CHAPTER 11

HYBRID CONCEPT EXTENDED TO BIGGER FRAMES

11.1 MATHEMATICAL MODELS DEVELOPED

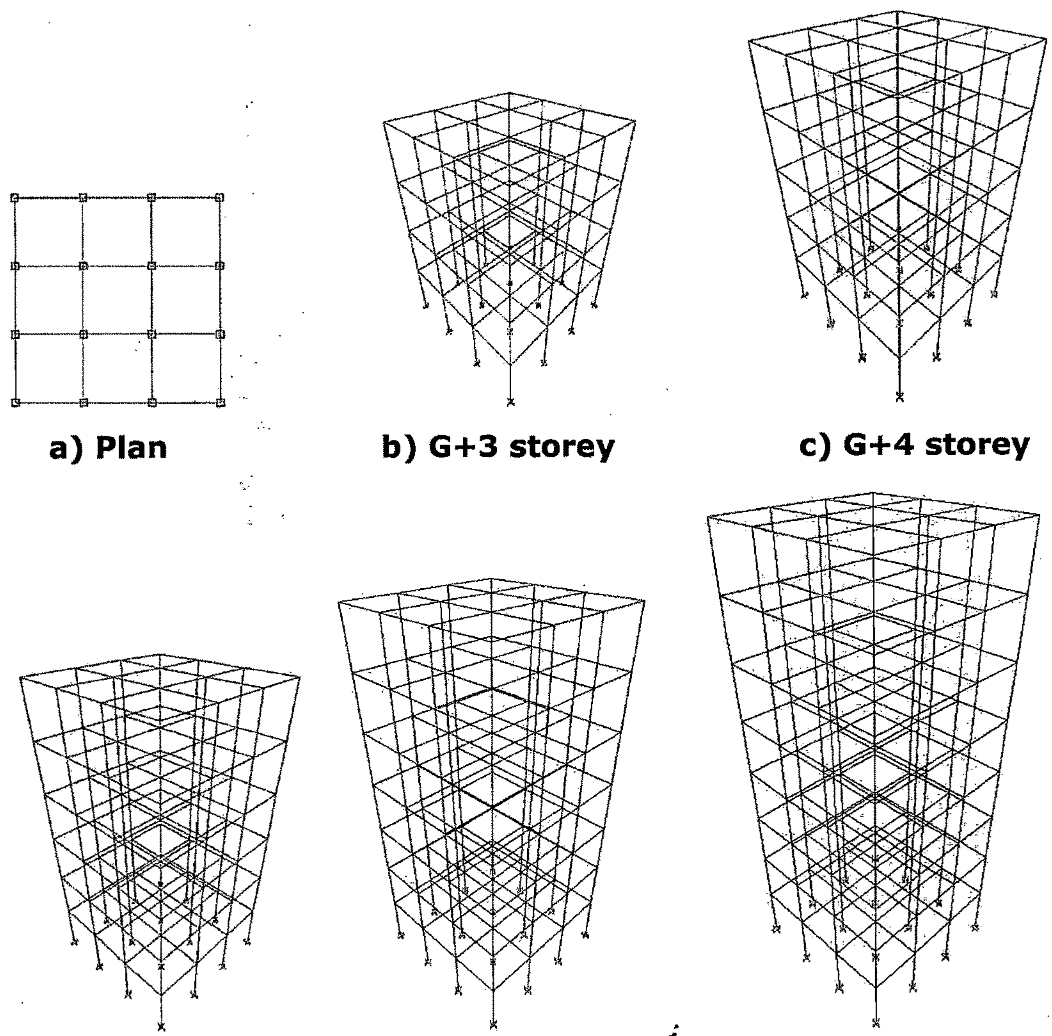
The concept of hybrid frames which was developed in the previous chapter has been extended here to larger sized frames. The main reason for doing this is that the 2 bay frame consisting of four panels in plan was having totally nine columns out of which there is only one column which can be considered as an interior column. The eight columns located on the peripherial frame were rigidly connected to the beam elements. This results in a strong hybrid frame which behaves very similar to a rigid frame.

G+3 storey to G+7 storey RC space frames having 3 bays, 4 bays and 5 bays of 3m x 3m panels in plan with columns at all points of intersection are considered for the analysis. Thus, the overall plan dimensions of the frames considered are 9m x 9m, 12m x 12m and 15m x 15m. For each of the frames, apart from the fully rigid case, hybrid and semi rigid frames with beam end flexural rigidities of 0, 7500, 100000 and 290000 kNm/rad are considered. Thus, 9 models for each frame are considered for the analysis. In all 45 models for each of the plan dimensions are analyzed using ETABS software making a total of 135 models for all the three cases. The properties considered for each models are as follows:

11.1.1 Geometry Considered

1. Overall plan dimensions considered are 9m x 9m, 12m x 12m and 15m x 15m of 3m x 3m panel size. A typical 9m x 9m frame is shown in **Fig. 11.1**.
2. Number of storeys considered are G+3, G+4, G+5, G+6 and G+7.

3. Storey height is 3m for all storey with columns considered as fixed at ground level.
4. All beams are of size 230 mm x 450 mm with a rigid diaphragm at each storey representing the slab.
5. Column size of ground story is considered as 372 mm x 372 mm and that for all stories above it are considered as 322 mm x 322 mm
6. Materials used are concrete of M25 grade and steel of Fe415 grade.



a) Plan **b) G+3 storey** **c) G+4 storey**

d) G+5 storey **e) G+6 storey** **f) G+7 storey**

Fig. 11.1 G+3 to G+7 Storey Frames of Overall Plan 9m x 9m

11.1.2 Loads Considered

For each of the models considered for analysis, the loads are considered as mentioned below:

1) Slab thickness considered = 0.15 m
2) Imposed loads:

   At terrace level = 3 kN/m^2

   On typical floor level = 3 kN/m^2
3) Floor finish load:

   On terrace level = 2 kN/m^2

   On typical floor level = 1.5 kN/m^2
4) Wall load on peripheral beams:

   On terrace level = 6 kN/m for parapet wall

   On typical floor level = 13 kN/m for 230mm thick brick walls.
5) Earthquake loads:

   As per IS 1893 Part 1: 2002 with the following factors,

   Imposed load at each storey = 3 kN/m^2

   Zone factor = 0.16, for Zone III

   Type of soil = Medium

   Importance factor = 1 and

   Response reduction factor = 5.

The earthquake load is program generated with specified time period. The values of equivalent static loads are calculated and scaled for the specified time period for each frame.

11.1.3 Push over Parameters Considered

The Combined Axial and Flexural (PMM) type of default hinges are defined at 5% span length from both ends for all columns and beams and flexural (M3) default hinges are also considered at mid-span of all beams. The flexural hinges at mid span of beams are provided to capture the maximum bending stress developed under gravity loads.

The static analysis is carried out for the given dead, live and earthquake loads. The concrete design of all members is carried out as per IS 456, 2000 for standard 13 load combinations described in IS 1893 Part 1, 2002. There are two push over analysis cases defined for the buildings. **PUSH1** is the case in which the gravity loads are applied stepwise up to their full force magnitude. **PUSH2** is defined as the push in the X direction and it starts from the end of PUSH1. The X-displacement of the roof level node is monitored up to the magnitude of 0.4 percent of the building height and the push is given as per the earthquake force profile in the X direction. Since only square shaped columns are considered for analysis and as the building is also symmetric, only one lateral direction push is required to be applied to get the performance point results. Once the performance point is achieved, the roof level displacement is modified to represent the one obtained at performance point and thus, the results obtained for hinges developed at performance point in specific category can be noted.

The other parameters considered for obtaining the performance point related to defining the push over case are

1. When a hinge drops load, the member unloading method considered is to apply local redistribution to the selected member.
2. Displacement controlled nonlinear static analysis is considered.
3. P-Delta type geometric nonlinearity is considered.
4. To evaluate seismic performance, considered seismic coefficients are C_A = 0.232 and C_V = 0.336 for medium soil and building in seismic zone III as per IS 1893 Part 1, 2002. (**Table 10.2** and **Table 10.4**)

5. Building of type B representing an average structural behavior as per ATC40 is selected for defining the performance point.
6. 5% inherent plus additional damping is selected in the parameters for defining capacity spectrum

11.2 RESULTS OF THE PUSH OVER ANALYSIS

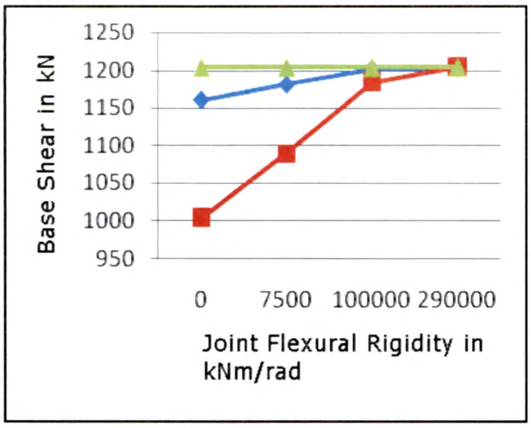
The results obtained by push over analysis for all the 45 models for the 9m x 9m overall plan dimension space frames with G+3 to G+7 storey are presented in **Table 11.1**. The parameters which are noted at performance point include the base shear V in kN and the roof displacement D in mm. The effective time period Teff in seconds and the effective damping in percentage is also reported in the same table. The values of the parameters under study are noted for three types of space frames viz. rigid, hybrid and semi rigid. The values are noted for four variations in the joint rigidity for the hybrid and semi rigid frames – 0, 7500, 100000 and 290000 kNm/rad. These values of rigidities correspond to 0%, 20%, 45% and 100% joint rigidity for the given beam sizes. Thus, the semi rigid and hybrid frame with joint rigidity of 290000 kNm/rad is as good as a rigid frame. The variation in base shear and roof displacement for each of the frames is graphically presented in **Figs. 11.2** and **11.3** respectively. The percentage variation in base shear is compared with that for fully rigid frame for hybrid and semi rigid frames for 45% rigidity (100000 kNm/rad) in **Fig. 11.4** and 0% rigidity in **Fig. 11.5.** The same variation in roof displacement for hybrid and semi rigid frames for 45% rigidity is shown in **Fig. 11.6** and 0% rigidity in **Fig. 11.7**. The hinges developed at performance point in the same set of frames is presented in **Table 11.2**. The corresponding comparison of hinges developed in specific categories at performance point for 45% rigidity and 0% rigidity are presented in **Fig. 11.8** and **Fig. 11.9** respectively.

Table 11.1 Values of Base Shear, Roof Displacement, Time Period and Damping - 9m x 9m Frame

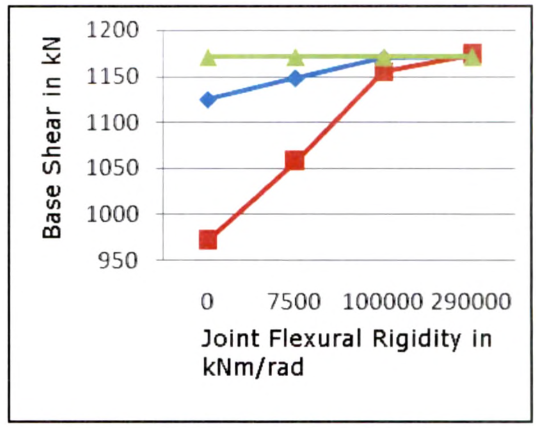
Frame	Parameter	Rigid	Semirigid				Hybrid			
			Flexural rigidity in kNm/rad				Flexural rigidity in kNm/rad			
			0	7500	100000	290000	0	7500	100000	290000
G+3	V in kN	2309	1958	2096	2274	2294	2171	2228	2288	2294
	D in mm	75.20	98.42	92.27	77.24	74.60	82.91	81.56	76.06	74.91
	Teff in sec	0.624	0.768	0.720	0.637	0.624	0.674	0.660	0.630	0.625
	βeff in %	6.6	5.4	5.4	6.5	6.8	6.2	6.1	6.6	6.8
G+4	V in kN	2244	1909	2046	2224	2246	2119	2180	2241	2244
	D in mm	96.05	126.66	118.42	98.80	95.44	106.03	104.38	97.34	95.80
	Teff in sec	0.800	0.987	0.924	0.814	0.797	0.862	0.844	0.805	0.798
	βeff in %	6.8	5.4	5.4	6.6	6.9	6.3	6.1	6.6	6.8
G+5	V in kN	2209	1870	2006	2183	2210	2080	2140	2204	2209
	D in mm	117.70	155.32	145.10	120.92	116.88	129.61	127.61	119.17	117.35
	Teff in sec	0.976	1.211	1.132	0.994	0.972	1.054	1.031	0.983	0.975
	βeff in %	6.8	5.4	5.4	6.6	6.9	6.3	6.2	6.7	6.8
G+6	V in kN	2179	1843	1980	2153	2183	2052	2110	2178	2176
	D in mm	140.04	184.97	172.82	143.88	139.28	154.15	151.73	141.93	139.51
	Teff in sec	1.156	1.438	1.343	1.179	1.152	1.249	1.221	1.164	1.155
	βeff in %	6.8	5.4	5.4	6.6	6.8	6.3	6.2	6.6	6.8
G+7	V in kN	2160	1816	1950	2154	2152	2021	2082	2148	2147
	D in mm	163.07	215.29	200.98	169.53	162.04	179.10	176.51	165.26	162.46
	Teff in sec	1.337	1.671	1.559	1.364	1.335	1.448	1.416	1.349	1.338
	βeff in %	6.7	5.4	5.4	6.3	6.8	6.3	3.2	6.6	6.8

V = Base shear, D = Roof displacement , Teff = Effective time period, βeff = Effective damping

