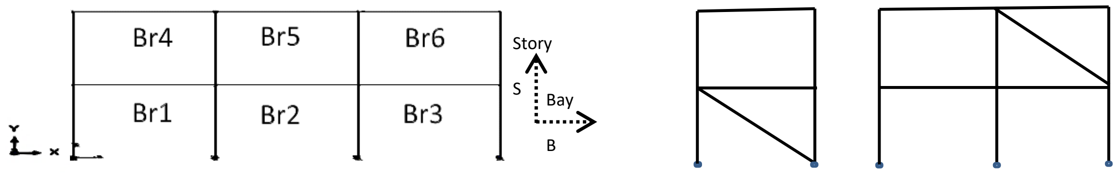
CHAPTER 4: LINEAR BUCKLING ANALYSIS OF BRACED FRAMES: THE EFFECT OF BRACING LOCATION

In this study, buckling analyses of two-dimensional steel frames have been carried out considering various combinations of 3 bays and 3 stories *(one bay/ story to three bays/ stories*). The linear perturbation buckling analysis was conducted on the Abaqus CAE software. The effect of particular bracing location on the overall buckling behavior of frames was studied by individually incorporating a brace (*single diagonal or cross-X brace*) in either of the bracing locations of the frame. The effects of the bracing location were compared between the bare frames, fully braced frames, chevron braced frames and the diagonal braces having same slenderness as that of beams and columns. Such type of analysis would be useful for the safe design of braced frame structures against buckling.

4.1 MODELING AND METHODOLOGY

Rigid jointed 2D frames having fixed base supports have been considered. All beams and columns were of length 3 metres. The concentric braces have been considered for this study. Design of connections was not done here as they were considered as ideal rigidly connected joints. The frames were modelled considering them to be non-ductile, NCBFs. Steel was used as the material for construction of all the members of the frame. Elastic properties used were, young's modulus, E= $2e8\ kN/m^2$, the Poisson's ratio= 0.3 and the self-weight was neglected. Homogeneous sections were used with sectional properties as, E= $2e8\ kN/m^2$, Shear modulus, G= $7.7e7\ kN/m^2$.

Firstly, to study of the effect of location of brace on the buckling behavior of braced frames, 45 frames made from various combinations of 3 bays and 3 stories have been analyzed. A single diagonal brace (*oriented at 135° angle with x-axis*) or a single X brace has been introduced at each bracing level individually (*as individual case of analysis*). For defining nomenclature to the bracing locations, they have been numbered as shown in Figure 4.1, where *Br* represents brace. To denote the number of bays and stories, abbreviations *B*n, *S*n are used (*where, n is the number of respective bays and stories in the frame*) respectively. All other abbreviations are given in their context itself.



a) b) c)

Figure 4.1 a) Numbering of braces; b) One bay - two stories frame (B1S2) with brace in Br1 location; c) Two bay - two stories frame (B2S2) with brace in Br3 location

For comparison, fully braced frames using diagonal or X braces; braces having same slenderness as that of beams and columns; and one other bracing type (*chevron bracing*), have been considered, as shown in Figure 4.2. Combinations of single story with bays varying from 1 to 4 have been analysed to access the best location of braces and to get the best combination of inserting braces at particular locations.

a) Diagonal brace b) cross (*X*) brace c) chevron brace

Figure 4.2 Types of braces used for comparison

The parameter of concern here was Critical load (P_{cr}) under vertical and lateral loadings (*from both lateral sides*). As this is a comparative study, the frames having higher P_{cr} values, were expected to have higher P_{cr} values in any other buckling analysis method also. So, the linear perturbation method was expected to fulfil the purpose of this study. Abaqus software (2014) has been used for analyzing the frames considering two-node cubic-beam element. In linear perturbation method, a unit load has to be applied on selected nodes and based on them critical load (*Eigen values*) would be obtained for various Eigen modes. Nearly 9 to 18 Eigen modes were requested for various cases. The first positive Eigen value has been chosen to be the P_{cr} value for each frame case.

As it is known that strong-column weak-beam would be ideal for the ductile behavior of framed structures under the influence of seismic loading. But it was also found in various researches that the presence of strong beam in chevron braced frames would be good for handling the unbalanced forces that come in presence after the post-buckling condition. But the inclusion of strong beam throughout the frame has been found to cause weak story problem in lower stories, resulting in a brittle failure.

