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SEISMIC RESPONSE OF REINFORCED CONCRETE CONCENTRICALLY A-BRACED FRAMES

Tanawade S. B.
Department of Civil Engineering, Solapur University, Solapur
shritanawade@rediffmail.com

Kore P. N.
Department of Civil Engineering, Solapur University, Solapur
korepralhad@gmail.com

Swami P.S.
Department of Civil Engineering, Solapur University, Solapur
s.prashant7474@gmail.com

Javheri S. B.
Department of Civil Engineering, Solapur University, Solapur
Sandeepjavheri14@gmail.com

ABSTRACT

Braced frames widen their resistance to lateral forces by the bracing action of inclined members. The braces stimulate forces in the associated beams and columns so that all work as one like a truss with all members subjected to stresses that are for the most part axial. This axial reaction results in less moments and in turn smaller sizes of beams and column sections compared to moment resisting frames. A concentrically braced frame has minor eccentricities in the joints of the frame that are accounted for in the design (which is tried with A-braced or K-braced or concentrically braced frames for this work). This paper presents the elastic seismic response of reinforced concrete frames with reinforced concrete bracing member in K or A – braced pattern which are analyzed numerically for twelve storey building with 5-bay structures. This approach focuses on the arrangements of A-braces in a particular bay, level and combinations thereof to reduce the lateral displacement ultimately to achieve an economy in comparison with similar moment resisting frames. Results are concluded from graphs and discussed comprehensively.

KEYWORDS : - Bare Frames, Baywise Braced Frames, Levelwise Braced Frames, A-Braced Frames, Concentrically Braced Frames (CBF), Outriggers.

INTRODUCTION

In order to make multi-storey structures stronger and stiffer, which are more susceptible to earthquake and wind forces, the cross sections of the member increases from top to bottom this makes the structure uneconomical owing to safety of structure [5]. Therefore, it is necessary to provide special mechanism and/or mechanisms that to improve lateral stability of the structure. Braced frames develop their confrontation to lateral forces by the bracing action of diagonal members. Fully braced frames are more rigid. From saving view point arbitrarily braced ones have least forces induced in the structure and at the same time produce maximum displacement within prescribed limits [10]. Frames can be analyzed by various methods [8]. However, the method of analysis adopted depends upon the types of frame, its configuration of (portal bay or multi-bay) multi-storey frame and degree of indeterminacy [8].

A-braced frames are one type of Concentrically Braced Frame (CBF) in which the arrangements of members form a vertical truss system to resist lateral forces. The main function of bracing system is to resist lateral forces. It is therefore possible in initial stage of design to treat the frame and the bracing as two separate load carrying system as shown in Figure 1. The behaviors of these frames with diagonals are evaluated through structural analysis [9].

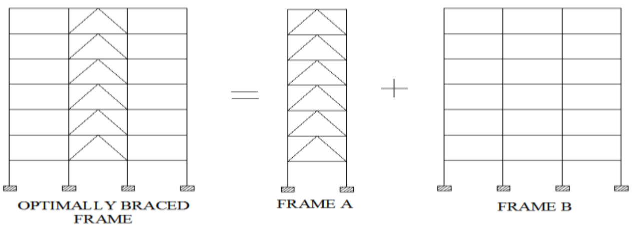


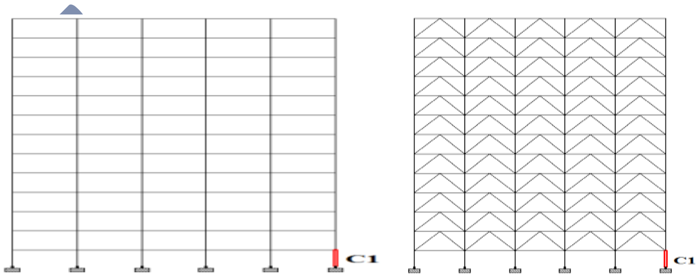
Figure 1: Braced frames split into two subassemblies

