Seismic Response of R.C.C. Framed Buildings with Different Brace Patterns

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Abstract: *Framed structures combined with Braces have been widely used for lateral load resistance in tall buildings. Braces are generally provided for full height of the frames and can be provided in various patterns. Each pattern of braces has an independent effect on the seismic response of reinforced concrete frames. This concept has been extended to symmetrical reinforced cement concrete special moment resisting frames (SMRF) by providing K, X, Diagonal, chevron and mega types of braces. Efforts have been made to find out the effects of different kinds of braces on lateral load resistivity of the structure under dynamic earth-quake shaking. 3-D models of SMRF with braces have been dynamically analyzed. The comparative study has revealed that Mega Braces can preferably be provided to considerably enhance the lateral strength of SMRF.*

Key Words : *Mega Braces , Chevron Braces, SMRF, CQC, Shear force.*

1. INTRODUCTION

Special moment resisting frames with braces are the principal structural systems used in RCC buildings to resist earthquake forces. Special moment resisting frames (SMRF) are moment resisting frames specially detailed to provide ductile behaviour and comply with requirements of latest IS codes [8] [9]. ACI committee 442 [1] considered in 1971 that SMRFs are generally efficient upto 10 to 15 storeys only. Taller moment resisting frames are undesirable for earthquake resistance as large inter-storey displacements can cause severe damage to the frames.

The most effective and practical method of enhancing the seismic resistance is to increase the energy absorption capacity of structures by combining bracing elements in the frame. The braced frame can absorb a greater degree of energy exerted by earthquake. A braced frame attempts to improve upon the efficiency of pure rigid frame action by virtually eliminating the column and girder bending moment. Kapur and Jain [10] reported that there was some advantage in using reinforced concrete braced frame over shear wall frame. Khaloo A R et al [11] studied nonlinear response of braced reinforced concrete frames and concluded that braces raise lateral stiffness and dissipate considerable amount of energy during earthquake loading. The shear is primarily absorbed by the diagonal braces as axial load, thereby creating an efficient structural system.

Desai et al [5] studied the inelastic seismic response of reinforced concrete frames with concrete bracing members arranged in X and K patterns. They observed that the concept of using bracing members of inter mediate slenderness ratio of the order of 80 in reinforced concrete frames was promising. The behaviour of braced concrete frames is different from the behaviour of braced steel frames. Maheri and Sahebi [13] investigated use of steel bracing in concrete-framed structures and found that a substantial increase in the shear resisting capacity of concrete frames could be achieved using diagonal steel X-bracing. The manner in which the braces failed indicated the importance of the connection between the brace and frame, as weak connections do not allow the full capacity of the braces to be utilized. Alberto et al [2] studied the behavior of low to medium rise ductile moment-resisting reinforced concrete concentric braced frame structures using chevron steel bracing. If a strong-column, weak-beam, weaker-brace collapse mechanism is prescribed, it was found that the capacity design methodology used by the authors was successful in the design of low and medium rise ductile RC-MRCBFs when the columns of the moment frames resist at least 50% of the total seismic shear force. Hajirasouliha and Doostan [7] conducted non-linear dynamic analysis on 5, 10 and 15 storey concentrically braced frames and proposed a simplified analytical model for seismic response prediction. It was shown that the modified shear-building model was not sensitive to the ground motion intensity and maximum story ductility and therefore, could be utilized to estimate the seismic response of concentrically braced frames from elastic to highly inelastic range of behaviour.

Popov and Engelhardt [14] studied the behaviour of seismic-resistant Eccentrically Braced Frames

(EBFs), with particular emphasis on the behavior and design of shear links. They provided additional useful rules for improving upon the basic code-based design procedures. Georgescu et al [6] examined the post-critical behaviour of the bracing bar of the 'K' braced frame, as well as of the entire structure. It was observed that 'K' shaped braced steel frames possessed a certain capacity to dissipate energy under seismic loading which may be appreciated. Xu and Niu [16] studied experimentally the behavior of RC frames with different bracings, an RC frame and RC frame with shear wall. It was observed that a high degree of rigidity and energy dissipation mechanism was secured in braced frames, so braced frames have better sesmic performance. Youssef et al [17] evaluated experimentally the efficiency of braced RC frames. They concluded that braced frames resisted higher lateral load than the moment frame and the brace member and their connections can be designed using a similar procedure to that for braces in steel structures. Bosco and Rossi [3] discussed the distribution of damage distribution capacity factor in eccentrically braced structures. An analytical relation between over strength factor of links, damage distribution capacity factor and plastic rotation of links was defined to obtain quantitative evaluation of structural damage upon first failure of links.