To prevent other such design complexities in the present analyses, for all the members, circular cross-section has been considered for simplicity and ease of understanding. Initially, radius of 0.05 m has been used for all structural members including braces. Radius of 0.07071 m was used for a comparison case of braces having slenderness equal to that of beams and columns. Concentrated vertical loads have been provided at all the nodes connecting the beams and the columns. Concentric lateral loads were provided at open end corner nodes only (*either side*). The loadings have been shown in Figure 4.3.

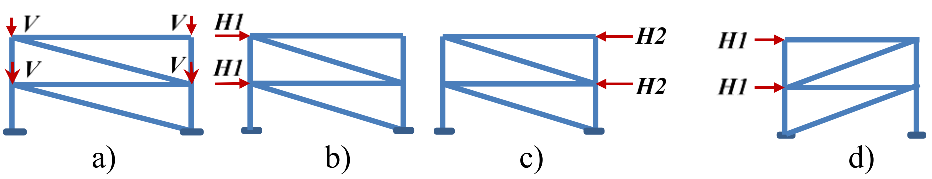


Figure 4.3 For *B1S2* frame, a) Vertical force *V*, b) Lateral force *H1* and c) Lateral force *H2*; d) Lateral force H1 for 45º oriented brace corresponds to lateral force H2 shown for the 135º oriented brace

4.2 RESULTS AND DISCUSSION

4.2.1 Effect of location of brace on P_{cr} value of steel frames

Single brace placed at a bracing location individually contributed to one frame case. The results were obtained in the form of Eigen values (*first positive values of which were considered as buckling load*) for particular eigen modes. Unit of the load was in kN. P_{cr} values *H1* and *H2* were the lateral (*Horizontal*) loads, and *V* was the vertical load as shown in Fig. 3. *H* was the lower value among *H1* and *H2*.

Effect of the location of brace for a specific bracing location in the frame was represented by buckling load values given for '*Brn*', (*where, 'Br' represented the symbol for brace and 'n' represented its numerically designated location in the particular frame, as explained in Figure 4.1*. For the single-storied frames with varying number of bays, the load values has been given in terms of P_{cr} values, in Table 4.1. The results were obtained by introducing the diagonal brace or the cross-brace at each bracing location.

Table 4.1 Bucking loads (kN) of single-storied frames having individual brace

Brace Location	Load Direction	Diagonal Brace			Cross Brace		
		Number of Bays, B			Number of Bays, B		
		1	2	3	1	2	3
No Brace	*H*	3340.13	3250.88	2961.45	3340.13	3250.88	2961.45
	V	804.62	829.64	854.52	804.62	829.64	854.52
Br1	*H1*	1323.73	1329.79	1333.20	5989.06	6172.90	6177.22
	H2	2445.05	2115.05	1994.90	5989.06	2665.64	2174.98
	H	1323.73	1329.79	1333.20	5989.06	2665.64	2174.98
	V	2936.39	2940.36	2941.47	4514.54	3049.60	2960.88
Br2	*H1*	-over-	1343.48	1349.15	-over-	2665.64	2668.44
	H2		2610.51	2166.73		6172.90	2668.44
	H		1343.48	1349.15		2665.64	2668.44
	V		2937.50	2940.26		3049.60	3044.95
Br3	*H1*		-over-	1350.53		-over-	2174.98
	H2			2616.27			6177.22
	H			1350.53			2174.98
	V			2938.41			2960.88

Effect of location of brace (*introducing single brace individually*) for a specific bracing location in the frame as shown in Figure 4.1 for the two-storied frames with varying number of bays has been given in terms of P_{cr} values, in Table 4.2. The results were obtained by introducing the diagonal brace or the cross-brace at each bracing location.

Table 4.2 Bucking loads (kN) for the two-storied frames having one individual brace