The structural analysis was based on structural models plotted in the STAAD- structural analysis and design commercial software. The frame shall be designed to resist the effect of gravity and earthquake loadings for strength and serviceability without aid of A-braces first, to ultimately represent a proposal of an introduction of A-braces having economical structure with good behavior and a convenient architectural distribution.
Shan – Hau Xu & Di – Tao Niu [1] had worked on seven reinforced concrete (RC) braced frame, one reinforced concrete frame and one reinforced concrete shear wall are tested under vertical loading and reversed cyclic loading. They focused mainly on the failure mechanism, strength, degradation in stiffness, and hysteresis loop of the RC braced frame. According to their study, in braced frames, not only lateral resistance and stiffness enhanced, but also energy dissipation amount increased significantly. A.R. Khaloo and M. Mahdi Mohseni [2] had worked on nonlinear seismic behavior of RC Frames with RC Braces. This study focuses on evaluation of strength, stiffness, ductility and energy absorption of reinforced concrete braced frames and comparison with similar moment resisting frames and frames with shear wall. J. P. Desai, A. K. Jain and A. S. Arya [3] had worked on two-bay, six-story frame designed by limit state method subjected to artificial earthquake and bilinear hysteresis model was assumed for girders, elasto-plastic model was assumed for columns and simple triangular hysteresis model was assumed for reinforced concrete bracing. It is concluded that the inelastic seismic response of X and K braced concrete frames with intermediate bracing members is satisfactory. M.A. Youssefa, H. Ghaffarzadehb, M. Nehdi [4] had worked on the efficiency of using braced RC frames is experimentally evaluated. Two cyclic loading tests were conducted on a moment frame and a braced frame. The moment frame was designed and detailed according to current seismic codes. A rational design methodology was adopted to design the braced frame including the connections between the brace members and the concrete frame.

DESCRIPTION OF STUDY BUILDING STRUCTURES

Bare and Fully Braced Frames

In order to study the behaviour of moment resisting A-braced frames (bare, fully, partially bay braced and partially level braced and outrigger frames) 5 bay 12 storey structures are modeled and analyzed numerically. The sections of columns are reduced from top to bottom which is same for every 3 storey (1-3, 4-6, 7-9, and 10-12) in order to achieve an economy in bare frames itself. In all cases, span length and story elevation are 4 and 3 meters, respectively. A typical frame of this type is shown in Figure 2.



a b

Figure 2: The specific worst loaded member considered for the analysis of various frames

BAYWISE AND LEVELWISE BRACED FRAMES

To study the behaviour of bay wise and level wise bracing pattern 5 bay 12 storeyed structures are modelled and analyzed numerically. A typical bracing pattern of this type is shown in Figure 3 (a and b). A number of structures and their different patterns with and without braces have been analyzed. The responses of braced frames of different configurations have been compared with bare frame and the same also have been compared with each other. Behaviours of fully braced frames with the partially braced frames also studied.

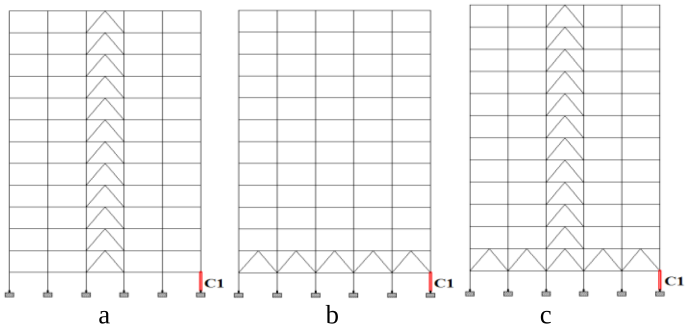


Figure 3: 5-bay 12 storey structures with particular Bay (a) & Level (b) and Outrigger Braced algorithms.

OUTRIGGER I.E. PARTIALLY BRACED FRAMES

The logic of placing the braces baywise and levelwise share the algorithm which allows for combining them evolving a "braced frame with outrigger" i.e. a partially braced frame which results the new combination of above two scenarios. To study the behavior of such outrigger frames 5 bay 12 storeyed structures are modeled and analyzed numerically. A typical frame of this type is shown in Figure 3 (c).