Sarno and Elnashai [15] studied the seismic performance of steel moment resisting frames retrofitted with different bracing systems i.e. concentric braces, buckling-restrained braces and mega braces. Mega braces performed better than other types of braces. Maheri et al [12] conducted pushover experiments on scaled models of ductile RC frames braced by direct steel X braces and knee-braces. It was found that X braces provided stiffer system but reduced ductility of frame while knee-braces provided desired ductility level. Desai [4] studied the behavior of concrete braced frames under cyclic loading and found that X and K braces performed satisfactorily, very strong braces cause buckling of columns, very slender braces cause excessive floor displacements and braces result in considerable increase in axial forces in the columns.

2. OBJECTIVE OF THE STUDY

The structure should have adequate lateral strength, lateral stiffness and sufficient ductility to meet the requirements of safety and minimum damage to non-structural elements, on occurrence of an earthquake. Among the various structural systems, RC Braced concrete frame could be a point of choice for designer. It is common in high rise structures to provide braces, preferably in the outer frames of the building, for increasing its lateral load resistivity. The objective of this study is to compare the seismic response of SMRF and reinforced concrete frames with various patterns of reinforced concrete braces.

3. PARAMETRIC DETAILS OF MODELS

12, 15 and 18 storeyed regular buildings consisting of symmetrical reinforced concrete frames with different arrangements of braces are assumed to be located in seismic zone IV. The braces have been provided in the outermost frames of the buildings. Depending upon the pattern of braces, various models of the building have been designated as shown in Table-1. The dynamic analysis has been carried out as per provisions of the IS Code 1893 (Part-I) 2002 [8] using three dimensional modeling in STAAD-Pro software. These models consist of 7 bays of 5 m each in global X- direction (7 x 5 = 35 m) and 3 bays of 5 m each in global Z-direction (3 x 5 = 15 m). The height of each storey of the buildings is 3 m. Size of the columns taken is shown in Table-2. All beams and braces are of 0.35 x 0.60 m section. The columns are assumed to be fixed at base. The effect of infill walls in resisting the earthquake forces has been ignored. The plan of the buildings is shown in the Fig 1 and the side elevation for different brace patterns adopted i.e. X, K, Diagonal, Chevron and Mega, is shown in Fig 2.

Table-1 : Building models studied

Designation of Building	Main Features of Building
12, 15, 18-Base	12, 15, 18 storey SMRF
12, 15, 18-BX	SMRF with X-Braces
12, 15, 18-BD	SMRF with Diagonal Braces
12, 15, 18-BK	SMRF with K- Braces
12, 15, 18-BM	SMRF with Mega Braces
12, 15, 18-BC	SMRF with Chevron Braces

Table-2 : Size of columns

Frame	Storey level	Column size (mm)
12-Storey	1 to 5	700 X 700
	6 to 12	550 X 550
15-Storey	1 to 5	700 X 700
	6 to 10	550 X 550
	11 to 15	400 X 400
18-Storey	1 to 7	750 X 750
	8 to 14	600 X 600
	15 to 18	450 X 450