Brace Location	Load Direction	Diagonal Brace Number of Bays, *B*			Cross Brace Number of Bays, *B*		
		1	2	3	1	2	3
No Brace	*H*	1386.56	2469.36	2614.52	1386.56	2469.36	2614.52
	V	378.23	401.59	415.40	378.23	401.59	415.40
Br1	*H1*	590.56	607.40	616.72	1856.08	3059.27	2873.01
	H2	1128.11	1270.99	1295.47	1855.76	2165.27	1757.03
	H	590.56	607.40	616.72	1855.76	2165.27	1757.03
	V	671.50	707.96	733.93	706.94	722.73	745.70
Br2	*H1*	793.41	613.08	623.60	1612.63	2165.29	2321.35
	H2	1199.15	1641.51	1638.35	1612.63	3059.30	2321.35
	H	793.41	613.08	623.60	1612.63	2165.29	2321.35
	V	445.77	702.16	729.90	470.69	722.73	738.89
Br3	*H1*	-over-	854.43	620.07	-over-	2057.28	1757.03
	H2		1396.42	1634.43		1931.50	2873.01
	H		854.43	620.07		1931.50	1757.03
	V		448.38	729.79		463.20	745.71
Br4	*H1*		849.06	869.44		1931.50	1978.63
	H2		1407.01	1486.18		2057.28	1859.54
	H		849.06	869.44		1931.50	1859.54
	V		454.54	455.51		463.20	466.82
Br5	*H1*		-over-	894.40		-over-	2293.06
	H2			1599.90			2293.06
	H			894.40			2293.06
	V			455.73			460.11
Br6	*H1*			874.19			1859.54
	H2			1335.78			1978.63
	H			874.19			1859.54
	V			459.31			466.82

Effect of location of brace (*single brace individually*) for a specific bracing location in the frame as shown in Figure 4.1 for the three-storied frames with varying number of bays has been given in terms of P_{cr} values, in Table 4.3. The results were obtained by introducing the diagonal brace or the cross-brace at each bracing location.

Table 4.3 Bucking loads (kN) for the three-storied frames having one individual brace

Brace Location	Load Direction	Diagonal Brace Number of Bays, *B*			Cross Brace Number of Bays, *B*		
		1	2	3	1	2	3
No Brace	*H*	657.001	1256.340	1755.950	657.001	1256.340	1755.950
	V	233.663	252.234	263.112	233.663	252.234	263.112
Br1	*H1*	375.212	388.554	396.061	805.894	1880.280	1837.530
	H2	566.004	719.650	778.346	805.894	1229.470	1309.370
	H	375.212	388.554	396.061	805.894	1229.470	1309.370
	V	327.279	351.102	364.405	340.416	356.969	369.235
Br2	*H1*	397.025	391.151	399.457	750.600	1229.470	1902.580
	H2	556.975	1060.780	1115.200	750.600	1880.280	1902.580
	H	397.025	391.151	399.457	750.600	1229.470	1902.580
	V	295.722	348.468	362.627	313.214	356.969	366.295
Br3	*H1*	649.610	435.625	398.490	664.898	1102.230	1309.370
	H2	649.993	677.719	1039.400	664.898	925.805	1837.530
	H	649.610	435.625	398.490	664.898	925.805	1309.370
	V	241.458	297.813	362.579	244.268	308.122	369.235
Br4	*H1*	-over-	427.760	445.735	-over-	925.805	1071.510
	H2		789.960	738.024		1102.230	1014.030
	H		427.760	445.735		925.805	1014.030
	V		301.832	302.682		308.122	310.531
Br5	*H1*		790.840	455.639		135.546	1235.900
	H2		920.392	901.090		951.571	1236.050
	H		790.840	455.639		951.571	1235.900
	V		256.781	302.804		258.133	305.973
Br6	*H1*		779.729	442.009		951.571	1014.030
	H2		1169.020	754.851		135.546	1071.510
	H		779.729	442.009		951.571	1014.030
	V		256.955	305.236		258.133	310.531
Br7	*H1*		-over-	814.825		-over-	1422.740
	H2			1067.530			1118.830
	H			814.825			1118.830
	V			266.587			267.458
Br8	*H1*			839.150			1610.550
	H2			1384.620			1610.550
	H			839.150			1610.550
	V			266.652			267.363
Br9	*H1*			815.929			1118.830
	H2			1164.520			1422.740
	H			815.929			1118.830
	V			266.688			267.458

Remark for all Considered Cases of Frames Singly Braced by Diagonal Brace

With the increase in the number of bays for the same number of stories, both vertical and horizontal critical loads increased except for the first story of no brace condition where horizontal P_{cr} value decreased. With the increase in the number of stories for the same number of bays both horizontal and vertical critical loads got reduced (*i.e. effect was detrimental with increase of stories*). *H1* value was less than *H2* value as there was no tension brace available against *H1* loading. Considering bracing condition alone, mostly the braces with minimum vertical P_{cr} value gave maximum horizontal P_{cr} value vice-versa. With the rise in the locations of brace in the same configuration of frame, horizontal P_{cr} value increased and vertical P_{cr} value decreased. Against the buckling due to the vertical load, braces at bottom story corner bay were preferable. Bracing at top stories were found to have more horizontal P_{cr} value but it wasn't enough to resist the buckling, in comparison to bare frame. For horizontal load single diagonal brace has been found to be detrimental whereas for the vertical load it was quite beneficial.