PARAMETRIC STUDY

Numbers of cases are tried for Bay wise and Level wise Braced Frames. The following Table 1 shows total number of cases for Bay wise and Level wise braced Frames for considered structures. In case of levelwise braced frames it is wise to restrict ourselves up to for higher level combinations since it will not going to procure any economy. Partially braced frames having combination of above two types i.e. baywise and levelwise braced frames shall be analyzed to study and compare the response of such frames. For this work 5 Bay 12 storeyed with 350 mm beam depth structure was used.

Table 1. No. of cases considered for Bay wise & Level wise braced Frames for 12 storey structures.

No. of Bays Braced	**No. of Bays Braced at a time**					
	One	Two	Three	Four	Five	Total
5-bay	5	10	10	5	--	30
No. of Levels Braced	**No. of Levels Braced at a time**					
	One	Two	Three	Four	Five	Total
5-bay	12	66	220	--	--	298
Total No. of Cases Studied						**328**

CHECK DIGIT ALGORITHEMS

Natural logarithm of reference number 'N' as dimensionless parameter has been used as abscissa with respect to considered parameters. The reference number used here is pure number, which is uniquely specified for the frame and bracing pattern tried. The check digits special algorithms are used for alpha and/or alphanumeric character fields. Each character is assigned a numeric equivalent. The numeric equivalents are weighted and the products are summed. The total is divided by the modulus to determine the remainder. The remainder is compared to a pre-assigned index to determine the check digit.

INTERNAL FORCES

Forces induced viz. axial force, shear force and bending moment in one particular worst loaded column segment is considered for this purpose as shown in Figure 2. In order to facilitate the direct comparison between bare and fully and/or partially braced frames the latter have been analyzed for the same geometry of mutually perpendicular/orthogonal members for the same loading combination for which the bare frame yielded the maximum design force in the members so selected as shown in Figure 3 (a, b & c). However, once the design forces are evaluated for fully and/or partially braced structures all individual segments are redesigned and the minimum required cross sections and steel percentage was calculated. Ultimately cost comparison is carried out to compute economy.

OPTIMUM BAYWISE AND LEVELWISE LOCATION FOR BRACING FRAMES

OPTIMUM BAYWISE LOCATION FOR BRACING FRAMES 5 BAY 12 STOREY STRUCTURES

Fully braced frames described previously, when analyzed, exhibit the values of forces and displacements which are changing with the variation of number of parameters. However, it was noticed that the frames underwent a very small lateral displacement than was permissible. It is but obvious that, when such frames are partially braced i.e. braced all along the height in a particular or a combination of number of bays which is less than total numbers of bays for the frame, similarly when braced all along the level or a combination of number of levels concerned, will produce a larger displacement compared to bare and fully braced frames but within permissible limit i.e. 0.004H [9]. Hence it was decided to find out such possibility of developing a particular pattern for partially braced frames, which would produce smaller forces for worst load combinations. It goes without saying that the bracing pattern tried always satisfied strength as well as serviceability criterion.
Here dimensionless parameter (R_a) i.e. ratio of axial force which is the ratio of value of axial force in member C1 for all cases of bays braced to axial force in same member of bare frame as shown in Figure 1 above. Same is applicable to ratio of shear force (R_s) and to ratio bending moment (R_m). The value of internal forces in worst loaded column segment (C1) of bare frame as shown in Figure 1 above is chosen as reference value for ratio $R_a/R_s/R_m$.