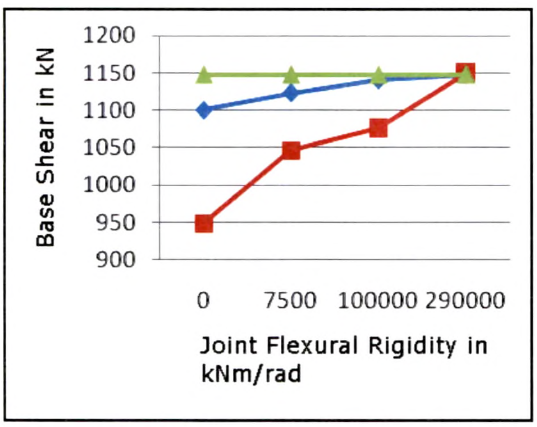
9m x 9m Overall Plan Dimension Models



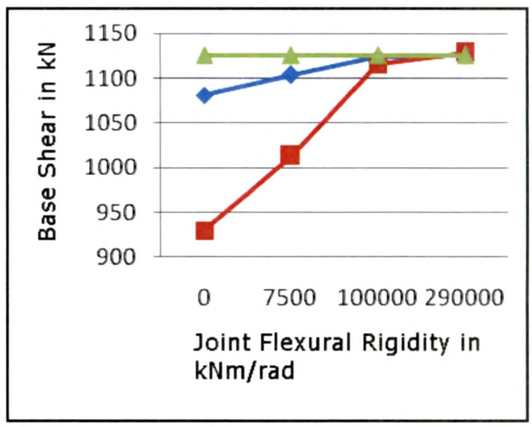
a) G+3 Storey



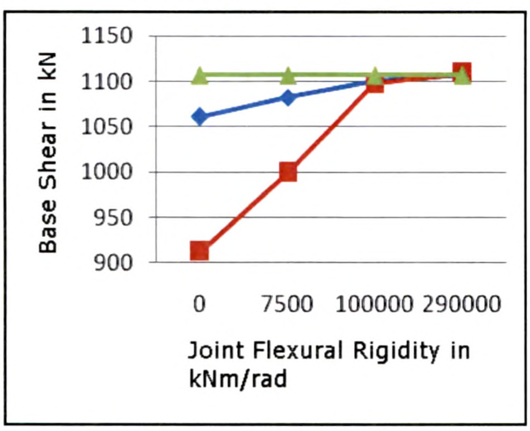
b) G+4 Storey



c) G+5 Storey



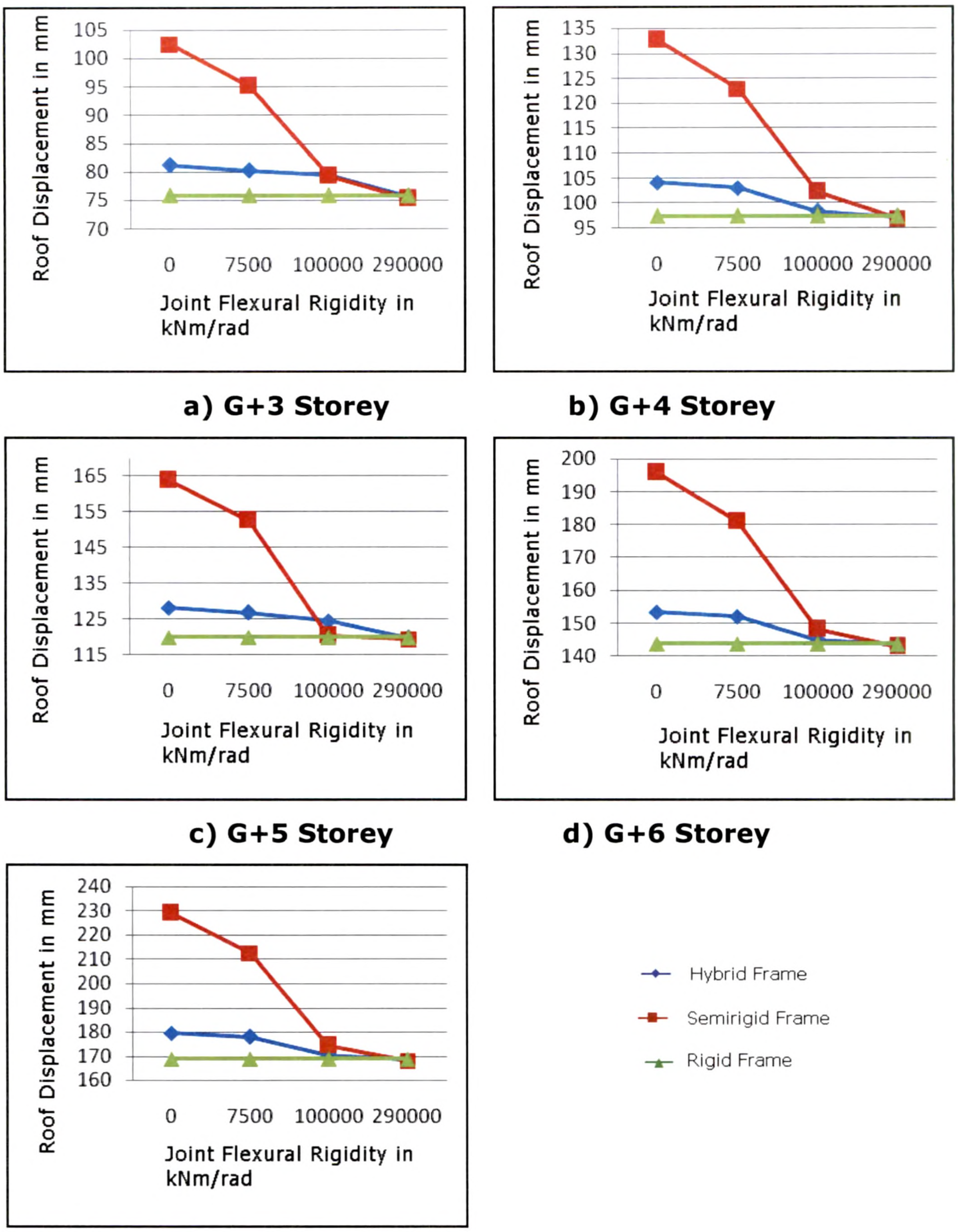
d) G+6 Storey



e) G+7 Storey

Fig.11.2 Base Shear Variation at Performance Point

9m x 9m Overall Plan Dimension Models



a) G+3 Storey

b) G+4 Storey

c) G+5 Storey

d) G+6 Storey

e) G+7 Storey

Fig.11.3 Roof Displacement Variation at Performance Point

9m x 9m Overall Plan Dimension Models

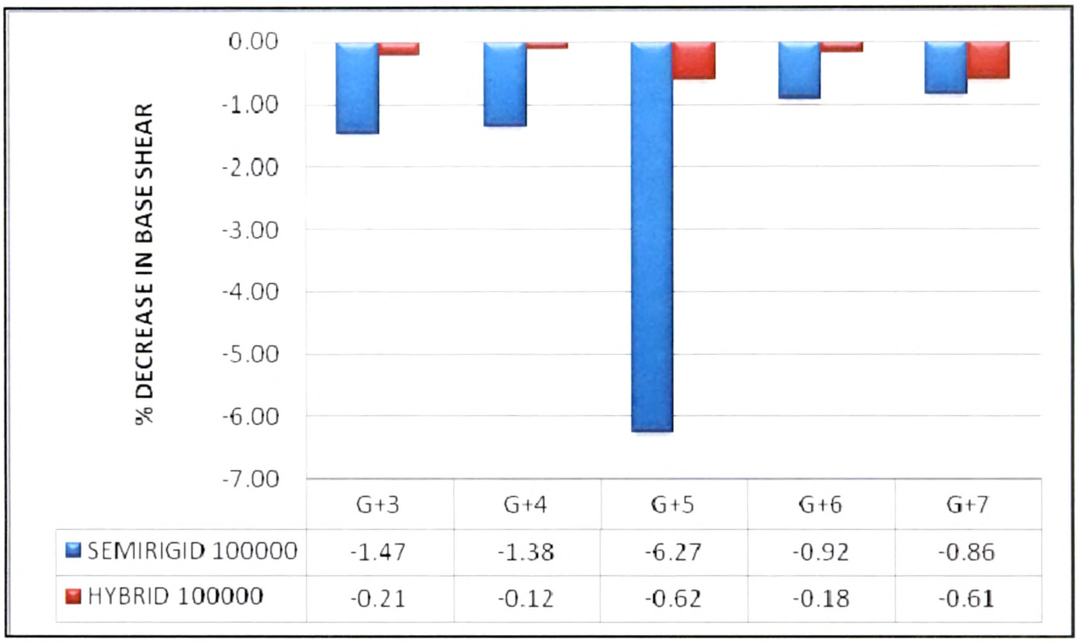


Fig. 11.4 Percentage Variation in Base Shear Relative to Rigid Frame

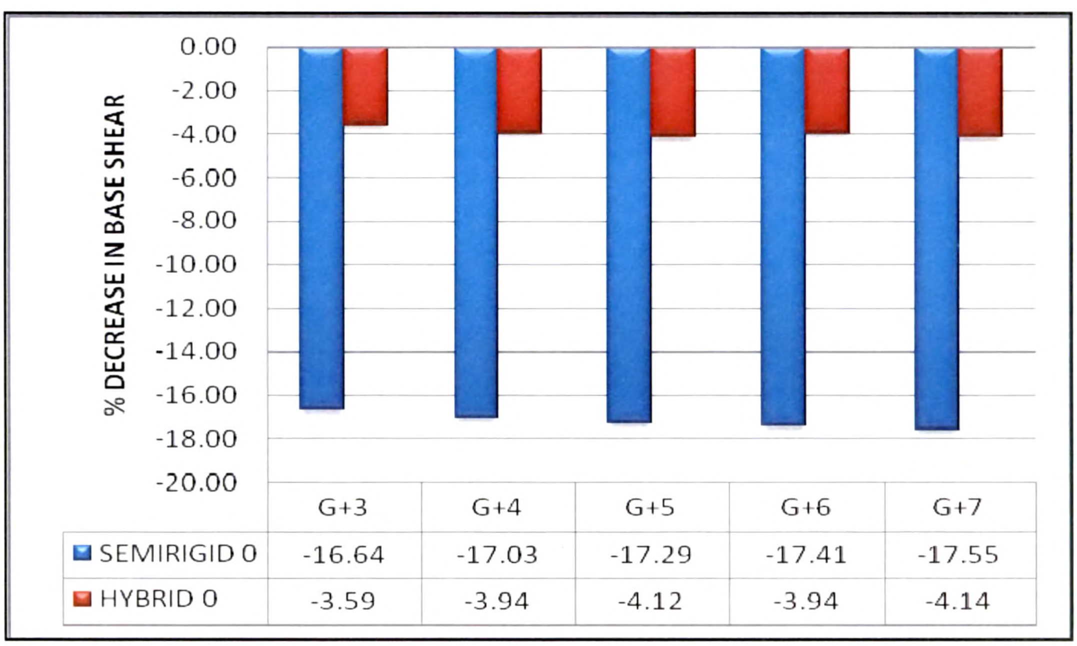
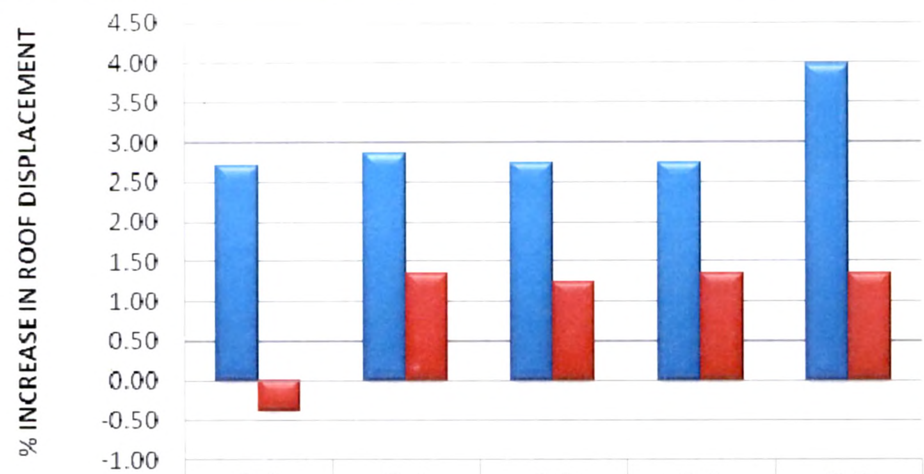


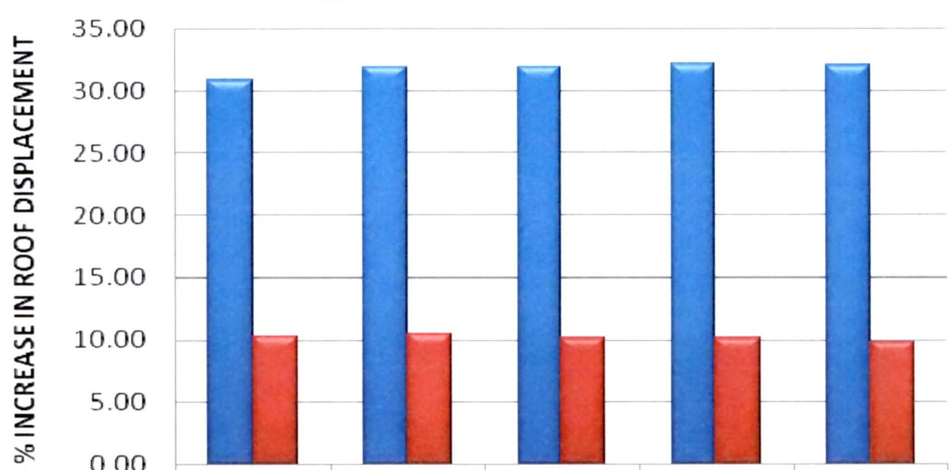
Fig. 11.5 Percentage Variation in Base Shear Relative to Rigid Frame

9m x 9m Overall Plan Dimension Models



	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 100000	2.71	2.86	2.74	2.74	3.96
HYBRID 100000	-0.39	1.34	1.25	1.35	1.34

Fig. 11.6 Variation in Roof Displacement Relative to Rigid Frame



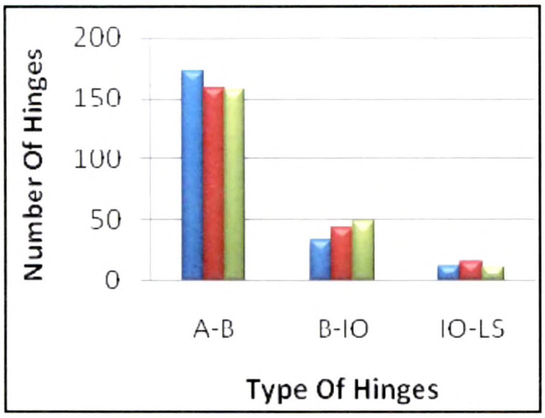
	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 0	30.88	31.87	31.96	32.08	32.02
HYBRID 0	10.25	10.39	10.12	10.08	9.83

Fig. 11.7 Variation in Roof Displacement Relative to Rigid Frame

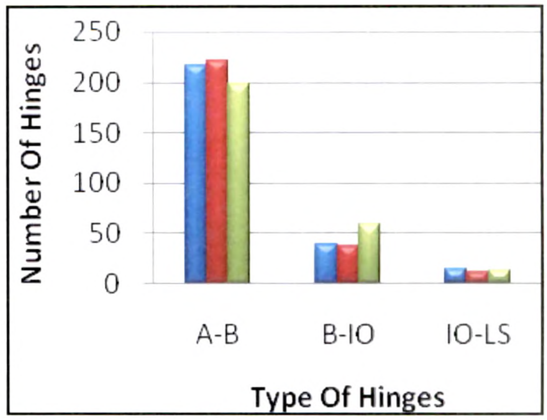
Table 11.2 Number of Plastic Hinges Developed - 9m x 9m Frame