Remark for all Considered Cases of Frames Singly Braced by X Brace

The behavior of X brace was very much different from diagonal brace, because of the symmetry of the brace. With the increased number of bays for the same number of stories, both vertical and horizontal critical loads increased. With the increased number of stories for the same number of bays both horizontal and vertical critical loads got reduced. In comparison to diagonal brace, cross braces were found to have higher resistance to buckling under both the vertical and the horizontal loads. Here, cross-braces were found to be more beneficial at bottom stories.

R*emark for both Diagonal and Cross Braces, considering Singly Braced Frames*

For given loadings, any kind of individually introduced brace in a frame individually was not enough for restraining the buckling due to lateral loading. What to speak of increasing the buckling resistance, under lateral load, in some cases it was detrimental for the stability of the structure as it degraded the buckling resistance of the frame. If a single ordinary brace was introduced in the frames in any of the configurations of bay and stories, it was for sure that the stability under lateral load was either going to reduce or not going to increase substantially. For B1S1 frame (*fully braced*), the *X* brace was found beneficial for considered profile, which has been found to have more buckling resistance than that of bare frame. If considering the strength gain against buckling due to axial (*vertical*) load, even a single brace provides substantially high restraint against buckling.

Like as used here, the braces (*cross-section same as that of beams and columns*) were having slenderness ratio more than that of beam and columns which would make them more prone to buckle early. Individually placed braces wouldn't resist the buckling substantially and in general practice also (*to avoid stiffness irregularity*), the bays have mostly been braced throughout its stories.

4.2.2 Comparison of the fully braced cases with cases of frame braced with one single brace, for each frame configuration

In upcoming sections, the comparison has been done between the bare frames, the braced frames with individually placed braces and the fully braced frames. In the upcoming tables, *S1, S2* and *S3* referred to the number of the stories and the buckling load values written under them (*for corresponding number of the bays (B) of the frame*) were for the cases of the singly braced frames resisting maximum P_{cr} load. '*Nbr*' represented the bare frame cases; whereas, '*Full*' represented the fully braced configurations.

4.2.3 Story-wise variation for a particular number of bays [*B1 (S1, S2, S3); B2 (S1, S2, S3); B3 (S1, S2, S3)*]

Considering the diagonal brace cases (*in Table 4.4*), under the vertical loading, in all the cases, fully braced frame was more stable than singly braced frame and singly braced was more stable than bare frame. But, under lateral loading, in case of single bay with increased in number of stories, fully braced frame showed less stability in comparison to best of singly braced frame cases, both being less than bare frame condition due to premature buckling. For two and three bay cases, the fully braced frames were found to have higher stability than singly braced frame (*except for B2S3 configuration*) both having stability less than bare frame condition.

Table 4.4 Maximum P_{cr} for singly or fully braced frames using diagonal brace

Lateral loading (kN)									
	S1	***S2***	***S3***	***Nbr S1***	***Nbr S2***	***Nbr S3***	***Full S1***	***Full S2***	***Full S3***
B1	1323.73	793.41	649.61	3340.13	1386.56	657.00	1323.73	699.19	610.30
B2	1343.48	854.43	790.84	3250.88	2469.36	1256.34	2309.54	1267.03	774.17
B3	1350.53	894.40	839.15	2961.45	2614.52	1755.95	2591.67	2034.27	1162.32
Vertical Loading (kN)									
B1	2936.39	671.49	327.28	804.62	378.23	233.66	2936.39	1618.85	1037.86
B2	2940.36	707.96	351.10	829.64	401.59	252.23	3003.32	1664.85	1069.99
B3	2941.47	733.93	364.41	854.52	415.40	263.11	3010.35	1670.45	1076.05

Considering X-brace cases (*in Table 4.5*), for one bay with stories varying from 1 to 3, it was found that under lateral loading, the best case of singly braced frame gave buckling resistance nearly similar to that of a fully braced case (*more than bare frame case*). For two and three bays with stories varying from 1 to 3, fully braced frame was more stable in comparison to singly braced and the bare frame. The singly braced frame showed stability even less than the bare frame (*except for B3S3 configuration*) because of the premature buckling. For vertical loading, in all cases fully braced frame was more stable than the singly braced frame and the singly braced was more stable than the bare frame.