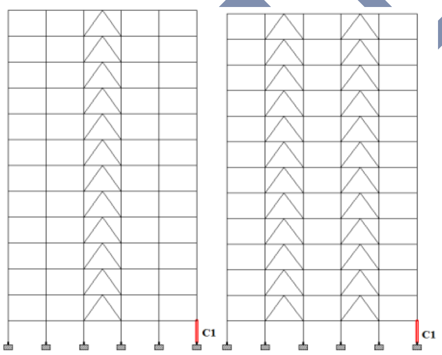
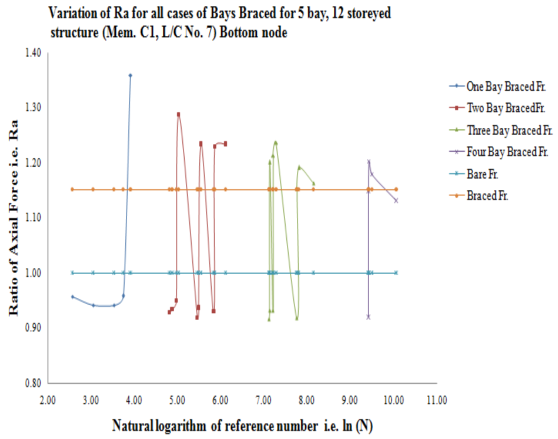


Figure 4: Optimum bay bracing pattern for 5 bay 12 storey structures

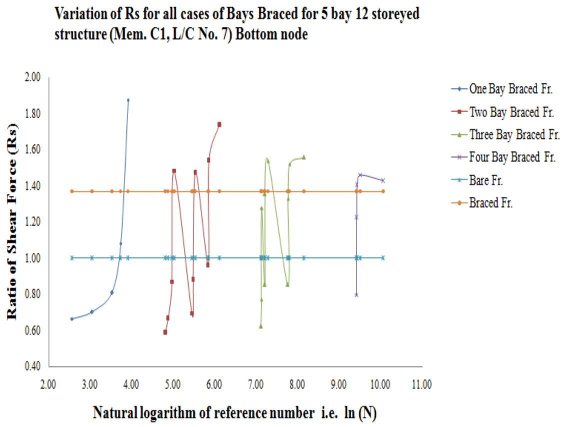
It seen clearly that every graph shows two lines parallel to the x-axis. If these are considered as the upper and the lower limits as may be appropriate to a particular dimensionless parameter, one finds that many a times in case of partially braced frames the dimensionless parameters observed exceeds the upper limits and/or is less than the lower limit so considered. From which it concludes that some of the braced frames may allow reduction in effect of considered parameters hence; it would be advantageous to suggest certain working range from specified/accepted minimum to maximum for various internal forces concerned within which a number of bracing patterns/cases produce the force being considered for different cases. However, a number of cases may be found common to all of them are the optimum cases as far as force levels are concerned. The frames which appear between those acceptable ranges were further taken into account for the analysis and design purpose. Often symmetrical cases are taken into account and tried in case of baywise bracings only.

Table 2. Showing percentage of Economy achieved in optimum Baywise and Levelwise location of bracings

Case No.	5 bay 12 storey structures	Percentage of Saving
a	For Baywise braced Pattern	**7.70%**
b		**3.20%**
c	For Levelwise braced Pattern	**7.87%**
d		**7.34%**



a



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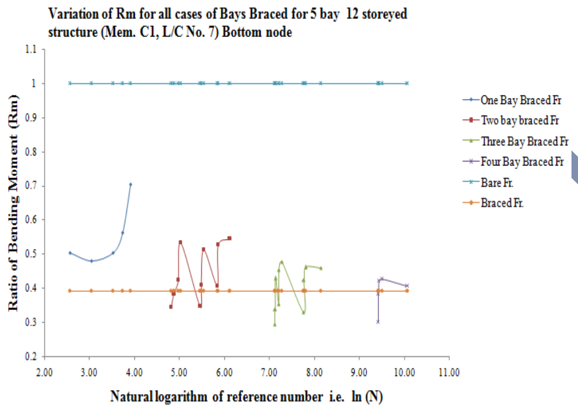


c

Figure 5: Variation of internal forces i.e. R_a, R_s, R_m of 5 bay 12 storey structures for Baywise combinations

All members of the frame are designed and saving in material is found out. Amongst all the so called best choices there is only one or more than one choice/choices is made available which reduce the total cost of structures compared to a bare frames, when all members are designed to carry the most critical combination of the largest developed forces. This bracing pattern/ these bracing patterns is/are the optimum solution/solutions. It is found that such bracing pattern is most economical than fully braced one. Following Figure 4 shows the variation of internal forces of 5 bay 12 storey structures and Figure 5 shows examples of optimum baywise braced frames for 5 bay 12 storey structures.