Frame type		A-B	B-IO	IO-LS	TOTAL
G+3	Hybrid 0	366	40	10	416
	Hybrid 7500	368	40	8	416
	Hybrid 100000	330	76	10	416
	Hybrid 290000	324	76	16	416
	RIGID	328	72	16	416
	Semi Rigid 0	406	10	0	416
	Semi Rigid 7500	398	18	0	416
	Semi Rigid 100000	330	78	8	416
	Semi Rigid 290000	324	76	16	416
G+4	Hybrid 0	458	50	12	520
	Hybrid 7500	458	50	12	520
	Hybrid 100000	414	92	14	520
	Hybrid 290000	408	94	18	520
	RIGID	410	92	18	520
	Semi Rigid 0	510	10	0	520
	Semi Rigid 7500	492	28	0	520
	Semi Rigid 100000	416	92	12	520
	Semi Rigid 290000	410	92	18	520
G+5	Hybrid 0	552	58	14	624
	Hybrid 7500	552	58	14	624
	Hybrid 100000	500	106	18	624
	Hybrid 290000	494	104	26	624
	RIGID	494	106	24	624
	Semi Rigid 0	614	10	0	624
	Semi Rigid 7500	592	32	0	624
	Semi Rigid 100000	500	112	12	624
	Semi Rigid 290000	492	106	26	624
G+6	Hybrid 0	644	66	18	728
	Hybrid 7500	648	66	14	728
	Hybrid 100000	584	124	20	728
	Hybrid 290000	576	128	24	728
	RIGID	576	130	22	728
	Semi Rigid 0	714	14	0	728
	Semi Rigid 7500	686	42	0	728
	Semi Rigid 100000	588	122	18	728
	Semi Rigid 290000	570	132	26	728
G+7	Hybrid 0	736	78	18	832
	Hybrid 7500	736	78	18	832
	Hybrid 100000	668	144	20	832
	Hybrid 290000	660	146	26	832
	RIGID	664	144	24	832
	Semi Rigid 0	818	14	0	832
	Semi Rigid 7500	786	46	0	832
	Semi Rigid 100000	684	128	20	832
	Semi Rigid 290000	660	144	28	832

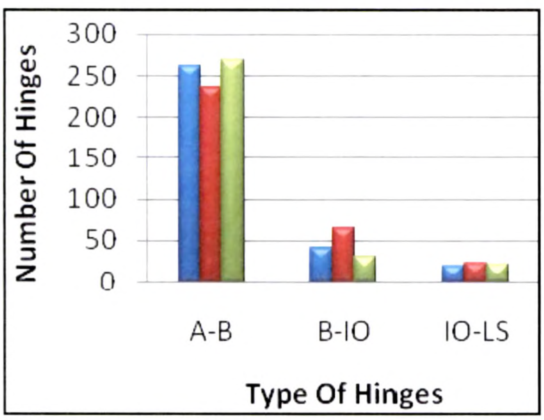
9m x 9m Overall Plan Dimension Models



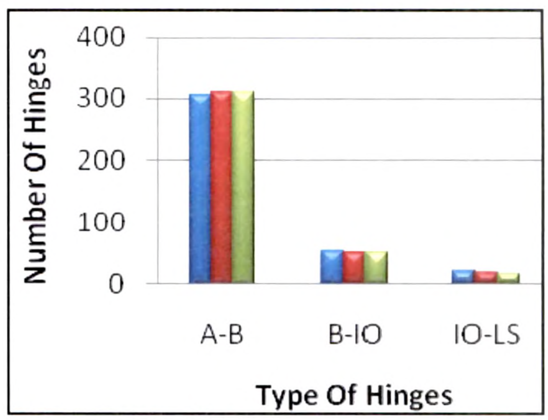
a) G+3 Storey



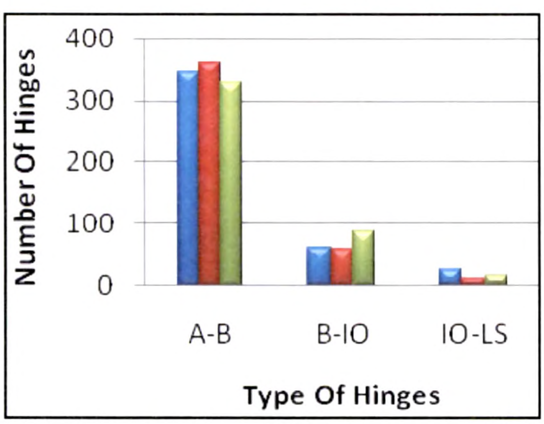
b) G+4 Storey



c) G+5 Storey



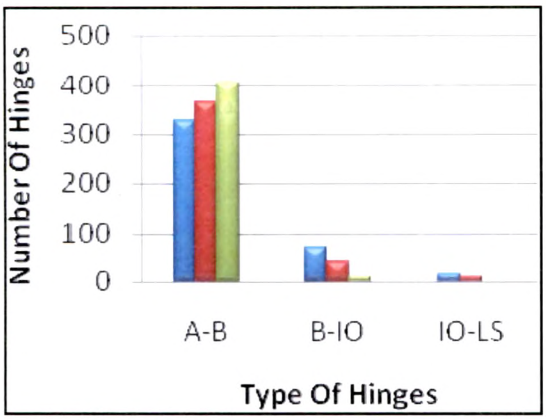
d) G+6 Storey



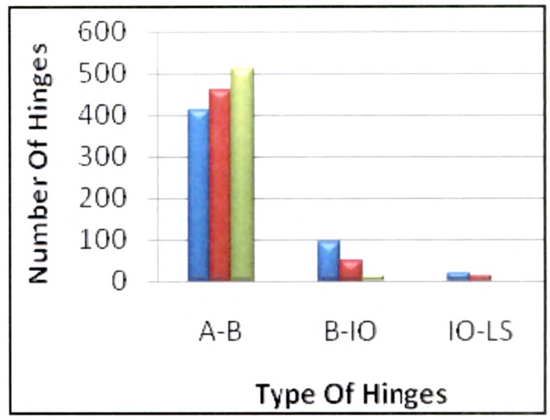
e) G+7 Storey

Fig. 11.8 Number of Hinges at Performance Point for 45% Rigidity

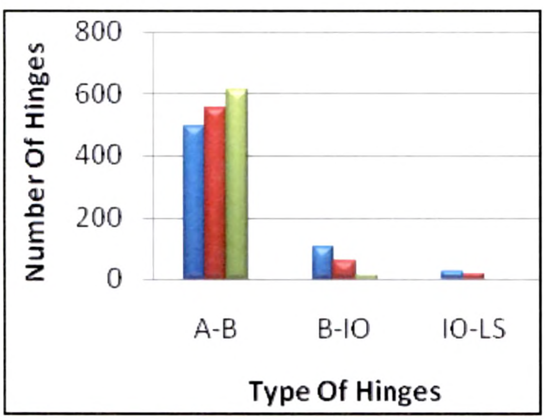
9m x 9m Overall Plan Dimension Models



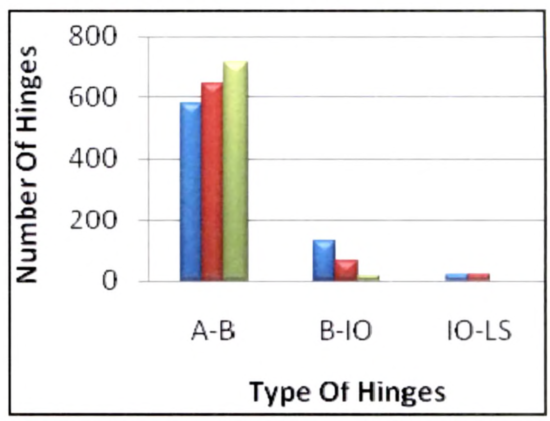
a) G+3 Storey



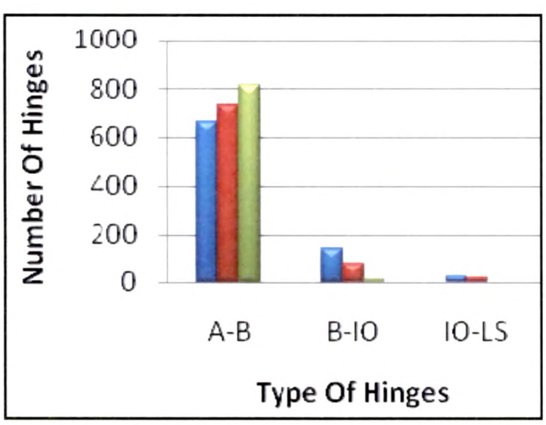
b) G+4 Storey



c) G+5 Storey



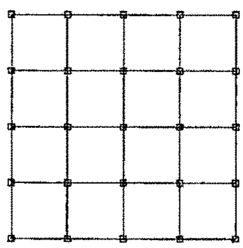
d) G+6 Storey



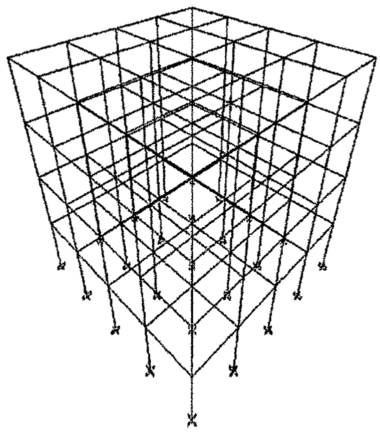
e) G+7 Storey

Fig. 11.9 Number of Hinges at Performance Point for 0% Rigidity

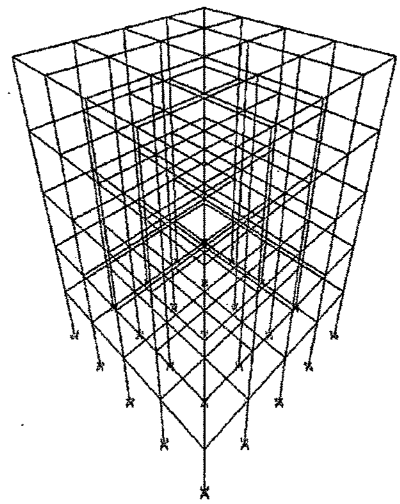
Figure 11.10 represents the line diagrams of space frames with an overall plan dimension of 12m x 12m. The results obtained by push over analysis for the 45 space frame models developed for the same are presented in **Table 11.3**. The parameters noted at performance point are the base shear V in kN, the roof displacement D in mm, the effective time period Teff in seconds and the effective damping in percentage. These parameters are noted for three types of space frames viz. rigid, hybrid and semi rigid. The values are noted for four variations in the joint rigidity for the hybrid and semi rigid frames - 0, 7500, 100000 and 290000 kNm/rad. These values of rigidities correspond to 0%, 20%, 45% and 100% joint rigidity for the given beam sizes. Thus, the semi rigid and hybrid frame with joint rigidity of 290000 kNm/rad is as good as a rigid frame. The variation in base shear and roof displacement for each of the frames is graphically presented in **Figs. 11.11** and **11.12** respectively. The percentage variation in base shear is compared with that for fully rigid frame for hybrid and semi rigid frames for 45% rigidity (100000 kNm/rad) in **Fig. 11.13** and 0% rigidity in **Fig. 11.14**. The same variation in roof displacement for hybrid and semi rigid frames for 45% rigidity is shown in **Fig. 11.15** and 0% rigidity in **Fig. 11.16**. The hinges developed at performance point in the 12m x 12m frames is presented in **Table 11.4**. The corresponding comparison of hinges developed in specific categories at performance point for 45% rigidity and 0% rigidity are presented in **Figs. 11.17** and **11.18** respectively. It may be noted that as there are no hinges developed beyond the category of Life Safety (LS), they are not shown in the table as well as the comparison charts.



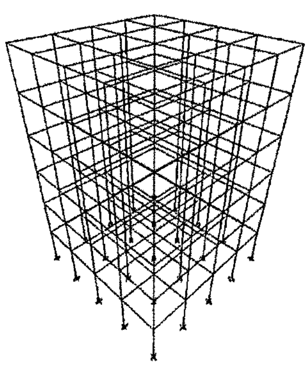
a) Typical Plan



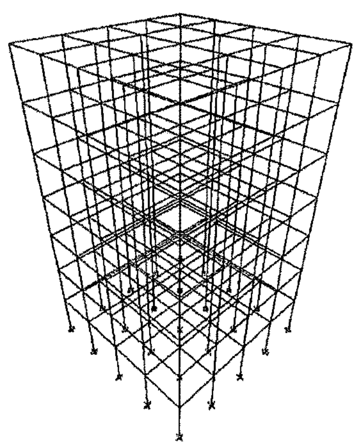
b) G+3 Storey



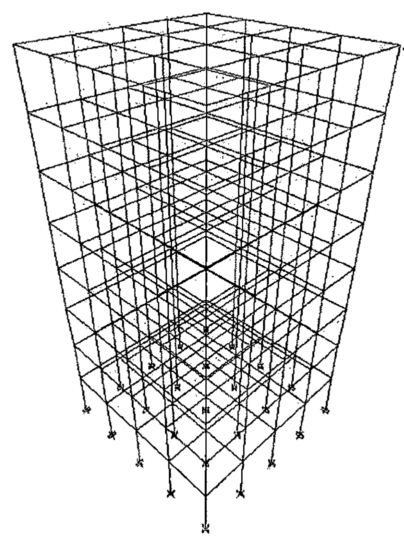
c) G+4 Storey



d) G+5 Storey



e) G+6 Storey



f) G+7 Storey

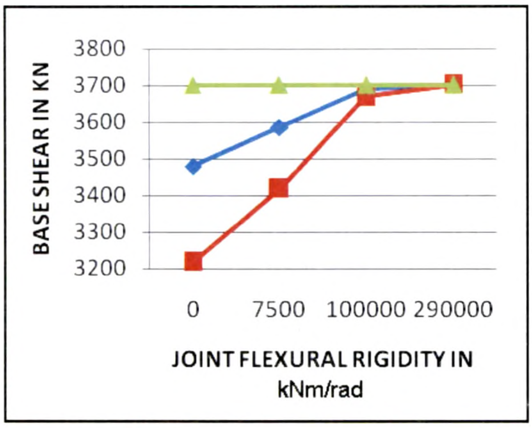
Fig. 11.10 G+3 to G+7 Storey Frames of Overall Plan 12m x 12m

Table 11.3 Performance Point Results of Push over Analysis for 12m x 12m Space Frames