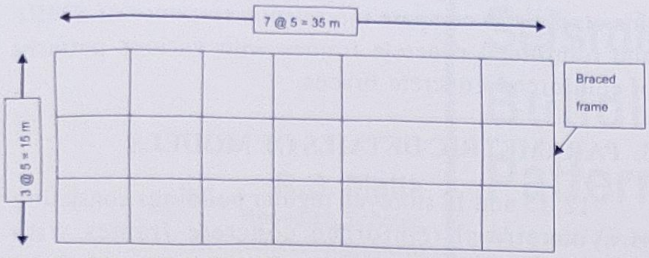


Fig. 1 : Plan of the building

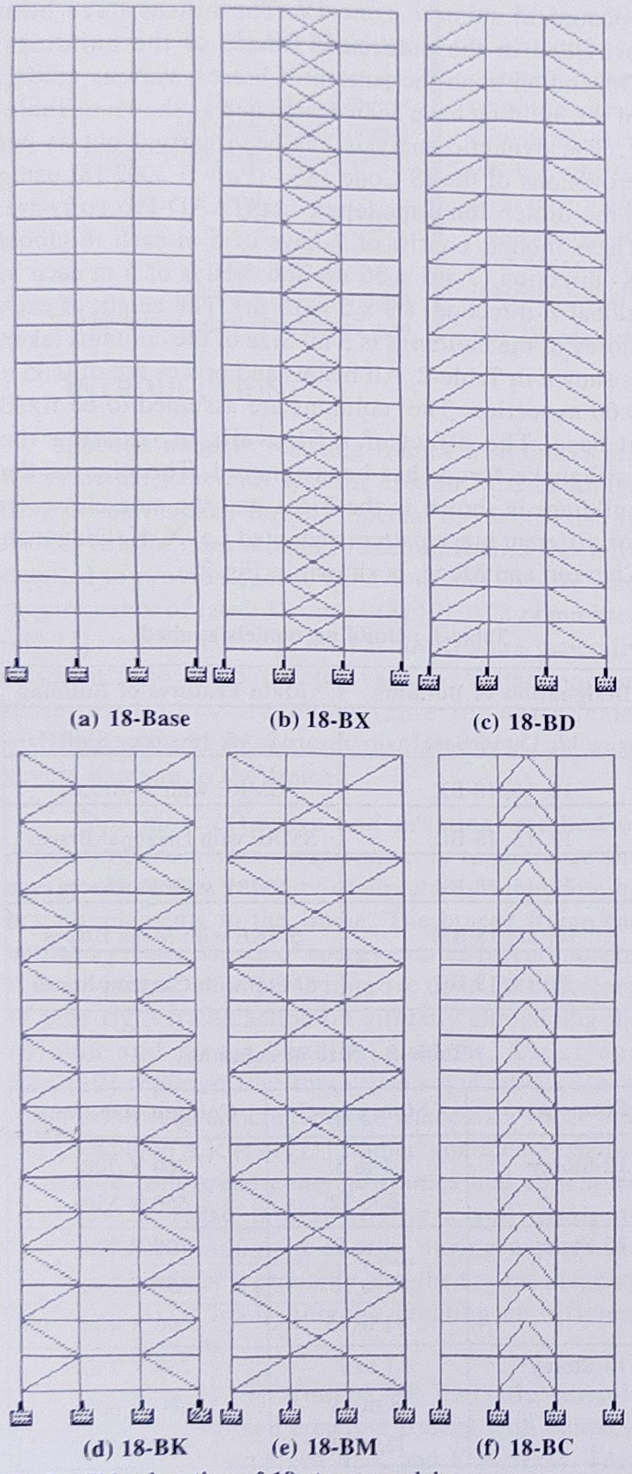


Fig 2 : Side elevation of 18 storey models

4. METHOD OF ANALYSIS

The analysis of the buildings has been done using three-dimensional modeling in STAAD-Pro. and as per IS -1893: 2002 (Part-I). X- RC braces are used with a node at the intersection. Floors are assumed to act as rigid diaphragms. For distribution of earthquake forces, the contribution of six interior frames without braces has been grouped together and remaining forces are assumed to be taken by the two exterior frames with braces. Related factors taken are; Zone factor 0.24, Response reduction factor 5, Importance factor 1.5, Structure type-concrete, Damping 0.05 and Foundation Soil type as medium. Dead load intensity at all floor levels is taken as 6 kN/m^2 and live load as 3 kN/m^2 for floors and 1.5 kN/m^2 for roof. For calculation of seismic weight no live load is considered at roof level.