OPTIMUM LEVELWISE LOCATION FOR BRACING FRAMES 5 BAY 12 STOREY STRUCTURES

The same is repeated for levelwise bracing for previously mentioned structures and is represented in the Figure 6 below. The graphs show variation of axial force, shear force and bending moment in member C1 as the bracing pattern changes.

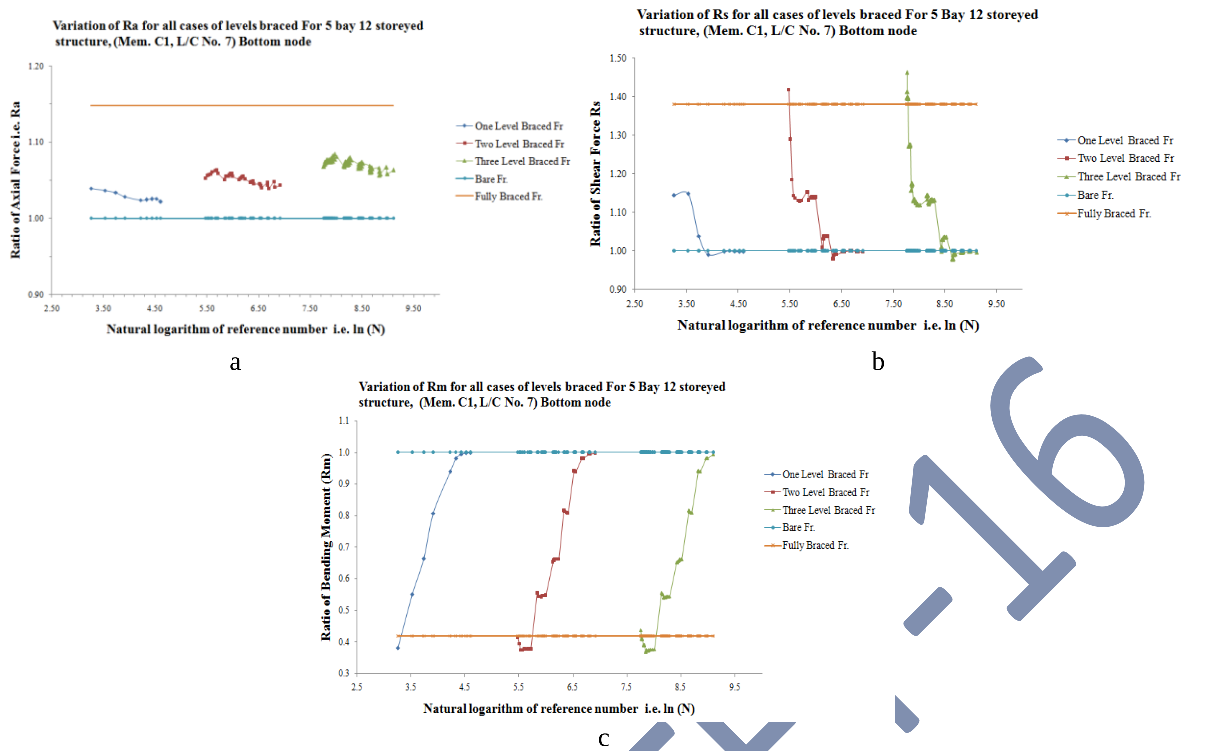
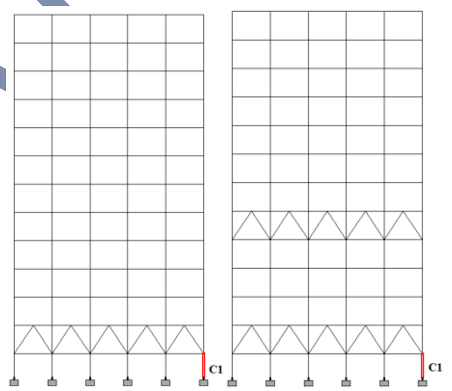