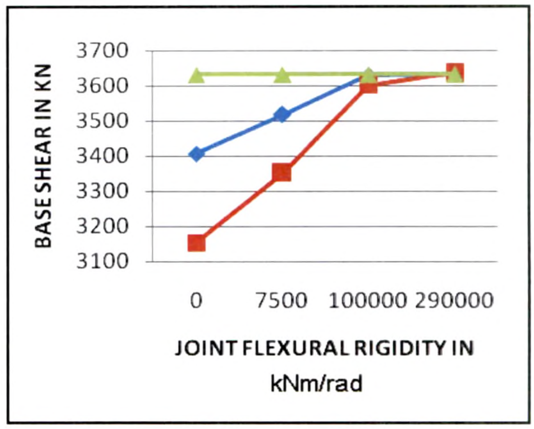
Frame	Parameter	Rigid	Semirigid				Hybrid			
			Flexural rigidity in kNm/rad				Flexural rigidity in kNm/rad			
			0	7500	100000	290000	0	7500	100000	290000
G+3	V in kN	3701	3218	3418	3670	3702	3480	3586	3689	3701
	D in mm	74.41	96.07	90.51	76.38	73.91	83.77	82.1	75.49	74.15
	Teff in sec	0.621	0.750	0.708	0.631	0.619	0.677	0.666	0.626	0.620
	βeff in %	6.7	5.3	5.3	6.4	6.8	6.0	5.9	6.5	6.7
G+4	V in kN	3632	3153	3352	3601	3636	3407	3518	3629	3633
	D in mm	94.86	123.39	116.00	97.45	94.31	106.99	104.87	96.40	94.57
	Teff in sec	0.790	0.960	0.904	0.804	0.788	0.864	0.842	0.797	0.789
	βeff in %	6.7	5.3	5.3	6.5	6.8	6.0	5.9	6.5	6.8
G+5	V in kN	3579	3097	3294	3547	3586	3354	3464	3577	3580
	D in mm	115.79	150.92	141.66	118.95	115.19	130.53	127.97	117.7	115.43
	Teff in sec	0.962	1.173	1.104	0.979	0.959	1.053	1.026	0.970	0.960
	βeff in %	6.8	5.3	5.4	6.5	6.8	6.1	5.9	6.6	6.8
G+6	V in kN	3544	3056	3255	3502	3547	3310	3419	3540	3542
	D in mm	137.36	179.16	168.17	140.97	136.53	154.37	151.39	139.56	136.86
	Teff in sec	1.136	1.390	1.306	1.157	1.131	1.243	1.211	1.145	1.134
	βeff in %	6.7	5.3	5.3	6.5	6.8	6.1	6.0	6.5	6.8
G+7	V in kN	3512	3024	3222	3472	3512	3270	3383	3503	3504
	D in mm	158.61	208.17	195.35	163.83	158.50	178.86	175.61	161.96	158.78
	Teff in sec	1.312	1.610	1.512	1.337	1.307	1.440	1.400	1.323	1.310
	βeff in %	6.8	5.3	5.3	6.5	6.7	6.1	6.0	6.5	6.8

V = Base shear, D = Roof displacement , Teff = Effective time period, βeff = Effective damping

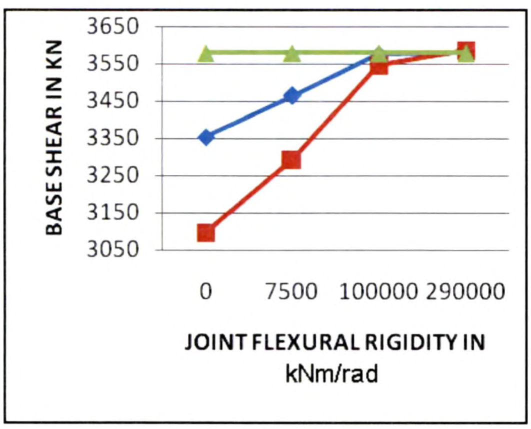
12m x 12m Overall Plan Dimension Models



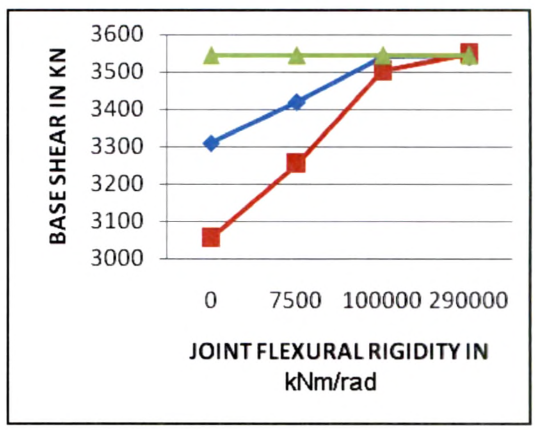
a) G+3 Storey



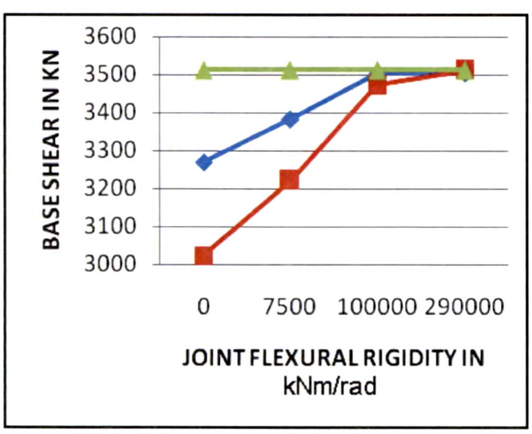
b) G+4 Storey



c) G+5 Storey



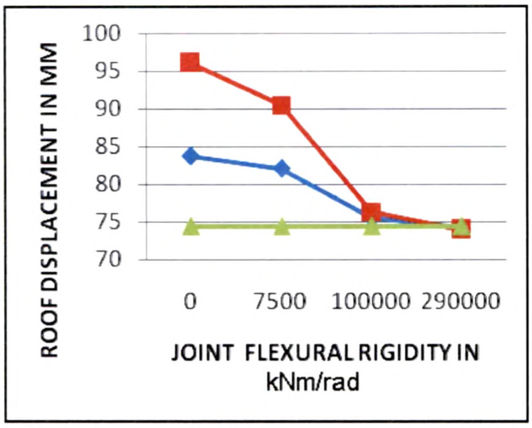
d) G+6 Storey



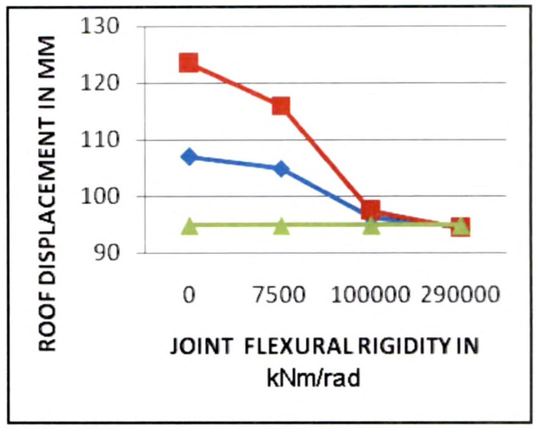
e) G+7 Storey

Fig. 11.11 Base Shear Variation at Performance Point

12m x 12m Overall Plan Dimension Models



a) G+3 Storey



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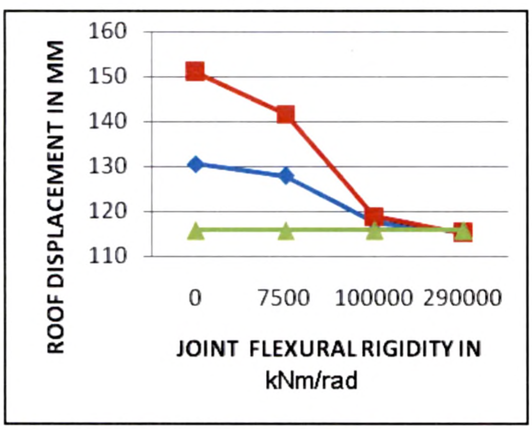
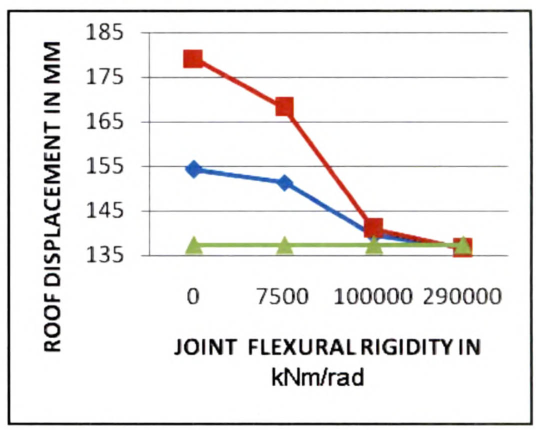
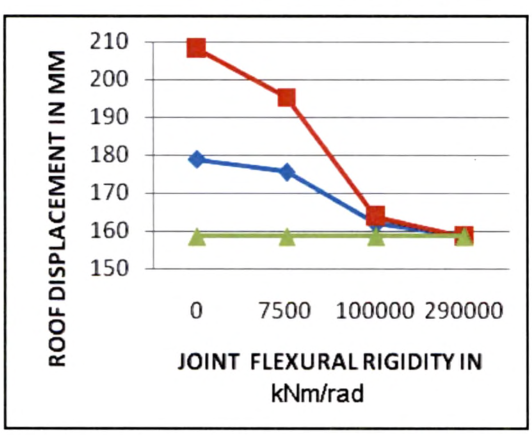


c) G+5 Storey



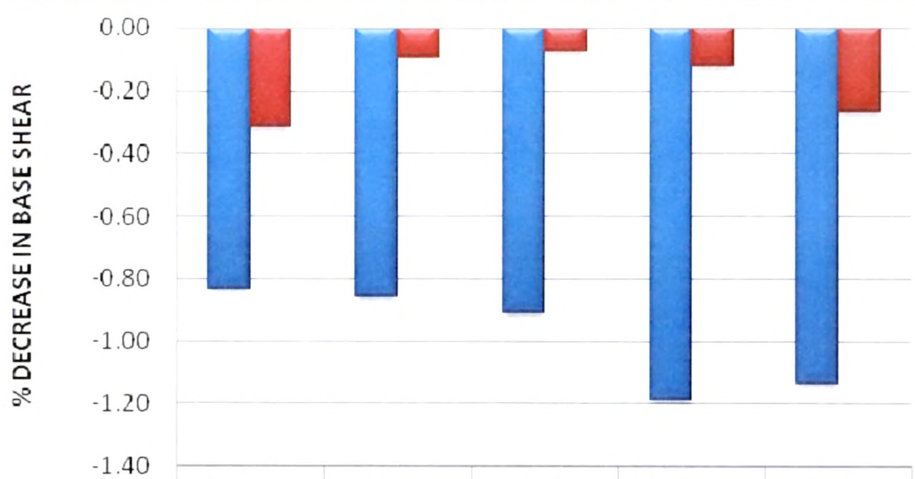
d) G+6 Storey



e) G+7 Storey

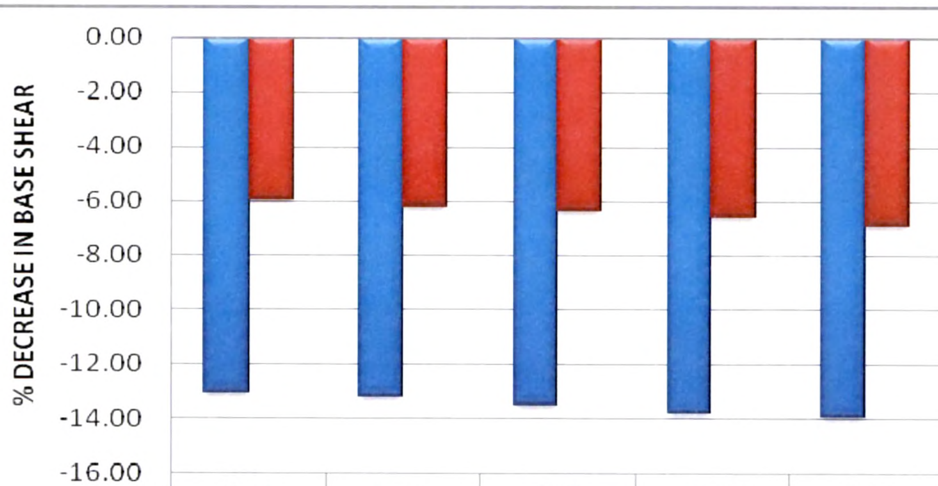
Fig. 11.12 Roof Displacement Variation at Performance Point

12m x 12m Overall Plan Dimension Models



	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 100000	-0.83	-0.86	-0.91	-1.19	-1.14
HYBRID 100000	-0.32	-0.09	-0.08	-0.12	-0.27

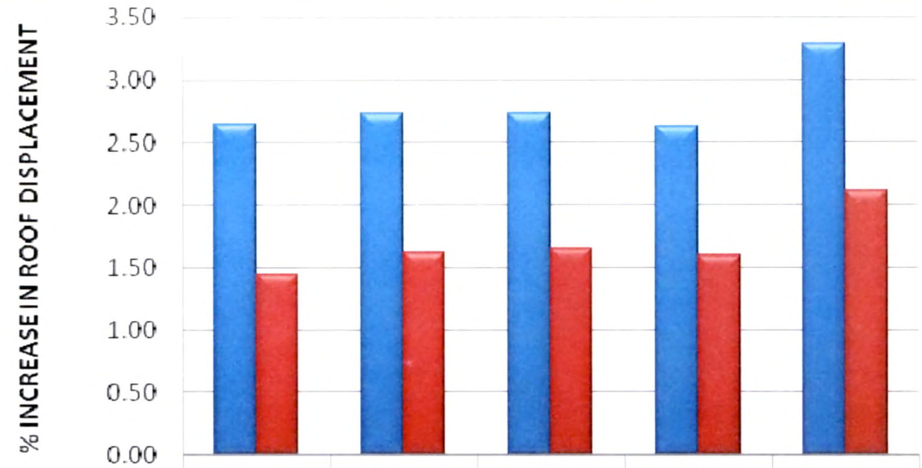
Fig. 11.13 Percentage Variation in Base Shear Relative to Rigid Frame



	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 0	-13.04	-13.19	-13.49	-13.78	-13.91
HYBRID 0	-5.97	-6.20	-6.32	-6.61	-6.90

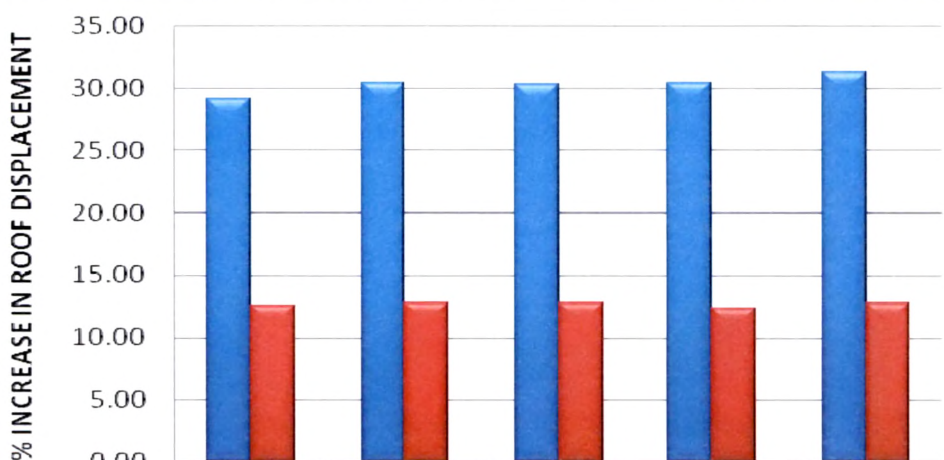
Fig. 11.14 Percentage Variation in Base Shear Relative to Rigid Frame

