study the effect of column shape (square and rectangular), joint stiffness (100000, 7500 and 0 kNm/rad) and type of frame (rigid, hybrid and semi rigid) on the storey drift values, three more plots are included based on the available data. Thus, Fig. 3 plots the storey drift for G+5 buildings having square columns only with all variations in rigidities for hybrid and semi rigid cases.

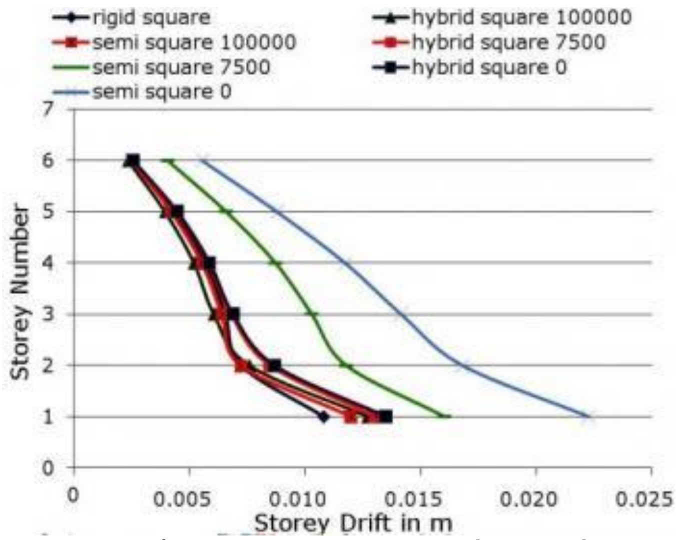

Fig. 3. Drift Variation in G+5 Storey Frame with Square Columns

Fig. 4 presents the drift values for G+5 frames with rectangular columns with all cases of joint rigidities for hybrid and semi rigid type. To study the effect of type of frame along with the shape of columns on the storey drift, the cases of fully rigid joints at one extreme is plotted against a rigidity of 0 kNm/rad (representing a hinge end) at the other extreme. These plots are shown in Fig. 5 for rigid, hybrid and semi rigid type of frames. The percentage difference in the drift value at each storey is presented in Table 4 for G+5 storey frame.

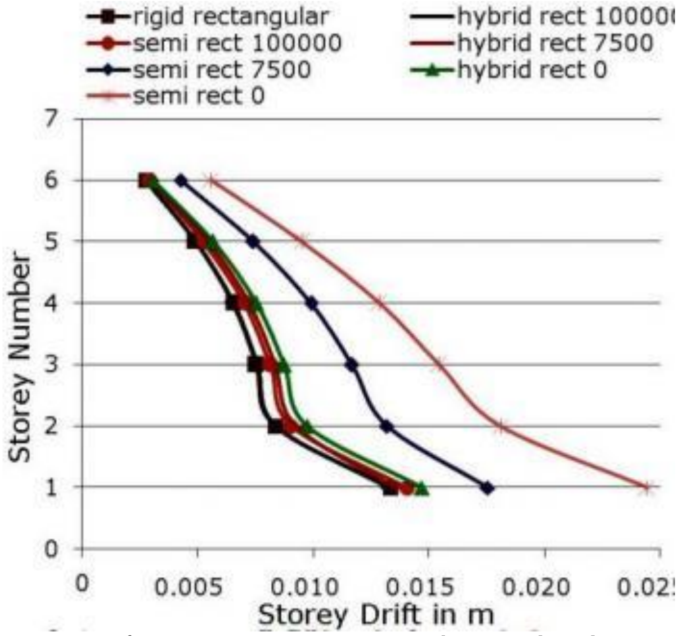

Fig. 4. Drift Variation in G+5 Storey Frame with Rectangular Columns

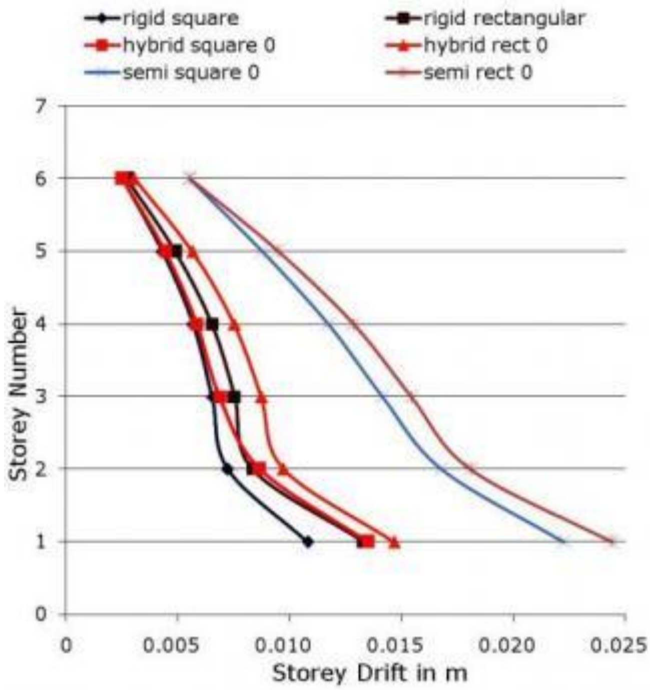

Fig. 5. Drift Variation in G+5 Storey Frame with Square and Rectangular Columns

VI. CRITICAL OBSERVATIONS

1. It is clear from Table I that the storey drift is maximum at the first storey level in all the frames for both square and rectangular columns for G+3 to G+7 storey space frames. Thus, from seismic performance point of view, the first storey is the most critical one.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 05, May-2016

