OPTIMIZATION OF BRACING TYPES ON AXIAL SHORTENING OF COLUMNS DUE TO DIAPHRAGM ACTION OF SLABS

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ABSTRACT

Bracings have evolved greatly as a lateral load resisting system in reducing the structures response to earthquake and wind forces. The phenomenon of diaphragm action in slabs have simplified the analysis of multi-storied buildings and detailing options to replicate the effect exactly on field has enabled accurate designs. Although bracings and slab diaphragms has received a fair share of research and development, the sensitivity analysis of Axial shortening due to different bracings and their comparison has received little to no-attention.

This paper deals with the determination of optimal bracing that will results in least Axial shortening in columns upon insistence of diaphragm action on slabs. For the study, three different types of bracings namely; X-bracing, V-bracing and Inverted V- bracing were analysed and compared with the Bare frame case. These bracings were also compared by taking four different patterns of their arrangement in elevation. The analysis was carried out for gravity loads and seismic loads and by varying seismic zones. Immediate Axial shortening and that due to staged construction were examined separately reporting the variance results for different types. The results obtained through the analysis is presented and observation discussed.

Keywords: Diaphragm action, Axial shortening, Bare frame, Sensitivity, Staged construction.

I. INTRODUCTION

A large portion of India is susceptible to damaging levels of seismic hazards. Hence, it is necessary to take in to account the seismic load for the design of structures. Increased use of concrete in high rise buildings has made these structures especially sensitive to delayed deformations due to concrete's natural tendency to creep and shrinkage. Axial shortening is experienced in load-bearing concrete columns and walls, it can be expressed as summation of elastic strain caused by load application, shrinkage strain caused by drying of concrete and creep strain induced by sustained stress over a long period of time.

Axial shortening is particularly relevant in tall buildings as loadings on the vertical structural member's result in significant stresses.

In the present study a 60 storied building is considered to understand the sensitivity of different bracings to axial deformation upon imposition of diaphragm action of floors. The analysis is carried out using SAP2000 by taking the Bare frame model for comparison.

S. Fragomeni and **H. Whaikawa** (2014) studied the Axial shortening of an 80 storied concrete building by using demountable strain gauges with a least count of 10micro strains. For measurement they have made a referral point on the column, with the referral point as the reference, two adjacent points were made close to that point such that the gauge length between them is 200mm. The experiment was conducted for two levels of basement (basement 1 and 2) and it was found that the Axial Shortening of basement 2 is having 0.43mm more than basement 1 and the differential Axial Shortening of basement 2 is 0.34mm more than basement 1.

P. Moragaspitiya and **D. Thambiratnam** (2010) studied the numerical method to quantify Axial shortening of vertical elements in concrete buildings by considering a 64 storied building by placing outrigger system between the core and walls of the structure between 10th and 12th floors and 42nd and 44th floors. It was found that effect and magnitude of Axial shortening and differential Axial Shortening has reduced within these floors compared to other floor levels.

T. Haa and **S. Lee** (2013) studied advanced construction staged analysis of a high rise building for creep and shrinkage of concrete by considering a 58 storied concrete building. It was concluded that the laboratory data bases which are available currently are outdated, for high strength concrete with regards to its creep and shrinkage. Advanced staged analysis was carried out by giving all time dependent variables and it was found that an overall Axial shortening of 100mm and differential Axial shortening of 10mm was observed.

R. correia and **P. silva Lobo** (2017) carried out assessment of the effects of column shortening on the response of a tall buildings by considering a 45 storied building, modelled in SAP2000. The structure was analysed using Simplified method and Staged construction method. They found that in Simplified method the Axial shortening of columns was 5.9cm and in Staged construction it was 6.3cm. This study concluded the importance of Staged construction analysis.

T. haa and **S. Lee** (2016) used a software tool for the analysis of time dependent effects in high rise buildings by considering a 42 storied building. Using advanced staged analysis program, they have made 86 construction stages with different time levels and analysed it for a period of 100years. They found that overall Axial shortening was 350mm at the top and the differential Axial shortening was 60mm. With this result, they inferred that the additional shortening is because of the displacement caused in the floors.