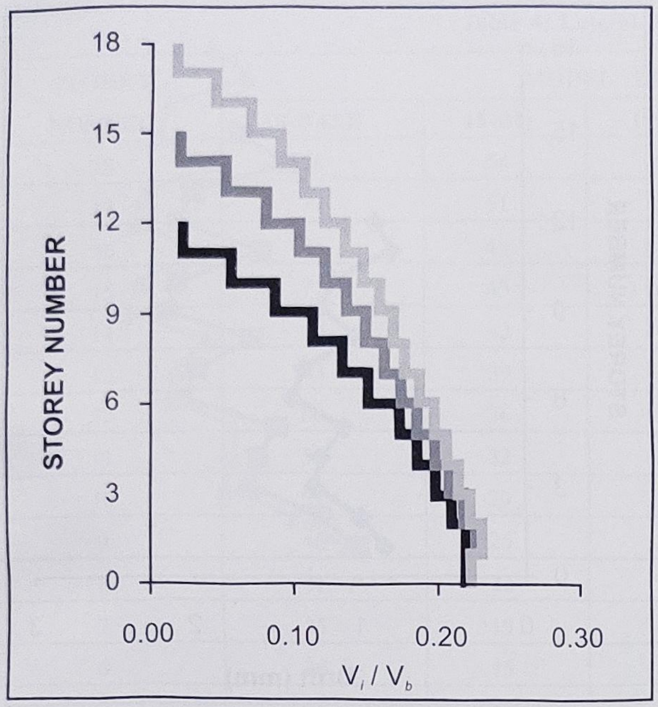
5. DISCUSSION ON RESULTS

The results of the analysis are presented in Tables 3-8 and Figs. 3-5.

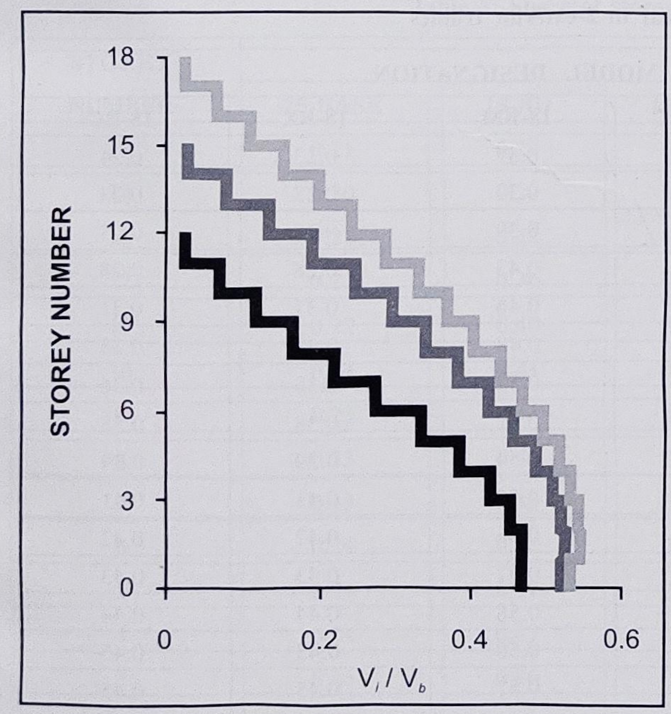
1. **Storey Shear:-** The 2-exterior frames with braces bear 43-53% of base shear (Vb) in all the models studied for 18-storey building, 43-52% for 15-storey building and 39-47% for 12-storey building. The stiffening effect of braces is apparent from the comparison of base and storey shear taken by base models with other braced frames (Tables-3, 5 and 7). The contribution of 2-exterior un-braced frames in base model ranges between 19 to 24 % only at various levels. The mega braces (BM models) attract the maximum storey shear (Vi) through out the height of frames. In the top storey it is 37, 36 and 28% respectively for 18,15 and 10 storey buildings, while 6-interior frames take the remaining shear. It is observed that the contribution of braces is reduced with the reduction in frame height. This has also been compared graphically in Fig. 3.