12m x 12m Overall Plan Dimension Models



	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 100000	2.65	2.73	2.73	2.63	3.29
HYBRID 100000	1.45	1.62	1.65	1.60	2.11

Fig. 11.15 Variation in Roof Displacement Relative to Rigid Frame



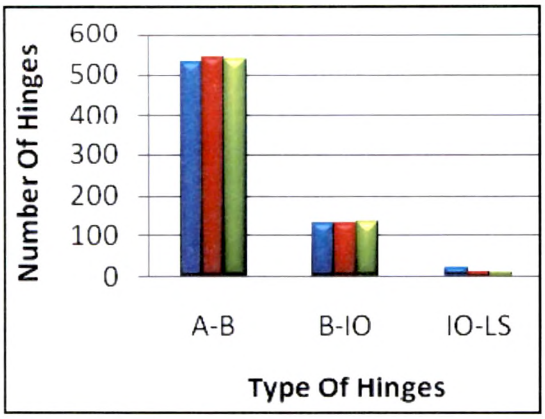
	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 0	29.11	30.39	30.34	30.43	31.25
HYBRID 0	12.58	12.79	12.73	12.38	12.77

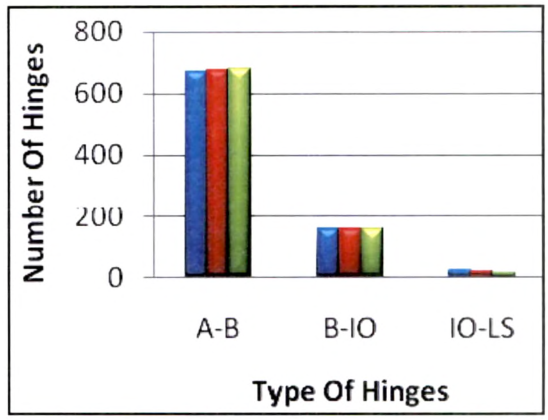
Fig. 11.16 Variation in Roof Displacement Relative to Rigid Frame

Table 11.4 Number of Plastic Hinges Developed - 12m x 12m Frame

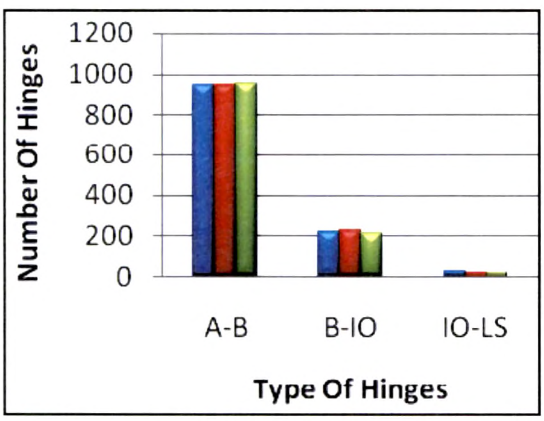
	Frame type	A-B	B-IO	IO-LS	TOTAL
G+3	Hybrid 0	612	58	10	680
	Hybrid 7500	612	60	8	680
	Hybrid 100000	539	130	11	680
	Hybrid 290000	529	131	20	680
	RIGID	531	129	20	680
	Semi Rigid 0	665	15	0	680
	Semi Rigid 7500	655	25	0	680
	Semi Rigid 100000	538	133	9	680
	Semi Rigid 290000	530	130	20	680
G+4	Hybrid 0	764	74	12	850
	Hybrid 7500	766	72	12	850
	Hybrid 100000	678	156	16	850
	Hybrid 290000	670	158	22	850
	RIGID	673	155	22	850
	Semi Rigid 0	833	16	0	850
	Semi Rigid 7500	812	38	0	850
	Semi Rigid 100000	679	157	14	850
	Semi Rigid 290000	670	158	22	850
G+5	Hybrid 0	922	84	14	1020
	Hybrid 7500	922	84	14	1020
	Hybrid 100000	810	190	20	1020
	Hybrid 290000	803	185	32	1020
	RIGID	806	182	32	1020
	Semi Rigid 0	999	21	0	1020
	Semi Rigid 7500	973	47	0	1020
	Semi Rigid 100000	818	188	14	1020
	Semi Rigid 290000	803	185	32	1020
G+6	Hybrid 0	1076	100	14	1190
	Hybrid 7500	1080	96	14	1190
	Hybrid 100000	945	227	18	1190
	Hybrid 290000	940	220	30	1190
	RIGID	945	218	27	1190
	Semi Rigid 0	1169	21	0	1190
	Semi Rigid 7500	1141	49	0	1190
	Semi Rigid 100000	955	216	19	1190
	Semi Rigid 290000	941	219	30	1190
G+7	Hybrid 0	1230	114	16	1360
	Hybrid 7500	1230	114	16	1360
	Hybrid 100000	1084	254	22	1360
	Hybrid 290000	1069	259	32	1360
	RIGID	1068	263	29	1360
	Semi Rigid 0	1333	27	0	1360
	Semi Rigid 7500	1296	64	0	1360
	Semi Rigid 100000	1087	254	19	1360
	Semi Rigid 290000	1068	263	29	1360

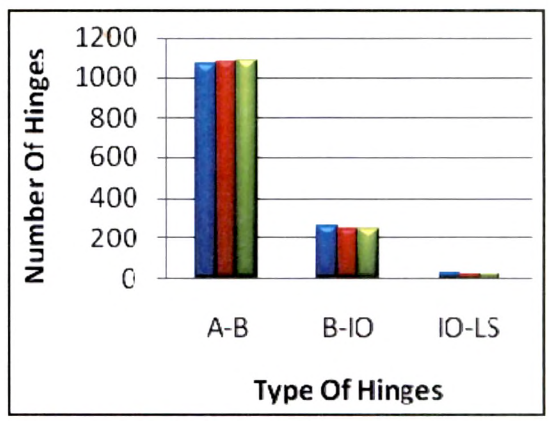
12m x 12m Overall Plan Dimension Models



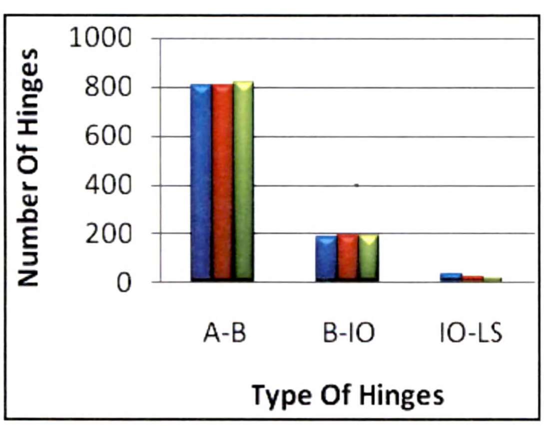


a) G+3 Storey **b) G+4 Storey**



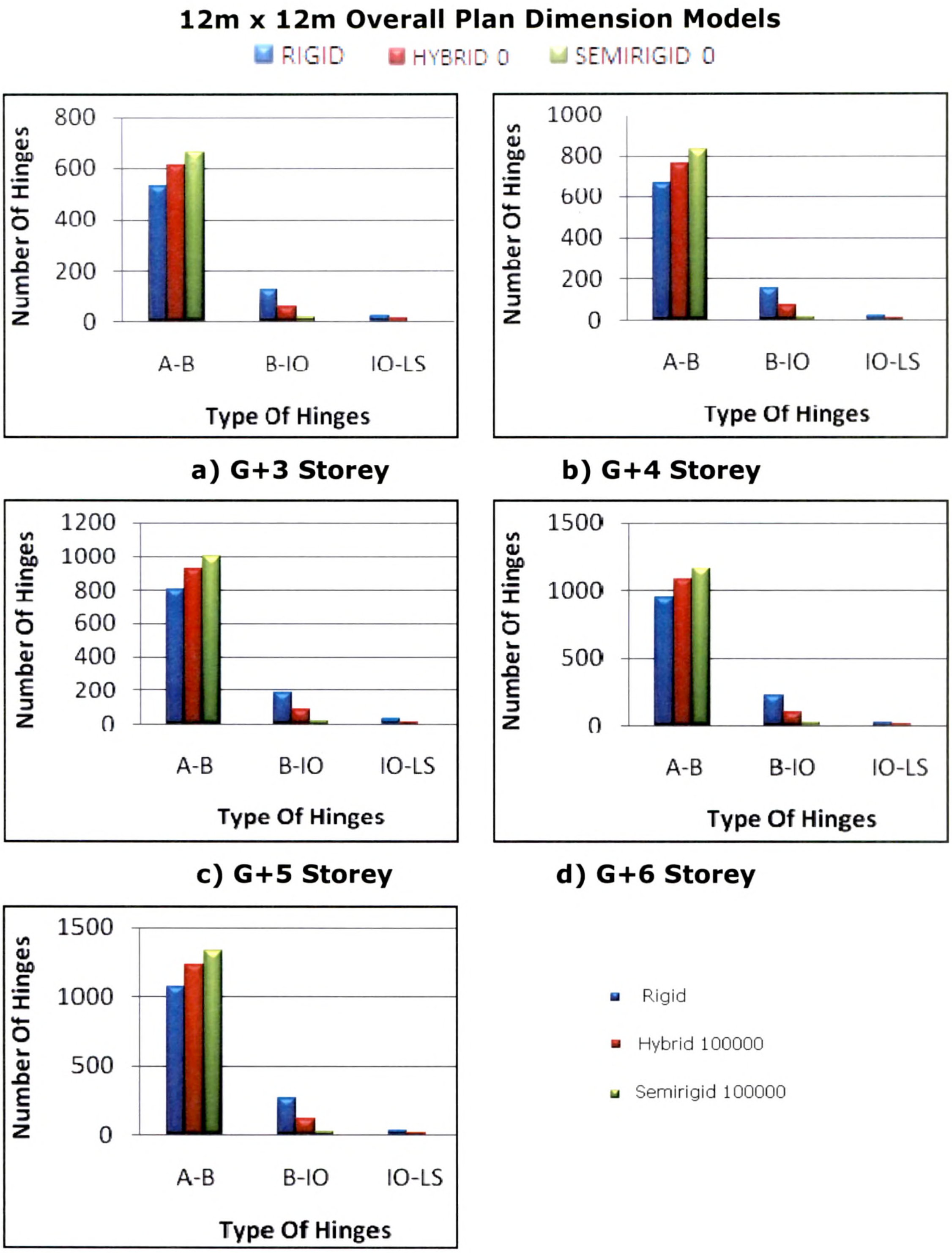


c) G+5 Storey **d) G+6 Storey**



e) G+7 Storey

Fig. 11.17 Number of Hinges at Performance Point for 45% Rigidity



a) G+3 Storey

b) G+4 Storey

c) G+5 Storey

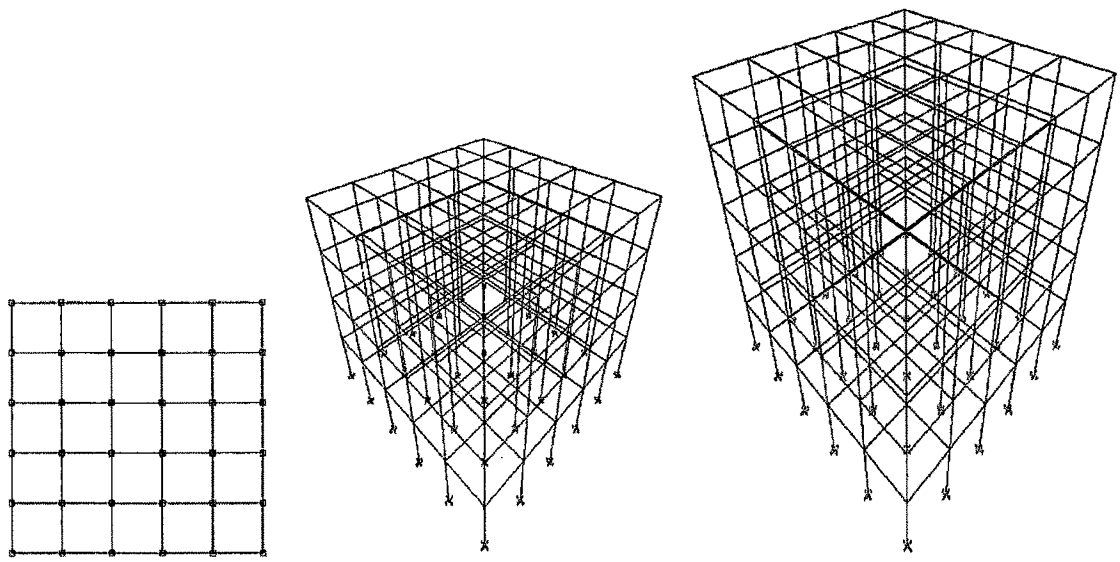
d) G+6 Storey

e) G+7 Storey

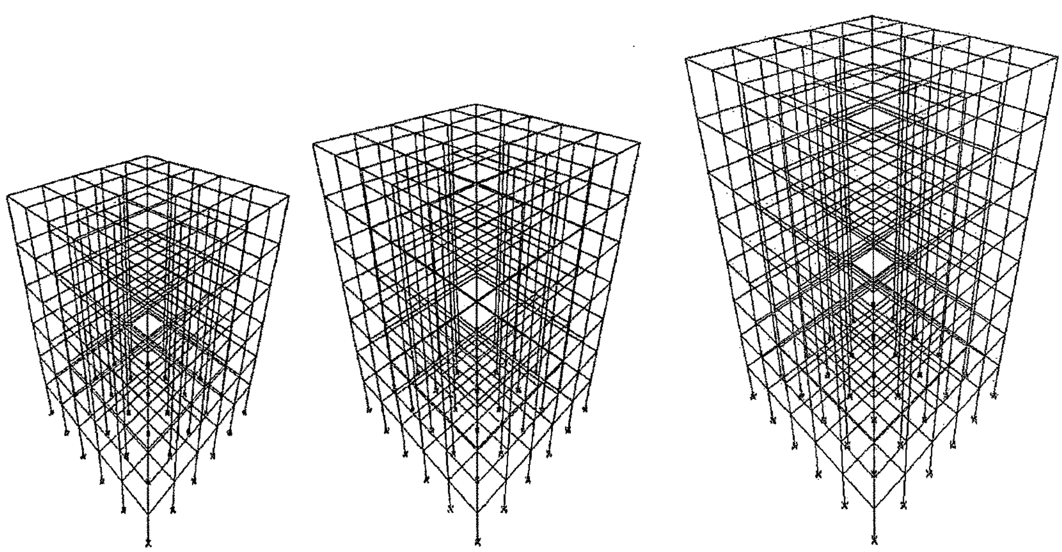
Fig. 11.18 Number of Hinges at Performance Point for 0% Rigidity

Figure 11.19 represents the line diagrams of space frames with an overall plan dimension of 15mx15m. The results obtained by push over analysis for the 45 space frame models developed for the same are presented in **Table 11.5**. The variation in base shear and roof displacement for each of the frames is graphically presented in **Figs. 11.20** and **11.21** respectively. The percentage variation in base shear is compared with that for fully rigid frame for hybrid and semi rigid frames for 45% rigidity (100000 kNm/rad) in **Fig. 11.22** and 0% rigidity in **Fig. 11.23**. The same variation in roof displacement for hybrid and semi rigid frames for 45% rigidity is shown in **Fig. 11.24** and 0% rigidity in **Fig. 11.25**. The hinges developed at performance point in the 15m x 15m frames is presented in **Table 11.6**. The corresponding comparison of hinges developed in specific categories at performance point for 45% rigidity and 0% rigidity are presented in **Figs. 11.26** and **11.27** respectively. It may be noted that as there are no hinges developed beyond the category of Life Safety (LS); they are not shown in the table as well as the comparison charts.