S. Ali (2014) carried out analysis on effects of Axial shortening of steel columns in frame structure by considering a 100 storied building. It was concluded that position of columns in regular frames of the steel structure has its influence in the acceleration of Axial shortening, moment at the beam column joint in the top floors is much higher than bottom floors.

K. Hansoo (2017) studied the effects of outriggers on differential column shortening in tall buildings by considering a 80 storied building. Three models were prepared for analysing differential Axial shortenings with single and dual outriggers, it was concluded that dual outriggers are more effective than single outrigger in reducing differential Axial shortening and found the optimum location of outriggers to be placed in 45th and 66th floor by considering the optimization problem, illustrating a contour plot which shows the reduction ratios of the whole analysis.

S. Vivek and **G. Sarangapani** (2015) studied the differential shortening of vertical members in high rise RCC buildings by considering a 40 storied building, modelled in ETABS. It was found that in construction stage the differential shortening increases with increase in the height of the floors, with increase in grade of concrete the differential shortening gets reduced, increase in shortening of 1.5 times where smaller column sizes are used in comparison to larger column sizes.

M. Fintel and **S. Ghosh** (1987) studied the column shortening in tall Structures. It was concluded that cracking and deflection of floor plates, damage to claddings, finishes, plumbing installations can result in differential Axial shortening which results in common effects on structural elements like sloping of floor plates, secondary bending moments and shear forces.

M. N. Bajad and **D. Patil (**2016) studied Axial shortening of vertical elements in high rise buildings using PCA method by considering a 40 storied building. It was concluded that inelastic shortening due to shrinkage and creep is 1.75 times the elastic shortening for a column and 3.38 times for a wall element, since there is considerable amount of changes in the structure due to shrinkage and creep their effect must be considered in analyzing the structure.

From literature review, it is concluded that Axial shortening in buildings occurs as two stages, Immediate and Time dependent, Axial shortening may occur due to mass irregularities between floor levels which leads to differential Axial shortening between columns of same floor. This Axial shortening is particularly more relevant in tall buildings made of RCC and the cumulative effect of all these shortenings in all the floors lead to several secondary effects on the structure. Providing outrigger systems in buildings is seen to reduce the Axial shortening tremendously and Staged construction analysis was found to be a necessity in obtaining more accurate estimate of Axial shortening.

Although the Axial shortening have been studied in detail from various perspectives, the effect of insisting diaphragm action of slabs on Axial shortening of high rise buildings has not taken up.

The paper reports the results of a study on the sensitivity of different bracing systems on Axial shortening in the columns immediately after construction stage and after a period of 30 years.

Conclusion were arrived at based on the analysis of a 60 storied building in SAP 2000. Diaphragm action is insisted on the slabs such that all the parts of the structure in a particular floor moves together. Three bracing types were used in the studies and they are arranged in four different pattern (P0, P1, P2, P3) to arrive at the optimum bracing system that will lead to the least amount of Axial shortening.

II. MODELLING OF THE BUILDING

To achieve the objective of this study, a 60 storied building with a height of 254m is modelled in SAP 2000. The storey heights are taken as 5.2m for first two floors and 4.2m for the remaining floors. The grade of steel for bracings were Fe 250. The grade of concrete of beams and slabs are M25 and the grades of concrete for columns varied from M25 to M60. The grade of reinforcing steel was Fe415.

The loads were taken as per IS:875–1987 (part – I), code of practice for design loads. The dead loads for external walls were calculated as 12.42kN/m, for internal walls of 8.1kN/m, and live load of 3kN/m² on all floors.

Diaphragms are assigned on the slabs, M_3 hinges for the beams, and PM_2M_3 hinges for the columns in each floor. With these features, the building is modelled with three types of bracings, X, V, Inverted V arranged in different patterns along with a Bare frame model with different Zone factors of 0.1, 0.16, 0.24, 0.36 and 0.48 with an Importance factor of 1.5 and response reduction factor of 3.0, 5.0, 7.0 and 9.0.

The values of 7.0, 9.0 for response reduction is not given in the code but were included in this study for understanding the behaviour of the structure.

In Simplified method the structure is analysed immediately after the construction where as in the Staged method the structure is analysed for a time period of 30 years.

The plan, Elevation, and 3D view of the structure are as shown in the figure 1 and 2.