2. **Lateral Displacement:-** For BM models, the lateral displacement in the braced frames at the top storey levels decreases by 55.1, 62.3 and 70.5 percent for 18, 15 and 12 storeys respectively, when compared with base models (Tables-4, 6 and 8). The stiffening effect of braces on the lateral displacement is also evident as a decrease in displacement at other storey levels. Every configuration of braces has a reducing effect on lateral displacement. The un-braced and mega braced frames have also been compared in Fig. 4.

3. **Inter-storey Drift:-** Inter-storey drift at each storey level is worked out and the values for each

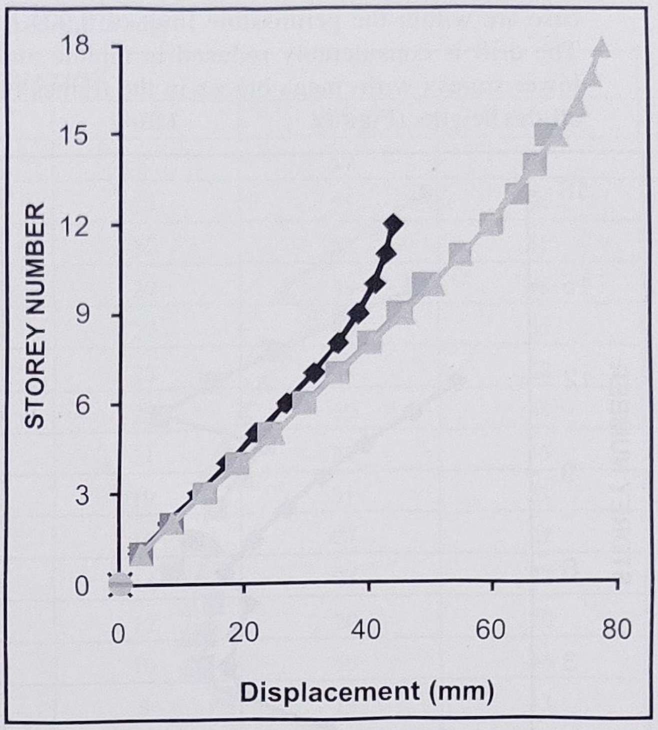


(a) Base models

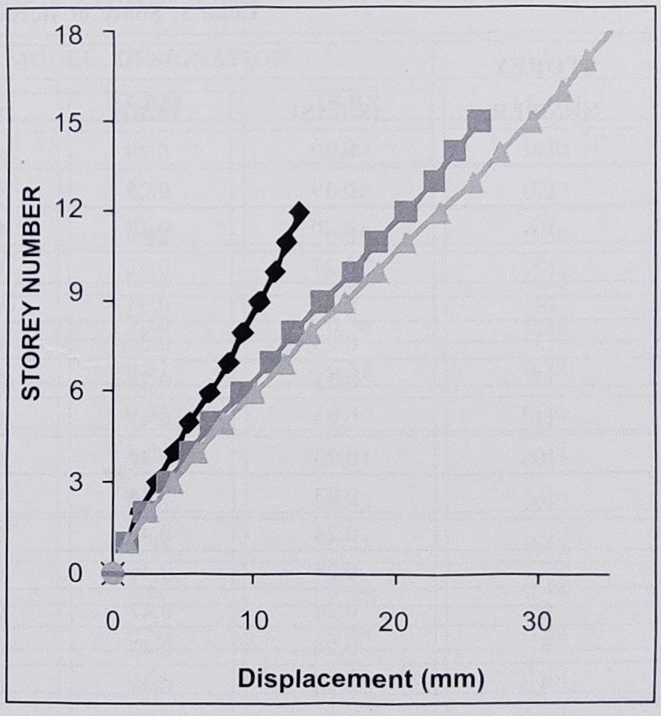


(b) BM models

Fig 3: Contribution of 2-Exterior Frames to Total Storey Shear



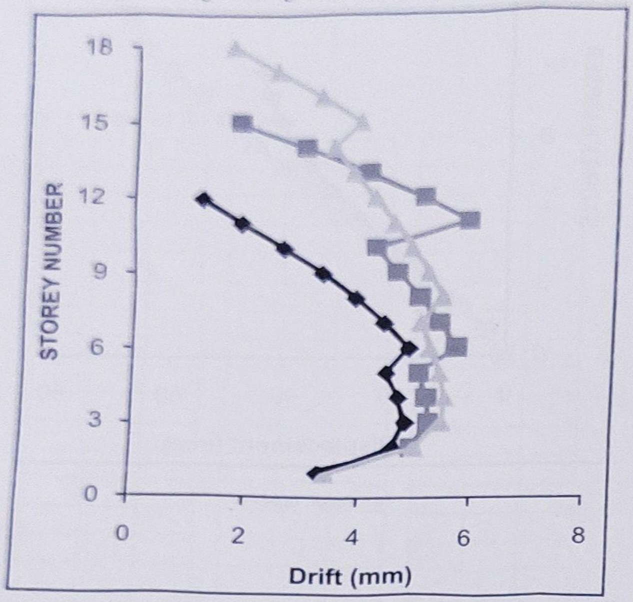
(a) Base models



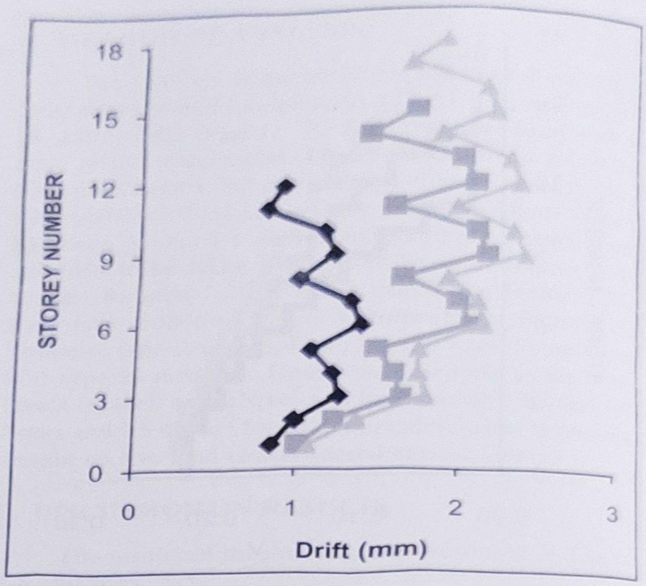
(b) BM models

Fig 4: Lateral displacements of frames