Figure 6: Variation of internal forces i.e. R_a, R_s, R_m of 5 bay 12 storey structures for Levelwise combinations

Overall, these graphs show the increment in the values of ratios of Ra as the bracing level and combinations of floor increases, Fig. 6 (b) show step variation except the cases which lie below and above the limit of bare and fully braced frames respectively, and Figure 6 (c) show the step variation except the cases which lie below the limit of bare frames. Hence, it seems reasonable to accept certain working range for axial force; shear force and bending moment from specified/accepted minimum to maximum for various internal forces concerned within which a number of bracing patterns/cases produce the force being considered different cases. However, a number of cases may be found common to all of them. These are most optimum cases as far as force levels are concerned. Figure 7 shows examples of optimum levelwise braced frames for 5 bay 12 storey structures and the economy is tabulated in table and the respective combinations are shown in Table 2 above.

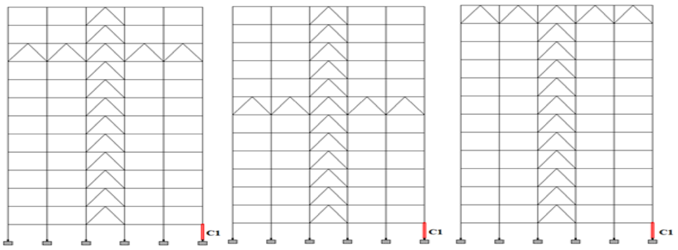


a b

Figure 7: Optimum level bracing pattern for 5 bay 12 storey structures

OPTIMALLY BRACED FRAMES WITH OUTRIGGERS

To begin with and to arrive at the outrigger orientation, a combination of optimum cases of baywise bracing and levelwise bracing pattern are tried. It may be noted that when a number of bays or levels braced simultaneously are increases then normally the cost effectiveness is lost, as the number of members increase which compensate the saving claimed due to reduction in the internal forces induced in the structures and the reduced cross sections commensurate with the same.



a b c

Figure 8: Optimum bracing patterns for 5 bay 12 storey structures

In order to reduce the material cost, optimum cases of baywise, levelwise and partially braced are considered and the section sizes are reduced to get minimum material cost and yet displacement remain within permissible limits. The following Figure 8 (a, b & c) shows the partially braced frame for the combination of specific bays and levels braced. The respective combinations and economy is tabulated as shown in Table 3 below.

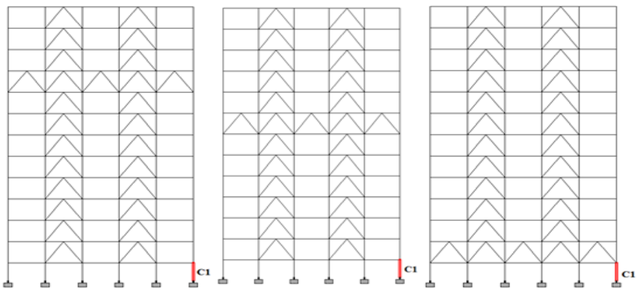
Table 3. Showing percentage of economy achieved in optimally braced frames with outriggers.

Case no. (For 5 bay 12 storey structures)	**Percentage of Saving**
B (3) + L (9)	**7.49%**
B (3) + L (6)	**7.41%**
B (3) + L (11)	**7.17%**

Another form of partially braced frame which is shown in Figure 9 (a, b & c) above, which comprises second and fourth bay braced throughout the height in combination with specific level is braced throughout are tried to obtain an economy. But such combinations are offering less economy as compared to partially braced frames i.e. frames with outriggers hence it is advantageous to adopt the previous combinations. The respective combinations and economy is tabulated as shown in Table 4 below.

Table 4. Showing percentage of Economy achieved in optimally braced frames with outriggers.