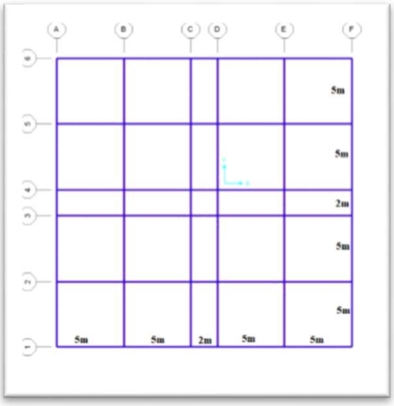


Figure 1: Plan of the structure

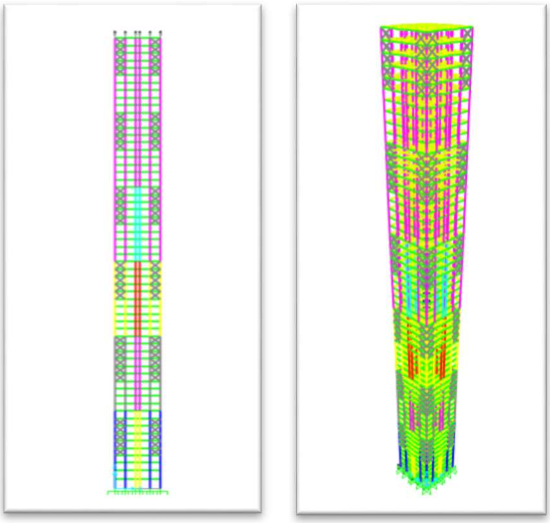
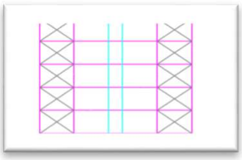


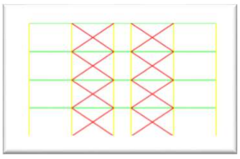
Figure 2: Elevation and 3D view of the structure

The bracings are arranged in four different patterns for analysis (Figure 3 and Figure 4). They are, without any bracings, bracings at corner, bracings interior, bracings at staggered position.

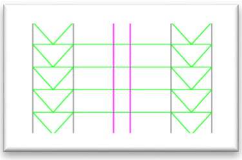
In pattern 0, each of the three different bracing types (X, V, Inverted V) are placed in corner location (between grid AB and grid EF) and are placed between interior grids (between grid BC and grid DE) (Figure 1).



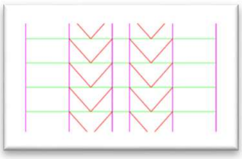
X bracing corner (P0)



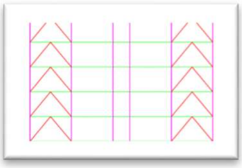
X bracing interior (P0)



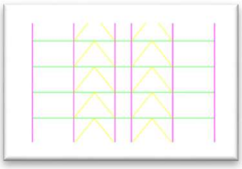
V bracing corner (P0)



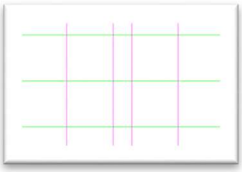
V bracing interior (P0)



Inverted V bracing corner (P0)



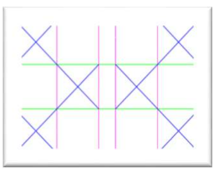
Inverted V bracing interior (P0)



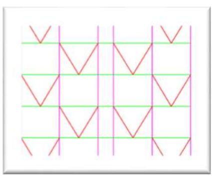
Bare Frame (no bracing)

Figure 3: Pattern 0 (elevation view)

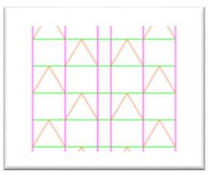
In pattern 1, 2 and 3 (Figure 4), the X, V and Inverted V bracings are placed in staggered position in plan. In pattern 1 (P1), the bracings are alternatively kept at corner and interior bays where as in pattern 2 (P2), they are placed alternatively after every two floors. In pattern 3 (P3), the bracings are shifted to every other bay in the succeeding floor level (Figure 4).