case are within the permissible limit of 0.004 h. The drift is considerably reduced in middle and lower storeys with mega braces in the frames of all the heights (Fig. 5).



(a) Base models



(b) BM models

Fig 5: Inter-storey drift of frames

Table 3: Share of storey shear in 2-exterior frames

STOREY NUMBER	MODEL DESIGNATION					
	18-BASE	18-BD	18-BK	18-BM	18-BX	18-BC
18	0.20	0.23	0.23	0.37	0.23	0.24
17	0.19	0.25	0.26	0.37	0.23	0.23
16	0.20	0.27	0.28	0.39	0.25	0.25
15	0.21	0.31	0.31	0.43	0.28	0.28
14	0.22	0.34	0.34	0.46	0.31	0.31
13	0.23	0.36	0.36	0.48	0.33	0.33
12	0.23	0.38	0.39	0.50	0.36	0.36
11	0.23	0.41	0.41	0.52	0.38	0.38
10	0.23	0.42	0.43	0.54	0.39	0.39
9	0.23	0.44	0.44	0.55	0.41	0.41
8	0.24	0.45	0.46	0.56	0.42	0.42
7	0.24	0.46	0.47	0.57	0.43	0.43
6	0.24	0.47	0.48	0.58	0.44	0.44
5	0.24	0.47	0.48	0.58	0.45	0.45
4	0.24	0.47	0.48	0.57	0.45	0.45
3	0.24	0.47	0.48	0.56	0.45	0.45
2	0.23	0.46	0.47	0.55	0.45	0.44
1	0.22	0.45	0.46	0.53	0.43	0.43