Table 4.5 Maximum P_{cr} for single location X-braced and fully X-braced frames

Lateral Loading (kN)									
	S1	***S2***	***S3***	***Nbr S1***	***Nbr S2***	***Nbr S3***	***Full S1***	***Full S2***	***Full S3***
B1	5989.06	1855.76	805.89	3340.13	1386.56	657.00	5989.06	1968.54	857.21
B2	2665.64	2165.29	1229.47	3250.88	2469.36	1256.34	4953.47	4731.260	1990.91
B3	2668.44	2321.35	1902.58	2961.45	2614.52	1755.95	4744.43	4449.75	3541.93
Vertical Loading (kN)									
B1	4514.54	706.94	340.42	804.62	378.23	233,66	4514.54	2393.95	1552.60
B2	3049.60	722.73	356.97	829.64	401.59	252,23	4468.67	2541.16	1662.49
B3	3044.95	745.71	369.24	854.52	415.40	263.11	4396.48	2540.05	1699.74

4.2.4 Diagonal braces having same slenderness as that of beam and column

The P_{cr} values of the diagonally braced frames with brace having 'cross-section' same as that of beams and columns, (*D*) were compared with the P_{cr} values those frames having brace of same slenderness as that of beams and columns, (*D-SS*), as given in Table 4.6.

Table 4.6 Diagonal brace having same slenderness as beams and columns (*Fully braced*)

Frame	***D-SS***		**No Brace**		***D***	
	H (kN)	*V* (kN)	*H* (kN)	*V* (kN)	*H* (kN)	*V* (kN)
B1S1	2773.33	3049.35	3340.13	804.62	1323.73	2936.39
B1S2	1283.32	1865.07	1386.56	378.23	699.19	1618.85
B1S3	640.45	1227.78	657.00	233.66	610.30	1037.86

'*D-SS*' type frames were found to have more stability against both the vertical and lateral loadings than the '*D*' type frames. Both '*D-SS*' and '*D*' type frames were found to have less stability in comparison to bare frame condition under lateral loading; whereas, higher stablity was observed in comparison to bare frames under vertical loading. Considering cases of inclusion of single brace at individual bracing level in *B1S3* configuration, the numerical analysis results have been given in Table 4.7. For both the single braced '*D*' type and '*D-SS*' type frames, nearly equal stability was obtained against vertical loading. On having a brace at either of the bottom two stories, the P_{cr} value for the '*D-SS*' type frame was higher than the '*D*' type frame but for the brace at third story, it was lower.

Table 4.7 For B1S3, per brace P_{cr} (kN) for single bracing per story

Braces	***D-SS***		***D***	
	H	*V*	*H*	*V*
Br1	609.90	334.77	375.21	327.28
Br2	530.27	303.78	397.03	295.72
Br3	547.66	242.87	649.61	241.46

Except for the first story case, for the other considered cases, columns buckled first (*very detrimental*) in case of '*D-SS*' type frame whereas brace buckled (*desirable*) in case of '*D*' type frames. It can be understood that trying to improve the buckling behaviour by excessively increasing the slenderness of the brace can be highly detrimental. Similar conclusion was drawn from the repeated loading experiment (Wakabayashi *et. al.* 1977).

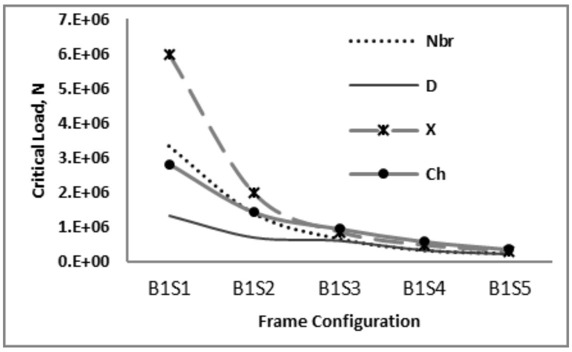
4.2.5 Comparison of considered braced frames with braced chevron (*Ch*) brace

One more type of bracing (*chevron bracing, Ch*) was included here for the comparison of the the P_{cr} values obtained by using the fully braced diagonal or the cross (*X*) braced frames. The comparison was made for one to five storied frames, as given in Table 4.8.