The overall performance over the entire range of space frames is compared to identify the trend of seismic behavior as the size of the structure increases laterally. The parameter taken as a representative of the trend is the base shear variation at performance point relative to the fully rigid frame. The percentage variation in base shear is plotted for the four joint rigidities for semi rigid and hybrid frames for a G+3 frame in **Fig. 11.28** and a G+7 frame in **Fig. 11.29**. The same variation is compared for entire range of frames from G+3 storey to G+7 storey for a joint rigidity of 0 kNm/rad in **Fig. 11.30** and for a joint rigidity of 100000 kNm/rad in **Fig. 11.31**. It may be noted that a similar trend is observed for roof displacement at performance point.



a) Plan b) G+3 Storey c) G+4 Storey



d) G+5 Storey e) G+6 Storey f) G+7 Storey

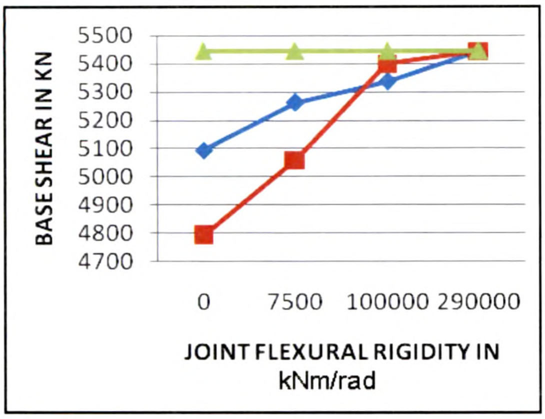
Fig. 11.19 G+3 to G+7 Storey Frames of Overall Plan 15m x 15m

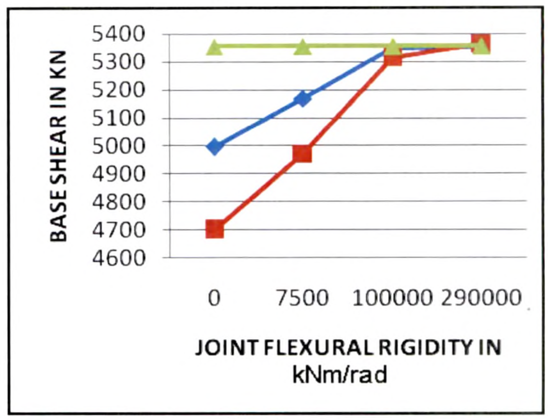
Table 11.5 Performance Point Results of Push over Analysis for 15m x 15m Space Frames

Frame	Parameter	Rigid	Semirigid				Hybrid			
			Flexural rigidity in kNm/rad				Flexural rigidity in kNm/rad			
			0	7500	100000	290000	0	7500	100000	290000
G+3	V in kN	5444	4791	5060	5400	5443	5094	5261	5335	5442
	D in mm	73.95	94.64	89.40	75.86	73.45	84.35	82.46	74.37	73.64
	Teff in sec	0.617	0.738	0.700	0.627	0.615	0.679	0.661	0.625	0.616
	βeff in %	6.6	5.2	5.2	6.4	6.7	5.8	5.7	6.8	6.7
G+4	V in kN	5357	4698	4972	5314	5364	4995	5169	5348	5355
	D in mm	94.12	121.2	114.4	96.63	93.62	107.6	105.2	95.79	93.76
	Teff in sec	0.783	0.942	0.891	0.796	0.780	0.864	0.840	0.790	0.782
	βeff in %	6.6	5.2	5.2	6.4	6.7	5.9	5.7	6.4	6.7
G+5	V in kN	5280	4632	4905	5243	5292	4922	5098	5281	5277
	D in mm	114.59	148.24	139.67	117.77	114.06	131.04	128.15	116.77	114.16
	Teff in sec	0.952	1.148	1.085	0.967	0.948	1.051	1.021	0.960	0.950
	βeff in %	6.7	5.2	5.2	6.4	6.7	5.9	5.8	6.5	6.7
G+6	V in kN	5234	4577	4842	5187	5231	4864	5038	5227	5234
	D in mm	135.68	175.68	165.26	139.31	134.77	154.79	151.39	138.11	135.17
	Teff in sec	1.121	1.358	1.282	1.141	1.118	1.240	1.204	1.131	1.119
	βeff in %	6.6	5.2	5.3	6.4	6.7	5.9	5.8	6.4	6.7
G+7	V in kN	5193	4535	4802	5140	5200	4808	4988	5185	5192
	D in mm	157.03	203.75	191.66	162.48	156.21	178.65	174.93	159.89	156.45
	Teff in sec	1.292	1.569	1.480	1.320	1.288	1.430	1.389	1.305	1.290
	βeff in %	6.6	5.2	5.2	6.3	6.7	6	5.8	6.4	6.7

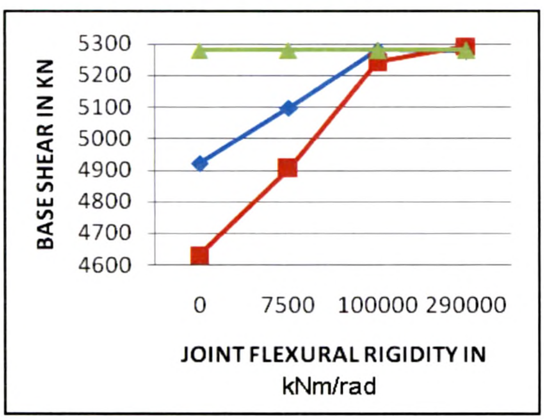
V = Base shear, D = Roof displacement , Teff = Effective time period, βeff = Effective damping

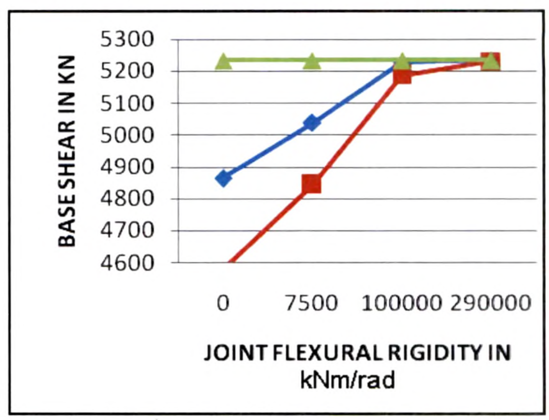
15m x 15m Overall Plan Dimension Models

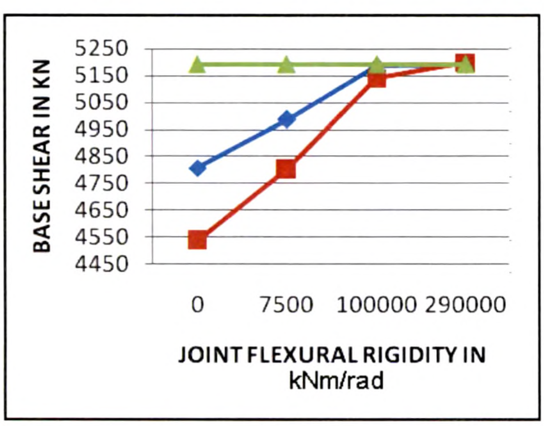




a) G+3 Storey **b) G+4 Storey**



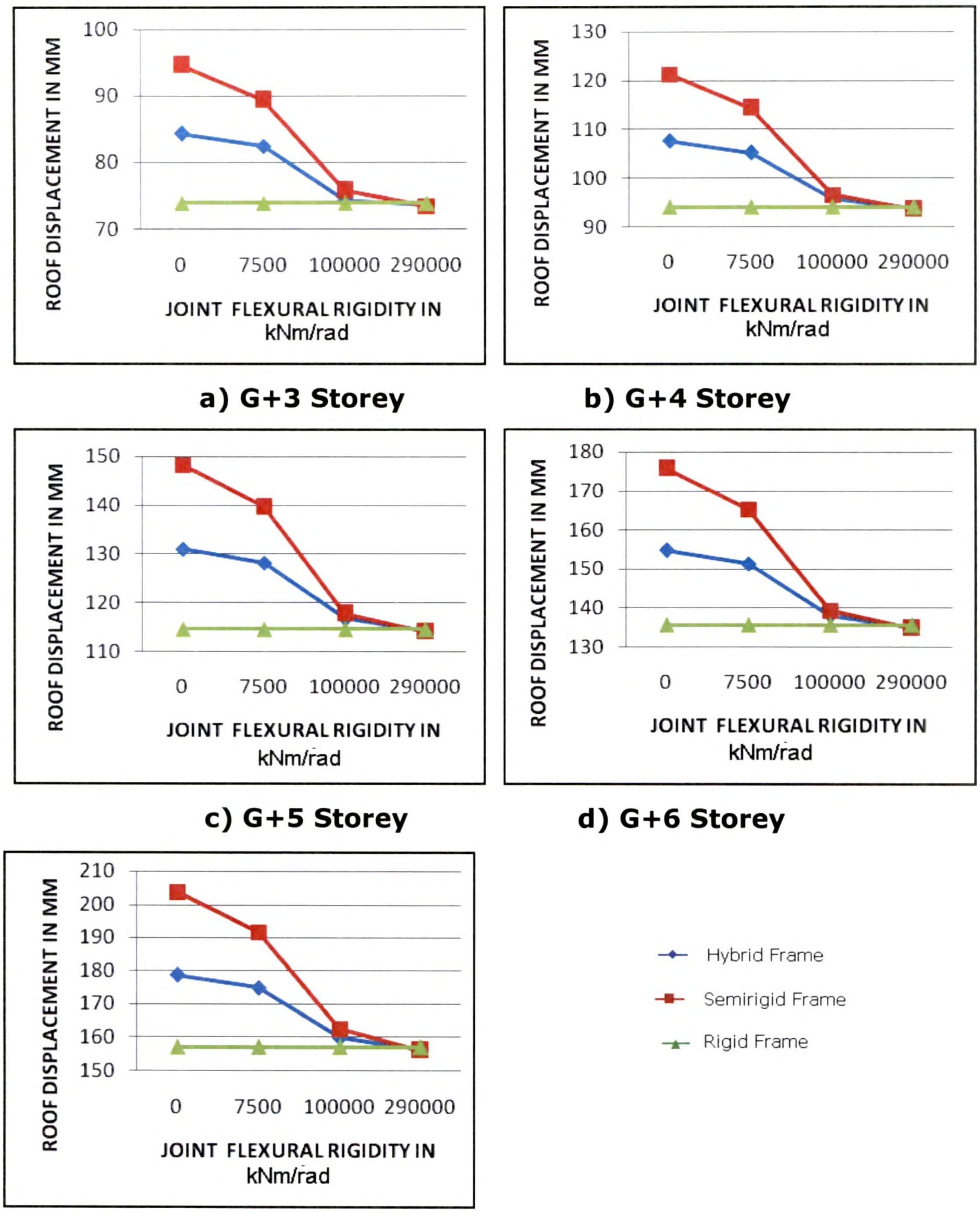




e) G+7 Storey

Fig. 11.20 Base Shear Variation at Performance Point

15m x 15m Overall Plan Dimension Models



a) G+3 Storey

b) G+4 Storey

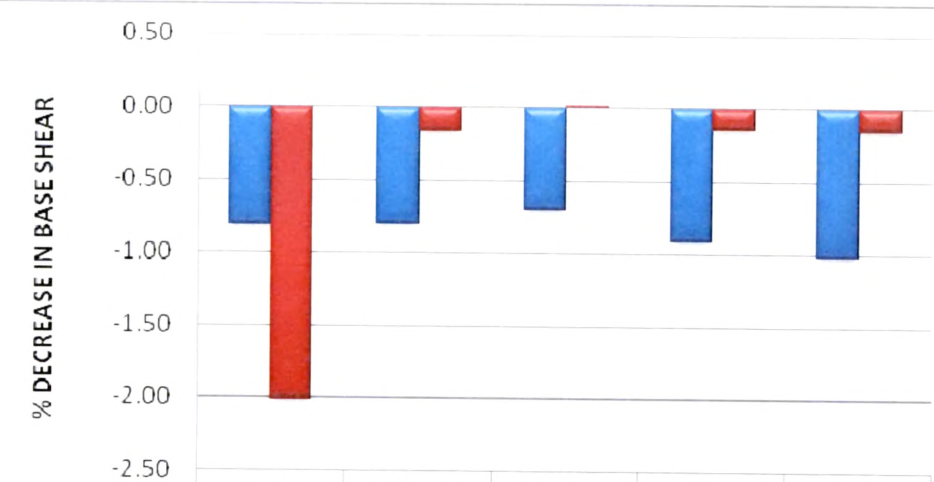
c) G+5 Storey

d) G+6 Storey

e) G+7 Storey

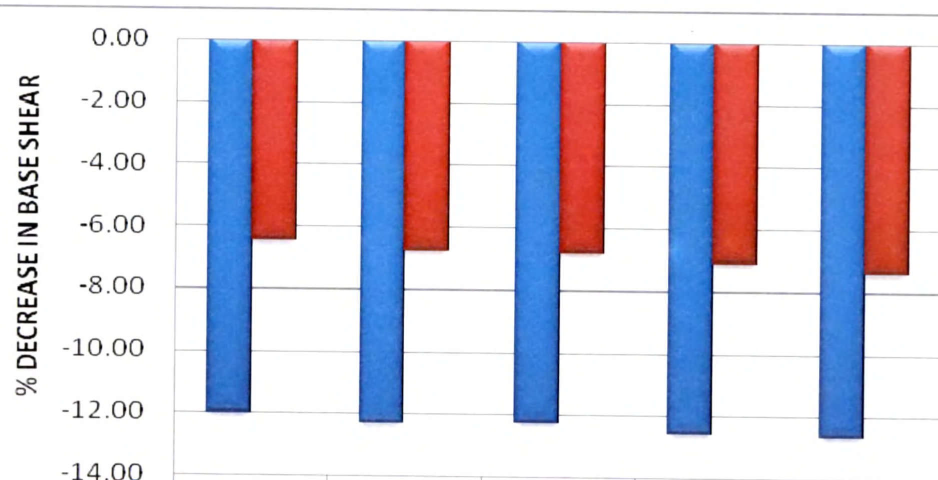
Fig. 11.21 Roof Displacement Variation at Performance Point