Table 4: Lateral displacement in mm

STOREY NUMBER	MODEL DESIGNATION					
	18-BASE	18-BD	18-BK	18-BM	18-BX	18-BC
18	78	54	53	35	57	57
17	77	51	50	33	55	54
16	74	48	47	32	52	51
15	71	45	44	29	49	48
14	67	42	41	27	46	45
13	63	39	38	25	42	42
12	60	36	34	23	39	38
11	55	32	31	21	35	35
10	51	29	28	19	31	31
9	46	25	24	16	27	27
8	41	22	21	14	23	23
7	35	19	17	12	20	20
6	30	15	14	10	16	16
5	25	12	11	8	13	13
4	19	9	8	6	9	9
3	14	6	5	4	6	6
2	8	4	3	2	4	4
1	3	2	1	1	2	2

Table 5: Share of storey shear in 2-exterior frames

STOREY NUMBER	MODEL DESIGNATION					
	15-BASE	15-BD	15-BK	15-BM	15-BX	15-BC
15	0.21	0.27	0.26	0.36	0.25	0.26
14	0.20	0.29	0.29	0.39	0.26	0.27
13	0.21	0.32	0.33	0.42	0.30	0.30
12	0.22	0.36	0.36	0.46	0.33	0.33
11	0.22	0.40	0.39	0.50	0.36	0.36
10	0.23	0.41	0.42	0.51	0.38	0.38
9	0.23	0.43	0.43	0.53	0.40	0.40
8	0.23	0.44	0.45	0.54	0.41	0.41
7	0.23	0.45	0.46	0.55	0.42	0.43
6	0.24	0.46	0.47	0.55	0.43	0.43
5	0.24	0.47	0.48	0.56	0.44	0.44
4	0.24	0.47	0.48	0.56	0.45	0.45
3	0.23	0.46	0.48	0.54	0.44	0.44
2	0.23	0.46	0.47	0.53	0.44	0.44
1	0.22	0.45	0.46	0.52	0.43	0.43

Table 6: Lateral displacement in mm

STOREY NUMBER	MODEL DESIGNATION					
	15-BASE	15-BD	15-BK	15-BM	15-BX	15-BC
15	69	42	41	26	46	45
14	67	39	39	24	43	43
13	64	37	36	23	40	40
12	60	34	33	21	37	37
11	55	31	29	19	34	33
10	49	27	26	17	30	30
9	45	24	23	15	26	26
8	40	21	20	13	23	23
7	35	18	16	11	19	19
6	30	14	13	9	15	15
5	24	11	10	7	12	12
4	19	9	8	6	9	9
3	14	6	5	4	6	6
2	8	4	3	2	4	4
1	4	2	1	1	1	2

Table 7: Share of storey shear in 2-exterior frames

STOREY NUMBER	MODEL DESIGNATION					
	12-BASE	12-BD	12-BK	12-BM	12-BX	12-BC
12	0.21	0.26	0.26	0.28	0.26	0.26
11	0.19	0.28	0.28	0.31	0.26	0.26
10	0.20	0.29	0.30	0.33	0.28	0.28
9	0.21	0.32	0.33	0.36	0.30	0.30
8	0.22	0.35	0.36	0.40	0.34	0.33
7	0.22	0.39	0.40	0.44	0.38	0.37
6	0.23	0.42	0.42	0.47	0.40	0.40
5	0.23	0.43	0.44	0.49	0.41	0.41
4	0.23	0.43	0.44	0.49	0.42	0.41
3	0.23	0.42	0.44	0.49	0.41	0.41
2	0.23	0.41	0.42	0.48	0.40	0.40
1	0.22	0.40	0.41	0.47	0.39	0.39

Table 8: Lateral displacement in mm

STOREY NUMBER	MODEL DESIGNATION					
	12-BASE	12-BD	12-BK	12-BM	12-BX	12-BC
12	44	24	23	13	26	26
11	43	22	21	12	25	24
10	41	20	19	12	22	22
9	38	18	17	10	20	20
8	35	16	15	9	18	18
7	31	14	13	8	15	15
6	27	12	11	7	12	12
5	22	9	8	5	10	10
4	17	7	6	4	7	7
3	13	5	4	3	5	5
2	8	3	3	2	3	3
1	3	1	1	1	1	1