Case no. (For 5 bay 12 storey structures)	**Percentage of Saving**
B(2+4) & L(8)	**3.42%**
B(2+4) & L(6)	**3.27%**
B(2+4) & L(G)	**2.10%**



a b c

Figure 9: Optimum bracing patterns for 5 bay 12 storey structures

STOREY DRIFT

The lateral displacement of frame was observed at common point at specific position in 5 bay 12 storey structures. The comparison is made between bare, fully braced, partially braced i.e. optimum bay braced and level braced and outrigger. It was checked whether the structure satisfies maximum permissible relative lateral drift criterion as per IS: 1893-2002 (Part-I) which is 0.004H [9]. To insure the serviceability criterion, considering the lowest point as base of structure and highest point as top of the structure maximum relative drift is found and simultaneously compared with the permissible one as well as with other analyzed structures such as fully braced, partially braced and outriggers. The values are tabulated in Table 5 and the variation is shown in Figure 10.

Table 5. Showing variation of lateral displacement along height of structure for 5 Bay 12 storey structure with 350 mm beam depth

Analyzed Structures of 5 Bay 12 storey structures for 350 mm beam Depth					
Ht. From Base (m)	**Bare Frame (mm)**	**Fully Braced Frame (mm)**	**Optimum Bay Braced (mm)**	**Optimum Level Braced (mm)**	**Frame with Outrigger (mm)**
0	0	0	0	0	0
2.44	1.05	0.55	0.71	0.57	0.72
5.44	4.14	1.21	2.08	1.61	2.06
8.44	8.72	1.84	3.88	4.07	3.78
11.44	14.23	2.43	5.93	7.94	5.72
14.44	21.12	3.34	8.45	13.79	8.08
17.44	28.95	4.17	11.23	21.09	10.6
20.44	36.98	4.92	14.15	28.85	13.15
23.44	45.00	5.71	17.19	36.75	15.72
26.44	52.32	6.37	20.21	44.01	18.00
29.44	58.58	6.92	23.1	50.25	19.58
32.44	63.56	7.34	25.77	55.22	20.67
35.44	67.1	7.64	28.16	58.75	21.62
38.44	69.57	7.85	30.32	61.22	22.82

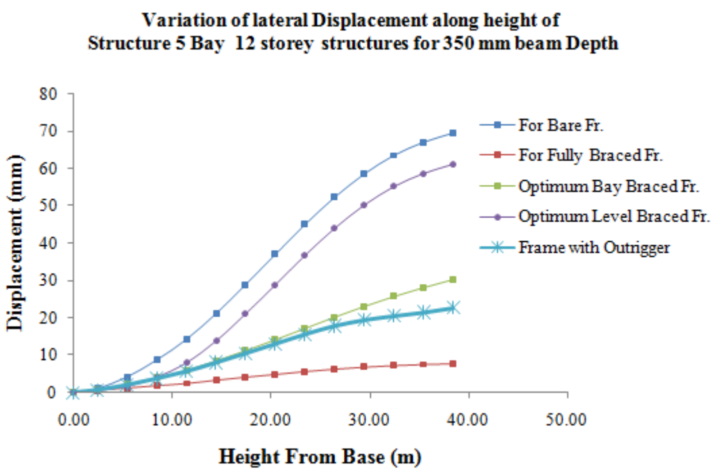


Figure 10: Variations of lateral displacement along height of structure for 5 Bay 12 storeyed with 350 mm beam depth for L/C (1.5 D.L. + 1.5 E.Q.)

For bare frames the lateral drift is well within the permissible one, but it is increasing as one move towards the top most point of structure. Also the lateral displacements for fully braced frames are getting substantially reduced as compared with bare frame, but these are uneconomical structures from saving point of view. For optimally bay braced frames and for outriggers the lateral displacements are getting reduced by near about half and more as compared to the bare frames. There is no valuable reduction in the lateral displacement for optimally levelwise braced frames.

CONCLUSION

It concludes that optimally braced frames are stiff, strong, and an economical structural system. Fully braced frames are very conservative in so far as lateral drift is concerned but uneconomical and at the same time optimally braced one have least forces induced in the structure and produce maximum displacement but within prescribed limit. However, further work is needed in order to achieve more economy by developing new scenario i.e. cellwise braced frames. This work is important, because braced frames are a very efficient and effective system for resisting lateral forces.

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