15m x 15m Overall Plan Dimension Models



	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 100000	-0.81	-0.80	-0.70	-0.91	-1.02
HYBRID 100000	-2.01	-0.16	0.02	-0.14	-0.15

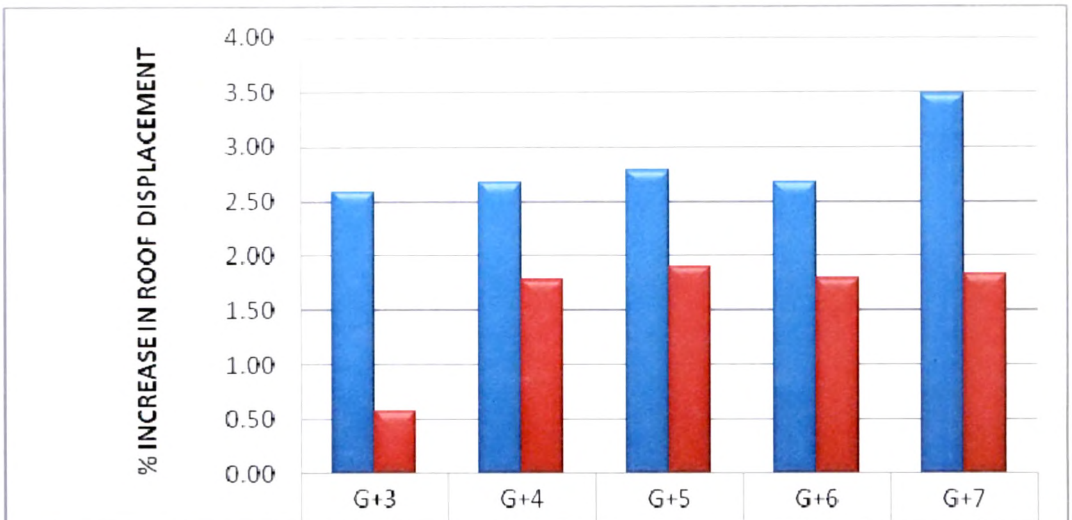
Fig. 11.22 Percentage Variation in Base Shear Relative to Rigid Frame



	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 0	-12.00	-12.29	-12.28	-12.55	-12.66
HYBRID 0	-6.44	-6.74	-6.79	-7.08	-7.40

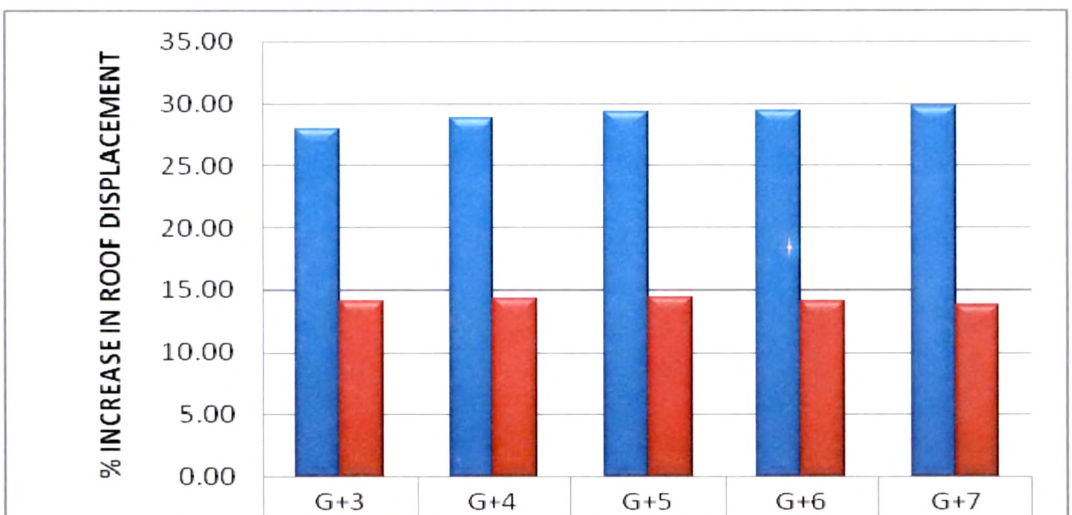
Fig. 11.23 Percentage Variation in Base Shear Relative to Rigid Frame

15m x 15m Overall Plan Dimension Models



	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 100000	2.58	2.67	2.78	2.68	3.47
HYBRID 100000	0.57	1.77	1.90	1.79	1.82

Fig. 11.24 Variation in Roof Displacement Relative to Rigid Frame



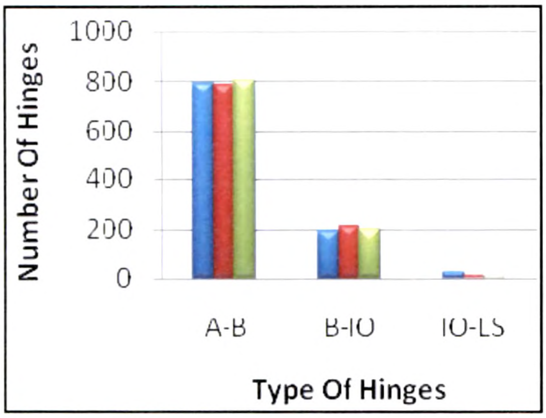
	G+3	G+4	G+5	G+6	G+7
SEMIRIGID 0	27.98	28.79	29.37	29.48	29.75
HYBRID 0	14.06	14.29	14.36	14.08	13.77

Fig. 11.25 Variation in Roof Displacement Relative to Rigid Frame

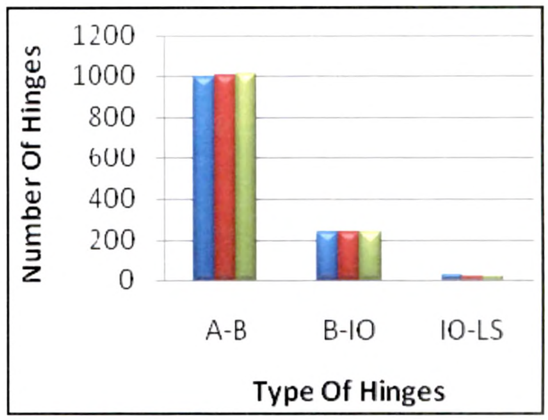
Table 11.6 Number of Plastic Hinges Developed - 15m x 15m Frame

Frame type		A-B	B-IO	IO-LS	TOTAL
G+3	Hybrid 0	926	72	10	1008
	Hybrid 7500	924	74	10	1008
	Hybrid 100000	786	212	10	1008
	Hybrid 290000	786	198	24	1008
	RIGID	790	194	24	1008
	Semi Rigid 0	984	24	0	1008
	Semi Rigid 7500	980	28	0	1008
	Semi Rigid 100000	804	198	6	1008
	Semi Rigid 290000	784	200	24	1008
G+4	Hybrid 0	1152	96	12	1260
	Hybrid 7500	1156	92	12	1260
	Hybrid 100000	1004	240	16	1260
	Hybrid 290000	992	242	26	1260
	RIGID	996	240	24	1260
	Semi Rigid 0	1240	20	0	1260
	Semi Rigid 7500	1218	42	0	1260
	Semi Rigid 100000	1006	238	16	1260
	Semi Rigid 290000	992	242	26	1260
G+5	Hybrid 0	1390	108	14	1512
	Hybrid 7500	1390	108	14	1512
	Hybrid 100000	1194	296	22	1512
	Hybrid 290000	1184	292	36	1512
	RIGID	1186	298	28	1512
	Semi Rigid 0	1480	32	0	1512
	Semi Rigid 7500	1454	58	0	1512
	Semi Rigid 100000	1202	294	16	1512
	Semi Rigid 290000	1184	290	38	1512
G+6	Hybrid 0	1620	130	14	1764
	Hybrid 7500	1626	124	14	1764
	Hybrid 100000	1392	352	20	1764
	Hybrid 290000	1388	342	34	1764
	RIGID	1384	348	32	1764
	Semi Rigid 0	1728	36	0	1764
	Semi Rigid 7500	1694	70	0	1764
	Semi Rigid 100000	1400	346	18	1764
	Semi Rigid 290000	1382	346	36	1764
G+7	Hybrid 0	1852	150	14	2016
	Hybrid 7500	1852	150	14	2016
	Hybrid 100000	1598	400	18	2016
	Hybrid 290000	1586	400	30	2016
	RIGID	1586	402	28	2016
	Semi Rigid 0	1980	36	0	2016
	Semi Rigid 7500	1944	72	0	2016
	Semi Rigid 100000	1510	494	12	2016
	Semi Rigid 290000	1586	398	0	2016