6. CONCLUSIONS

Dynamic analysis of eighteen, fifteen and twelve storeyed reinforced concrete frames with different arrangements of concrete braces was carried out based on specific parameters chosen in this study. Following remarks are concluded:-

(i) In the dual system of frames with braces the mega braces increase the lateral stiffness appreciably more than the other types of braces. Diagonal and K arrangement of braces also perform better in sharing the storey shear caused by earthquake loads due to their proximity to the edge columns in this study. The share of braced frames in storey shear is considerably higher in the mega braced models. The contribution of braces is also reduced with the reduction in building height.

(ii) The frames with braces reduce the lateral displacement to a greater extent but mega braces perform further better in preventing excessive damage to nonstructural elements by reducing the displacement of top storey to the extent of 55-70.5% for frames of different heights considered.

(iii) The mega braces are also more effective in controlling inter storey drift throughout the height of the frame, while all other arrangements also decrease the drift in the storeys over the SMRF except the top storey.

REFERENCES

1) ACI committee 442, "Response of Buildings to Lateral forces", Journal of American Concrete Institute, February 1971, Proc. Vol 68 pp 81-106.

2) Alberto E, Dominguez G and Colunga A T, "Nonlinear behavior of code-designed reinforced concrete concentric braced frames under lateral loading", Engineering Structures (2010), doi:10.1016/j.engstruct.2009.12.020

3) Bosco M and Rossi P P, "Seismic behavior of eccentrically braced frames" Engineering Structures 31 (2009) pp 664-674.

4) Desai J P, "Hysterisis behavior of reinforced concrete braces and seismic response of braced frames" PhD Thesis (1986) Roorkee University, Roorkee.

5) Desai J P, Jain A K and Arya A S, "Seismic response of R.C. braced frames", Computers and structures (1988) Vol 29, No. 4, pp557-568.

6) Georgescu D, Toma C and Gosa O, "Post-critical Behaviour of 'K' Braced Frames", J. Construct. Steel Research Vol 21 (1992), pp 115-133

7) Hajirasouliha I and Doostan A, "A simplified model for seismic response prediction of concentrically braced frames", Advances in Engineering Software, Vol 41 (2010), pp 497-505.

8) IS 1893-2002(Part I), "Criteria For Earthquake Resistant Design of Structures", Bureau of Indian Standards New Delhi.

9) IS 13920 : 1993, "Ductile Detailing of Reinforced Concrete Structures subjected to Seismic Forces" Code of Practice, Bureau of Indian Standards New Delhi.

10) Kapur V. And Jain A.K. ''Seismic Response of Shear wall Frames Versus Braced Concrete Frames'', Indian Concrete Journal, April-1983, pp-107-114.

11) Khaloo A R and Mohseni M Mahdi, ''Nonlinear Seismic Behaviour of RC Frames with RC Braces'' Asian Journal of Civil Engineering (Building and Housing) vol. 9, No. 6(2008) pp 577-592.

12) M R Maheri, R Kausari and M Razazan, ''Pushover tests on steel X-braced and knee-braced RC frames'' Engineering Structures 25 (2003) pp 1697-1705.

13) Maheri M R and Sahebi A, ''Use of steel bracing in reinforced concrete frames'', Engineering Structures, (1997) Vol. 19, No. 12, pp. 1018-1024.

14) Popov E P and Engelhardt M D, ''Seismic Eccentrically Braced Frames'', J. Construct. Steel Research, Vol 10 (1988), pp 321-354.

15) Sarno L Di and Elnashai A S, ''Bracing systems for seismic retrofitting of steel frames'' Journal of constructional steel research 65 (2009) pp 452-465.

16) Xu Shan-Hua and Niu Di-Tao, ''Seismic Behaviour of Reinforced Concrete Braced Frame'' ACI structural Journal, Jan-Feb 2003, pp 120-125.

17) Youssef M A, Ghaffarzadeh H and Nehdi M, ''Seismic performance of RC frames with concentric internal steel bracing'' Engineering Structures 29 (2007) pp 1561-1568.