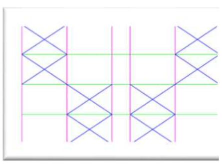
X bracing (P1)



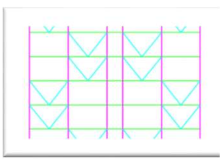
V bracing (P1)



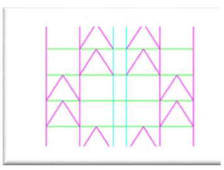
Inverted V bracing (P1)



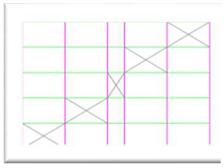
X bracing (P2)



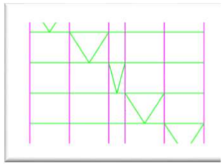
V bracing (P2)



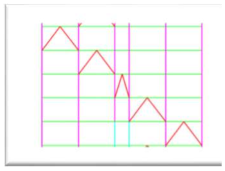
Inverted V bracing (P2)



X bracing (P3)



V bracing (P3)



Inverted V bracing (P3)

Figure 4: Pattern 1, 2, 3 (elevation view)

The analysis is done for Simplified method i.e., immediately after the construction and in Staged method for a time period of 30 years by considering the creep and shrinkage.

III. RESULTS AND DISCUSSION

From the analysis of the building, Axial shortening is found out. The graphs are plotted for maximum percentage change in displacement (U3) for the type of bracings for different patterns using Simplified and Staged construction methods.

U3 is the percentage change in displacement in the z-direction of the structure and bracing types are X bracing at the corner bays (XC), X bracing at the interior bays (XI), V bracing at the corner bays (VC), V bracing at the interior bays (VI), Inverted V bracing at the corner bays (IVC), Inverted V bracing at the interior bays (IVI), Bare frame model with Response reduction factor R=5.0 (B5), Bare frame model with R=7.0 (B7), Bare frame model with R=9.0 (B9).

For result interpretation, the efficiency of the bracing system is determined based on the Axial shortening. Lesser the Axial shortening, more efficient is the bracing.

Figure 5 shows the percentage change of Axial shortening due to dead load case in pattern 0 when compared with Bare frame model as the base case. For X corner bracing, it was 2.17% in staged method which is less efficient when compared to Bare frame and for X interior bracing it was -0.7% which is more efficient in Simplified method when compared with the Bare frame model. It is also easily observable that the corner bracing types give higher Axial shortening when compared with interior bracing cases.

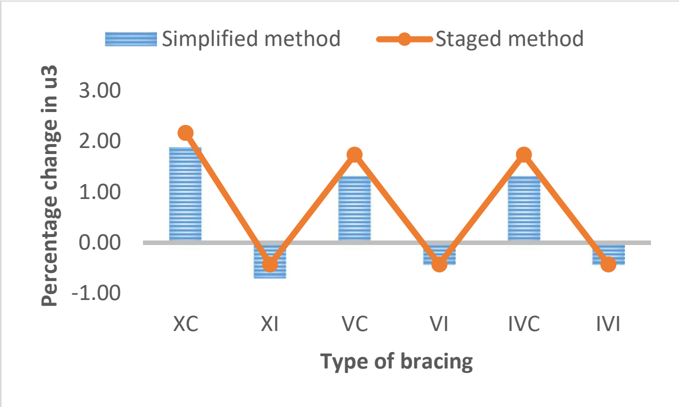


Figure 5: Axial shortening for dead load for pattern 0

Figure 6 shows that Axial shortening for dead load and live load case using pattern 0. It was found that Axial shortening is more for all the bracings except for Inverted V bracing placed in interior bays in Staged construction than that of Simplified construction.

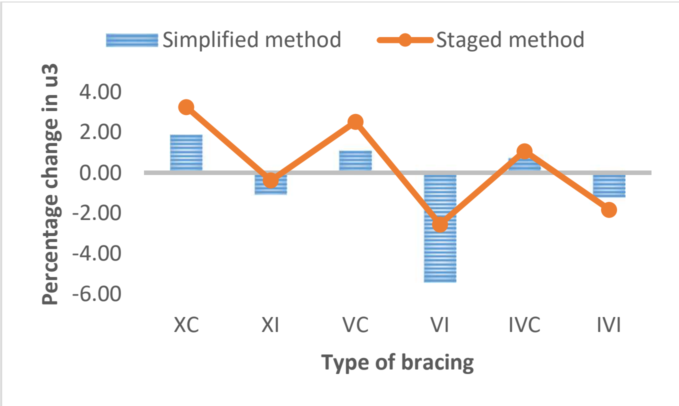


Figure 6: Axial shortening for dead load and live load for pattern 0

Figure 7 shows the Axial shortening of structure in different Zones namely, Zone I, III, IV, V, VI for pattern 0 using Simplified method. Zone I and VI are factious Zones defined to carry out the studies.