Table 4.8 Comparison of P_{cr} (kN) with fully braced chevron up to five stories

Bracing	**Loading direction**	***B1S1***	***B1S2***	***B1S3***	***B1S4***	***B1S5***
No Brace	*H*	3340.13	1386.56	657.00	320.82	231.76
	V	804.62	378.23	233.66	164.55	125.41
Diagonal	*H*	1323.73	699.19	610.30	336.25	223.05
	V	2936.39	1618.85	1037.86	744.68	541.91
X Brace	*H*	5989.06	1968.54	857.21	475.60	300.99
	V	4514.54	2393.95	1552.60	1128.37	894.78
Chevron	*H*	2812.40	1419.69	941.97	572.64	346.05
	V	3399.20	1818.78	1181.29	861.86	673.01

For all the braced frames, under both the vertical and the lateral loadings, the P_{cr} value decreased with the increase in the number of stories. For the considered bracing, under lateral loading, the effect of bracing on P_{cr} was found to be insignificant at 5^{th} story. Story-wise variation of fully braced frames under lateral loading has been shown in Figure 4.4.



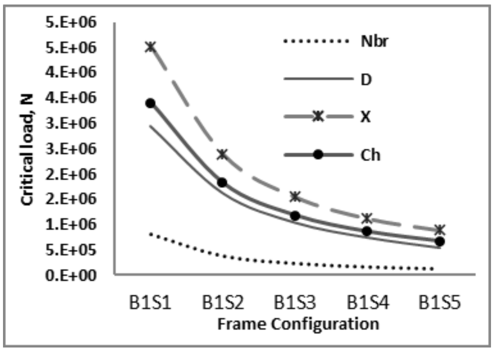


Figure 4.4 P_{cr} values (lateral loading)

Figure 4.5 P_{cr} values (vertical loading)

Referring Figure 4.5 for the story-wise variation of fully braced frames under vertical loading, the buckling load capacities were found to be more than bare frame condition. Considering the X Brace, under lateral loading. an abrupt reduction in buckling load capacity was observed. But for vertical loading, X-braced frames were found to work best. Being unsymmetrical and more slender, diagonal braces could buckle at lesser lateral loads. Considering chevron braced frames, under both lateral and vertical loadings, the rate of decrement was small. and under lateral loading up-to two stories, the lateral stability was less than that of the X-brace and the bare frame but for the higher stories (*except B1S5*), P_{cr} values were higher than the other bracing types.

The comparison of P_{cr} values using various braced frames for bay-wise (single story with a varying number of bays) comparison has been given in Table 4.9. Under lateral loading, among all considered types of braces, diagonally braced frames were found to have the lowest P_{cr} values. chevron braced frames were found to have less stability than that of the bare frames for the one-storied frame but for three and four storied frames, the Pcr values were even higher than those of the X braced frames (*X-braced frames were found to have P_{cr} values higher than the bare frame for all the considered frames*). Under vertical loading, P_{cr} values for the braced frames was higher than the bare frames; and among braced ones, X braced frames were found to be the most stable ones.

Table 4.9 P_{cr} (kN) for single story fully braced frames having multiple bays

Bays	**Load**	***X***	***Ch***	***D***	***Nbr***
B4S1	*H*	4705.86	5809.68	2582.66	2670.50
	V	4357.00	3450.05	3010.97	867.35
B3S1	*H*	4744.43	5551.05	2591.67	2961.45
	V	4396.48	3449.75	3010.35	854.52
B2S1	*H*	4953.47	4756.96	2309.54	3250.88
	V	4468.67	3445.79	3003.32	829.64
B1S1	*H*	5989.06	2812.40	1323.73	3340.13
	V	4514.54	3399.20	2936.39	804.62

To was attempted to find the best bay-wise arrangement of braces in terms of P_{cr} (kN), from various arrangements for the same number of braces in a particular frame. The best arrangements have been listed here in Table 4.10.