2. Table I also indicate that the drift is less for models with square shaped columns as compared to rectangular shaped columns for G+3 storey frame to G+7 storey frames.

3. Table II shows that the percentage difference in the drift value observed between square and rectangular columns is as high as 48.5% at first storey level for G+7 storey frame and it is as low as 7.9% for the terrace storey of G+5 storey frame.

4. It is also observed from Table II that the percentage difference in the drift is minimum for G+5 storey frames when subjected to a lateral push. The percentage difference in drift between square and rectangular columns for 6m x 6m frames increases as number of storey increases or decreases from G+5 storey.

5. Fig. 2 and Table III indicates that the drift values at performance point for G+5 frame under push in the lateral X direction is the maximum for rectangular columns with all beam to column joints released and it is minimum for frame with square columns with full rigidity.

6. It is also observed from Fig. 2 that the performance of hybrid frame with square columns having all internal beam to column connections as released is better than the same frame with rectangular columns with fully rigid joints as far as the storey drift is concerned. From the same graph it is also seen that the storey drift for square as well as rectangular columns is relatively high for semi rigid frames with low rigidity. This fact is also supported by the high values of percentage difference in drift with reference to fully rigid frames shown in the last two columns of Table IV.

7. Comparison of plots given in Fig. 3 for G+5 storey frame with square columns shows that the drift values for joint rigidity below 100000 kNm/rad for semi rigid frames is quite high and should be avoided. The drift performance of square columns is almost unaffected by the joint rigidity in hybrid frames.

8. Fig. 4 shows identical behavior in case of rectangular columns for G+5 storey frame. Thus, the column shape does not help in reducing the storey drift for low joint rigidity. Thus, hybrid frames with any joint rigidity is showing almost similar drift.

9. The storey drift for square columns with hybrid frames having 0 kNm/rad joint rigidity is less than that for rectangular columns with fully rigid joints. This fact is evident from Fig. 5 which shows the superiority of hybrid frames. At the same time it is also observed that semi rigid frames with low rigidity show excessive drifts regardless of their cross sectional shape.

VII. CONCLUSIONS

For low rise frames having G+3 to G+7 storey, the seismic performance of a frame with square columns is found better than that having rectangular columns from the storey drift criterion. Also, the storey drift is found maximum at the first storey level regardless of the size, column shape or the joint rigidity for G+3 to G+7 storey frames.

It is clear from the present study that the hybrid frames show less drift as compared to semi rigid frames keeping all other parameters the same. Also, there is a negligible difference in storey drift when hybrid frames with a joint rigidity of 100000 kNm/rad is considered for G+5 storey frame having either square or rectangular shaped columns.

REFERENCES

[1] IS 1893: 2002, Indian Standard Criteria for Earthquake Resistant Design of Structures, Part 1: General Provisions and Buildings, Bureau of Indian Standards, New Delhi, 2002.
[2] Joshi M. K., Murty C. V. R. and Jaisingh M. P.: "Cyclic Behaviour of Precast RC Connections", The Indian Concrete Journal, Vol. 79, No. 11, pp 43 – 50, Nov. 2005.
[3] Uma S. R. and Jain S. K.: "Seismic Design of Beam-Column Joints in RC Moment Resisting Frames – Review of Codes", Journal of Structural Engineering and Mechanics, Vol. 23, No. 5, pp 579-597, 2006.
[4] Shah B. A., Patodi S. C. and Shah N. J. : "Effect of Semi Rigid Joints on Seismic Performance of RC Framed Structures", 1st European Conference on Earthquake Engineering and Seismology, ECEES, Geneva, Switzerland, pp 189-190, Sep. 2006.
[5] Shah B. A., Rana P. and Patodi S. C. : "Seismic Evaluation of Building Frames with Semi Rigid Joints using Push Over Analysis", National Conference on Current Trends in Technology NUCONE 2007, Nirma University, Ahemdabad, pp 411- 416, Nov. 2007.
[6] ATC-40, "Seismic Evaluation and Retrofit of Concrete Buildings", Volume 1 and 2, Report No. SSC 96-01, Seismic Safety Commission, Redwood City, CA, 1996.
[7] IS 456: 2000, Indian Standard Code of Practice for Plain and Reinforced Concrete, Bureau of Indian Standards, New Delhi, 2000.