It is observed that the maximum Axial shortening (-1.12%) for Zone V for X interior bracing of is more efficient and X corner bracing in Zone VI (2.23%) is less efficient when compared to Bare frame.

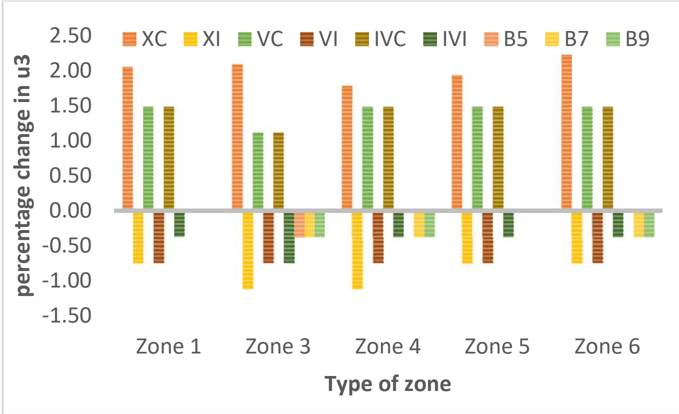


Figure 7: Axial shortening in Zones in Simplified method

Figure 8 shows the maximum Axial shortening of structure in different Zones I, III, IV, V, VI using pattern 0 for Staged method. It is observed that the maximum Axial shortening in Zone IV for X interior bracing (-1.11%) is more efficient and for V corner bracing and X corner bracing in Zone VI and Zone V (2.94% and 2.93%) are less efficient compared to Bare frame.

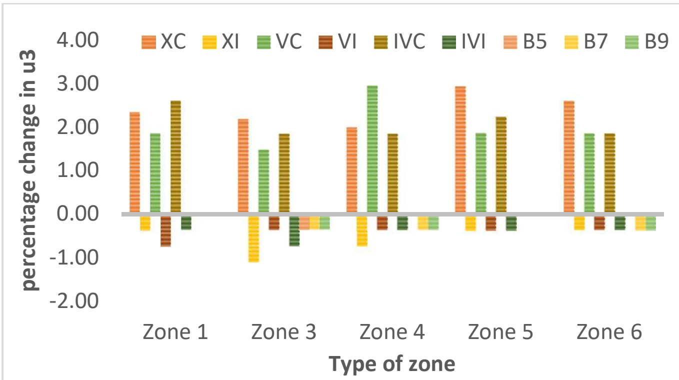


Figure 8: Axial shortening in Zones in Staged method

After the analysis of results for pattern 0, other patterns were taken up to determine the optional configuration of bracing types (X, V, Inverted V) that will minimize Axial shortening.

PATTERN 1

Figure 9 shows the Axial shortening of 60 storied building (5.2m and 4.2m story height and 254m building height) with bracings arranged in pattern 1. In this pattern, the bracings are placed at exterior and interior bays in the alternate storey and the maximum Axial shortening for the dead load case is 2.30% higher for X bracing in Staged method compared to Bare frame model.

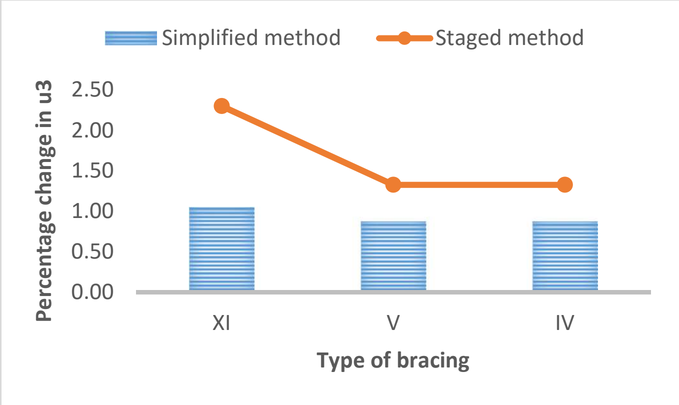


Figure 9: Axial shortening for dead load in Pattern 1

Figure 10 shows the Axial shortening of dead load and live load case in pattern 1. It was found that, X bracing in Staged method (1.42%) is less efficient compare to Bare frame model.