Table 4.10 Best arrangements giving higher P_{cr} (*location-wise bracing, 1 means brace and 0 means no brace*)

***B4S1* 3 Brace**	**X brace 1101**	**Chevron 1101**	**Diagonal 1101**	**Diagonal 1110**
H	4817.11	4820.23	2593.35	2154.07
V	4418.79	3442.68	3005.48	2955.89
***B4S1* 2 Brace**	**X brace 1001**	**Chevron 1001**	**Diagonal 1001**	**Diagonal 0110**
H	5285.64	4101.42	2152.80	2033.15
V	3416.97	3357.96	2954.43	3003.40
***B3S1* 2 Brace**	**X brace 101**	**Chevron 101**	**Diagonal 101**	**Diagonal 110**
H	5117.64	4356.88	2147.89	2158.13
V	4479.79	3438.02	3003.42	2954.77

For *B4S1* and *B3S1* configurations, all the considered configurations having bracing arrangements of one brace less than the full bracing were found have he P_{cr} values approximately equal to that of fully braced cases under vertical loading. In case of *X*-braced frames, P_{cr} values were even higher than its fully braced case under both vertical and lateral loads. For *B4S1* configuration, under lateral loading, X brace has maximum P_{cr} value on using just two braces at the end corner bays. So, it would be good to suggested to have braces at both corner bays on either side of the frame. For *B2S1* configuration, fully braced cases were found to have higher P_{cr} value. But for *B1S1* configuration, amongst various braced frames, different behavior in comparison to a greater number of bays was observed; as for the same cross-sectional area, only *X*-brace was found to be effective under both the vertical and the lateral/ horizontal loadings; whereas chevron and diagonal brace are found work better than bare frame condition only under vertical load.

4.2.6 *H/V* Ratio

The ratio of P_{cr} value under lateral loading to the corresponding vertical load value for same braced frame configuration has been denotede here as *H/V* ratio. This ratio would indicate about the uniformity in the increase or decrease of either of the loadings in comparison of other loading, with an increase in the number of bays or stories. On comparing the bare frame case ratios with that of the braced frame cases, this ratio indicated towards the change in the buckling behavior under various loadings. This ratio would be useful for ascertaining the optimised increase in stability (*under both the vertical and the lateral loadings*) on introduction of different type of bracings in a frame.

Comparison of the *H/V* ratio with the increase in the number of the stories for various fully braced frames has been given in Table 4.11. For chevron braced frames (*except for the first story*), all the values of P_{cr} under lateral and vertical loadings were higher than bare frame (see Table 4.8) and the deviation in values of *H/V* ratio was lesser (*optimized stability*) than other braced frames (see table 4.11).

Table 4.11 Comparison of *H/V* ratio for fully braced frames

Brace	***B1S1***	***B1S2***	***B1S3***	***B1S4***	***B1S5***
No Brace	4.15	3.67	2.81	1.95	1.85
Diagonal	0.45	0.43	0.59	0.45	0.41
X Brace	1.33	0.82	0.55	0.42	0.34
Chevron	0.83	0.78	0.80	0.66	0.51

The comparison of H/V ratio for fully braced frames and bare frame has been given in Table 4.12. The table has two parts; first one showing bay-wise variation (*with three stories and varying bays*) where, *H/V* ratio was found to increase with the increase in the number of bays.

Table 4.12 *H/V* ratios for the separate cases of varying bays and varying stories

Bays	**diagonal**	**X brace**	**No Brace**	**Stories**	**diagonal**	**X brace**	**No Brace**
Full	H/V	H/V	H/V	Full	H/V	H/V	H/V
B1S3	0.59	0.55	2.81	B3S1	0.86	1.08	3.47
B2S3	0.72	1.20	4.98	B3S2	1.22	1.75	6.29
B3S3	1.08	2.08	6.67	B3S3	1.08	2.08	6.67

In the second part of the Table, story-wise variation has been given (*with three bays and varying stories*) where, the *H/V* ratio was found to be inconsitant for the unsymmetric bracing like diagonal brace but for the symmetric braces like *X*-brace and chevron brace, *H/V* ratio was found to increase with the increase in the number of stories.

4.3 CONCLUDING REMARKS

It has been observed that the lateral buckling resistance was mostly influenced by very few braces at few lower stories (*but the irregularity perspective would be equally important while deciding the location*). All the considered braces were found to improve the stability against vertical loading. Here, in most of the cases, symmetric braces with a symmetric arrangement of bracing have been found to work well against both vertical and lateral load to avoid the premature buckling. Conclusions have been discussed elaborately in the last chapter, 'SUMMARY AND CONCLUSIONS'.