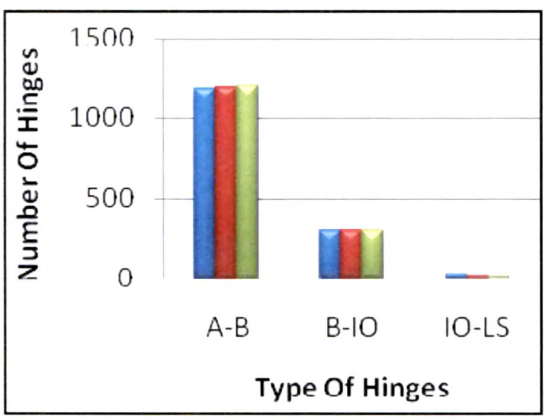
15m x 15m Overall Plan Dimension Models



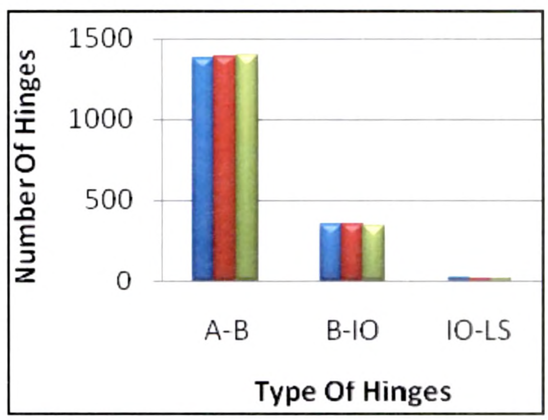
a) G+3 Storey



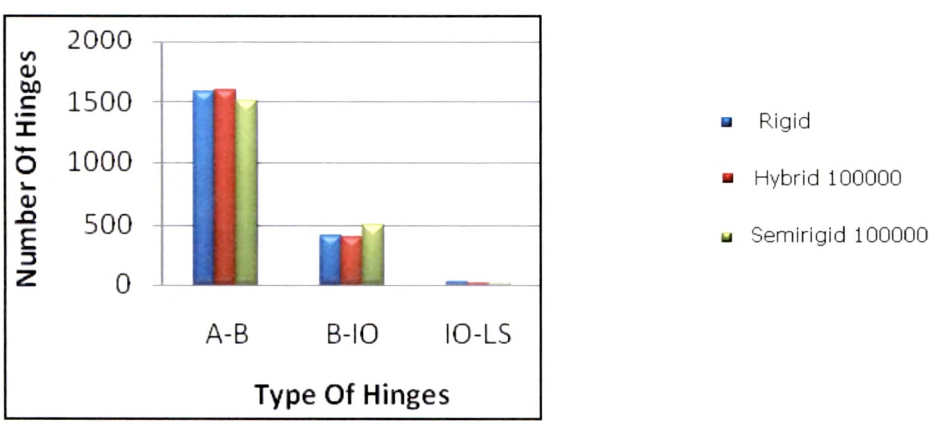
b) G+4 Storey



c) G+5 Storey



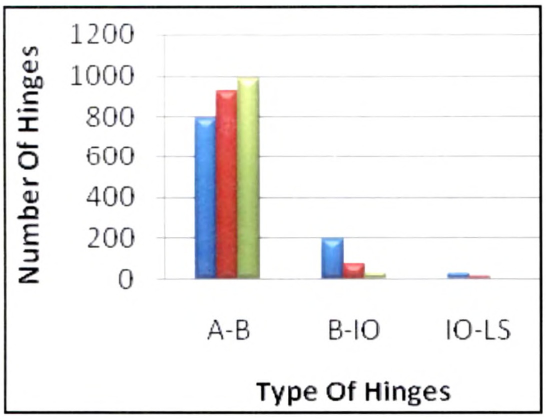
d) G+6 Storey



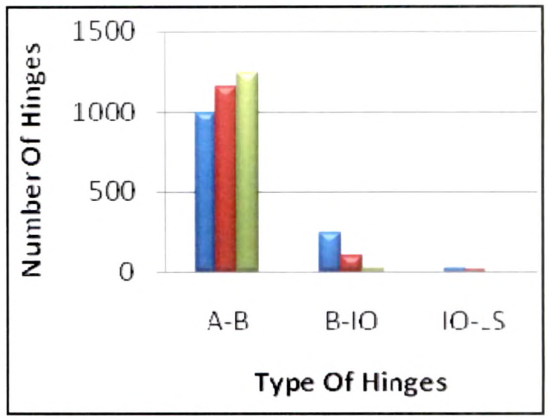
e) G+7 Storey

Fig. 11.26 Number of Hinges at Performance Point for 45% Rigidity

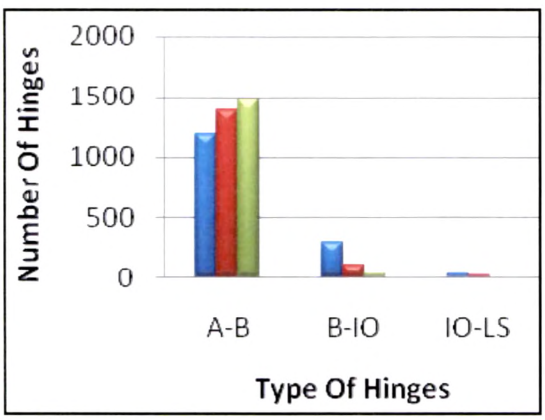
15m x 15m Overall Plan Dimension Models



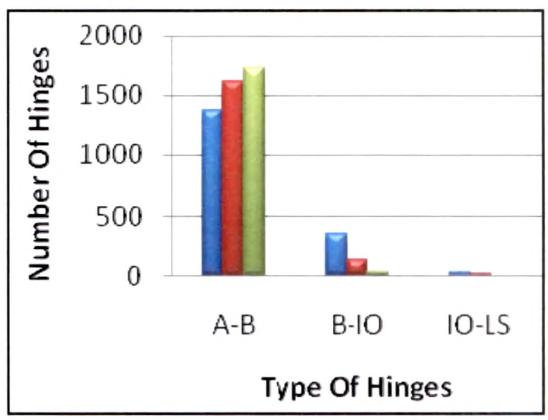
a) G+3 Storey



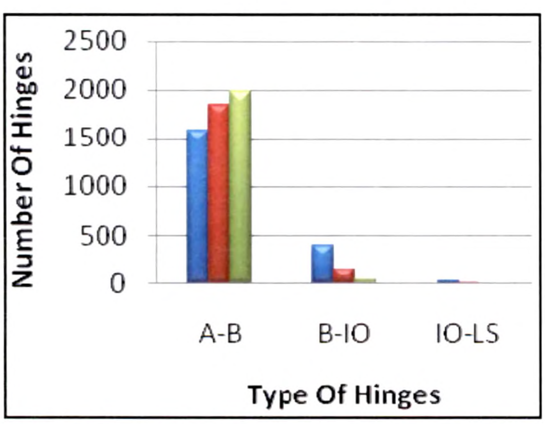
b) G+4 Storey



c) G+5 Storey



d) G+6 Storey



e) G+7 Storey

Fig. 11.27 Number of Hinges at Performance Point for 0% Rigidity

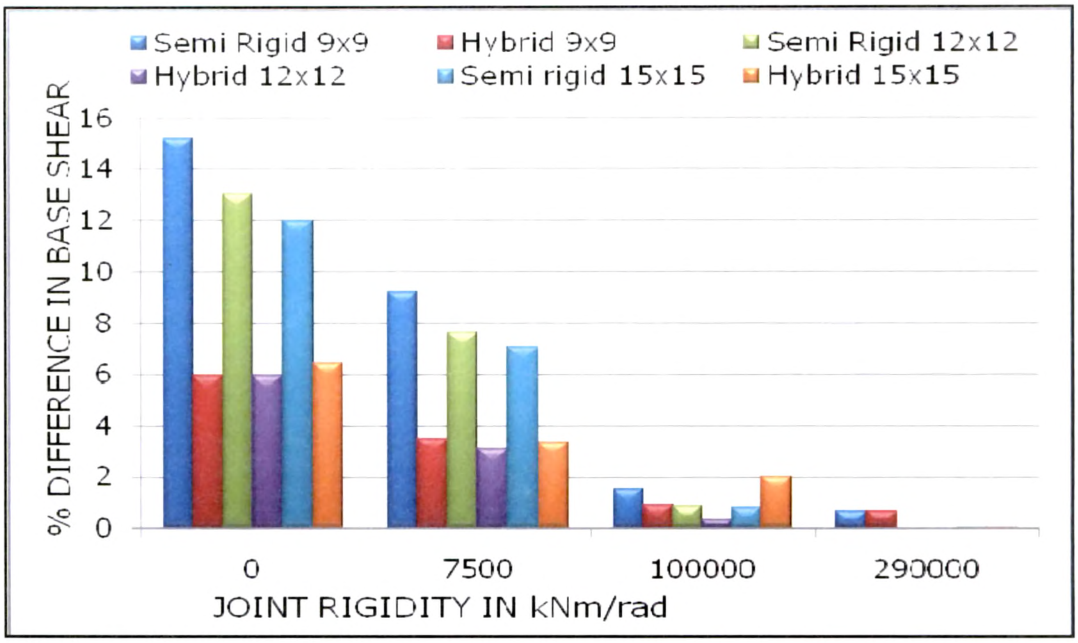


Fig. 11.28 Base Shear Variation Relative to Fully Rigid Frames – G+3

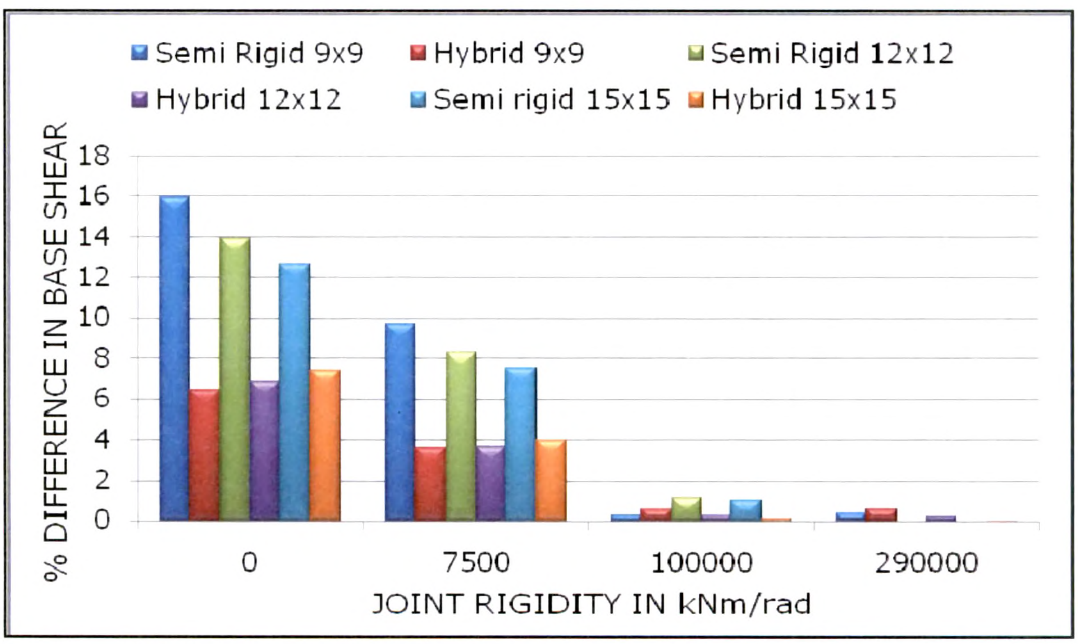


Fig. 11.29 Base Shear Variation Relative to Fully Rigid Frames – G+7

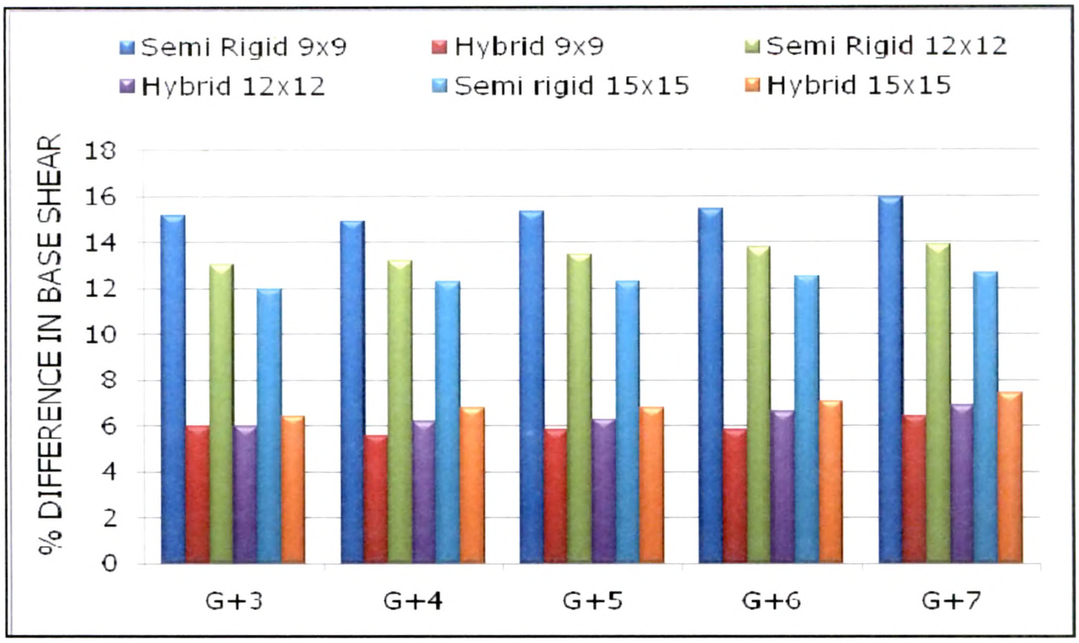


Fig. 11.30 Base Shear Relative to Fully Rigid Frames – 0% Rigidity

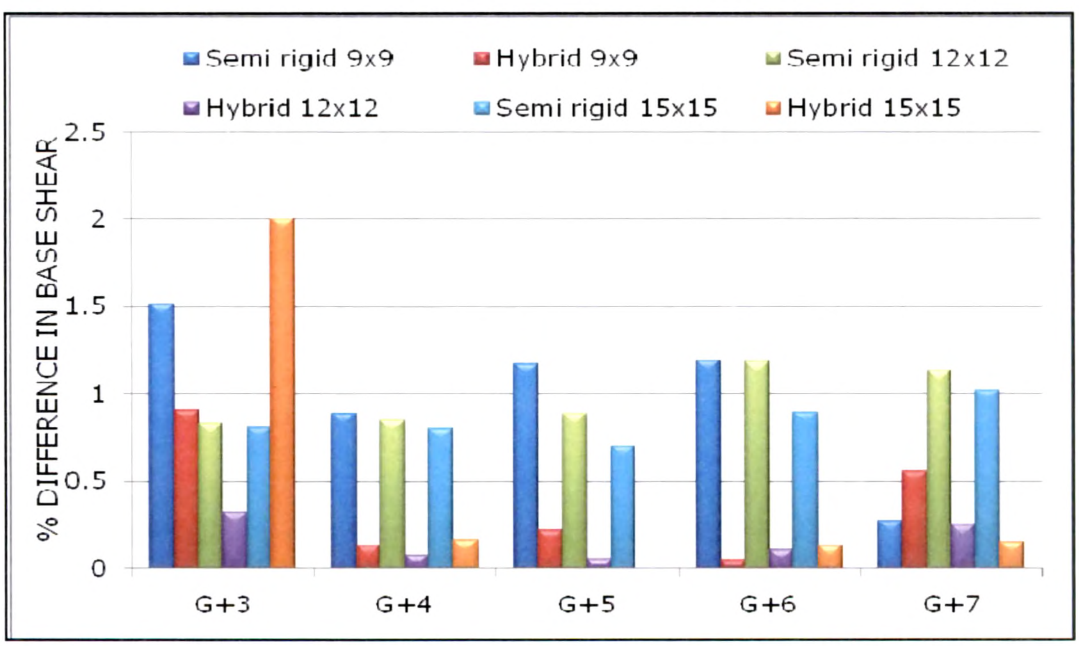


Fig. 11.31 Base Shear Relative to Fully Rigid Frames – 45% Rigidity

11.3 DISCUSSION OF THE RESULTS

1. From **Figs. 11.2** and **11.3** it can be seen that for the 9m x 9m frames for G+3 to G+7 storey, the hybrid frame behaves similar to the rigid frame for all joint stiffness variation at performance point. From **Figs. 11.11** and **11.12** it can be seen that the performance of hybrid frame is almost midway between rigid and semi rigid frames for 12m x 12m models. **Figures 11.20** and **11.21** indicates that for a 15m x 15m frame, the performance of hybrid frame deteriorates and tends to be more towards semi rigid frame. Thus, as the size of the frame increases, the advantage of hybrid frame decreases as far as the seismic performance is concerned. This trend is observed for G+3 to G+7 storey frames. From the same figures, it is also clear that for the joint rigidity of 45%, the performance of both semi rigid and hybrid types of frames is very near to that of fully rigid frame.
2. From the plot of variation in roof displacement for 45% joint rigidity, **Fig. 11.6** shows an average variation of less than 2.7% for 9m x 9m models. The same value increases to 32% for semi rigid and 10% for hybrid for 0% joint rigidity as seen in **Fig. 11.7**. Thus, the difference in roof displacement increases considerably on decreasing the joint rigidity. Moreover, the difference between hybrid and semi rigid frames at a value of very low joint rigidity is considerable. This indicates that hybrid frames help in controlling the drift to a great extent.
3. The study of roof displacement variation for 12mx12m size frame presented in **Figs. 11.15** and **11.16** reveal that the variation for 45% rigid joints of semi rigid and hybrid frames relative to fully rigid frames is 2.5% and 2% respectively, it rises to 30% and 12.5% for fully released joints.
4. Similarly the variation in roof displacement for 15m x 15m frame is 3.5% and 2% for semi rigid and hybrid frames with 45% joint rigidity.

The same variation increases to 29.5% and 14% for semi rigid and hybrid frames with 0% rigid ends. These observations are derived from **Figs. 11.24** and **11.25**.

5. From observation numbers 2, 3 and 4, it can be stated that the variation in roof displacement for semi rigid and hybrid frames relative to a fully rigid frame decreases for semi rigid and increases for hybrid with the increase in frame size for 9m x 9m to 15m x 15m regardless of number of storey. This means that the difference in variation between hybrid and semi rigid frames decreases with increase in the size of the frames.
6. The variation in Base Shear for 45% joint rigidity for 9m x 9m semi rigid frames is not exceeding 1.5% except for G+5 frames which seems to be an exception. There is hardly any difference for hybrid frame for 9m x 9m frame which is depicted in **Fig. 11.4**. The variation in base shear for 0% rigidity is 17% for semi rigid and 4% for hybrid frame for the 9m x 9m model for all variation in storey. This is seen in **Fig. 11.5**.
7. For the 12m x 12m frame, the base shear variation is less than 1.2% for a 45% joint rigidity for semi rigid case whereas it is very low for hybrid frames as seen in **Fig. 11.13**. The variation increases to 13.5% for semi rigid frames and 6.5% for hybrid frames when the joint rigidity is considered as 0%. This is depicted in **Fig. 11.14**.
8. For the 15m x 15m frames, the variation in base shear is less than 1% for semi rigid case with joint rigidity of 45% as seen in **Fig. 11.22.** The same difference rises to 12.3% for semi rigid and 6.75% for hybrid frames as seen in **Fig. 11.23** for 0% joint rigidity.
9. The trend in the variation in base shear with increase in joint flexural rigidity and plan size of the frames is clearly depicted for G+3 storey frame in **Fig. 11.28** and for G+7 storey frame in **Fig. 11.29**. The similarity of the two plots shows the trend is independent of number

of storey. From the two plots, it is observed that for joint flexural rigidity more than 45%, the base shear variation is negligible for rigid, semi rigid and hybrid frames.

10. It is also observed that the variation in base shear for low flexural rigidity decreases with increase in rigidity and increase in plan size for semi rigid frames. For hybrid frames, the variation in base shear relative to fully rigid frame decreases with increase in joint flexural rigidity, but for a given joint flexural rigidity, it increases with increase in the plan size. This trend is indicated in **Fig. 11.30** which shows that the trend is independent of number of storey.
11. **Figure 11.31** shows that for a higher joint flexural rigidity of 45%, the trend in variation in base shear is insignificant as the variation itself is less than 1.2% for all cases.
12. It can be seen from **Tables 11.2, 11.4** and **11.6** and the corresponding plot of number of hinges developed for G+3 to G+7 storey frames that in all the cases, majority of the hinges are in the elastic zone i.e. A-B. The number of plastic hinges developed in the rigid frames is highest followed by hybrid and the lowest number of hinges develop in semi rigid frames for low flexural rigidity. For flexural rigidity of 45%, the number of plastic hinges developed in all types of frames is almost the same. This is observed for all variation in number of storey and plan dimensions.