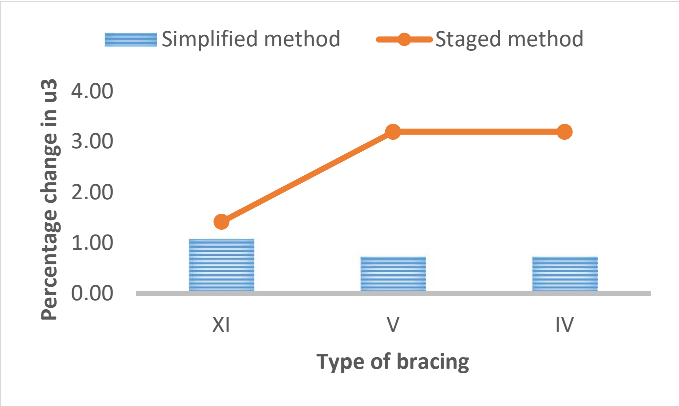


Figure 10: Axial shortening for dead load and live load in pattern 1

Figure 11 shows the Axial shortening of building in Zone III having bracings at exterior and interior bays in the alternate storey. It demonstrates that the Axial shortening for all 3 bracings i.e., X, V, Inverted V are 1.12% less efficient in Simplified method and 1.42% less efficient in Staged method compared to Bare frame.

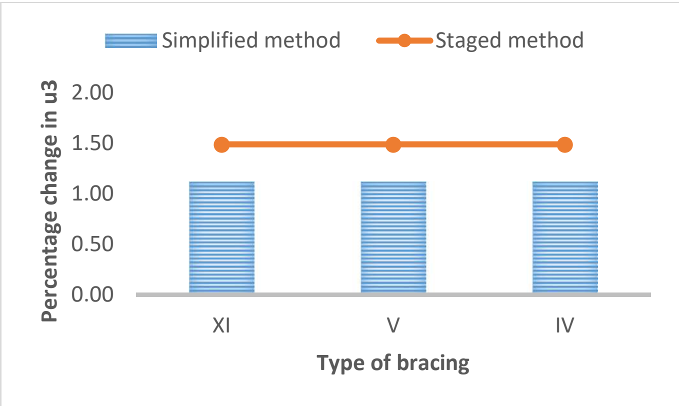


Figure 11: Axial shortening in Zone III for pattern 1

PATTERN 2

Figure 12 shows the Axial shortening of 60 storied structure with bracings arranged in pattern 2. In this case, the bracings are placed at exterior and interior bays in alternate stories and Axial shortening for the dead load case is 0.87% in simplified method and 1.30% in Staged method which are less efficient compared to Bare frame model.

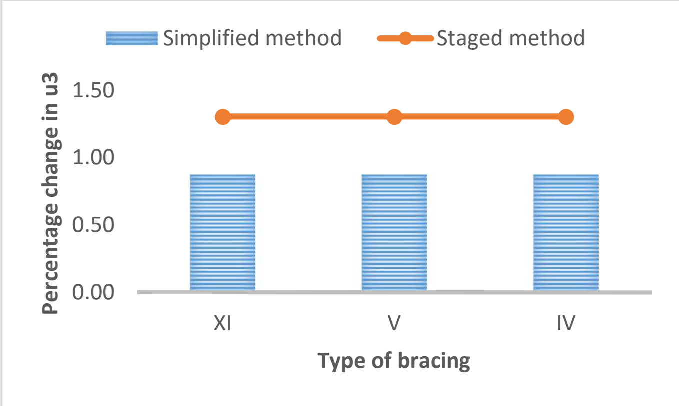


Figure 12: Axial shortening for dead load in Pattern 2

Figure 13, shows the Axial shortening of dead load and live load case in pattern 2, it was found that for X bracing it is 1.42% less efficient compared to Bare frame model.

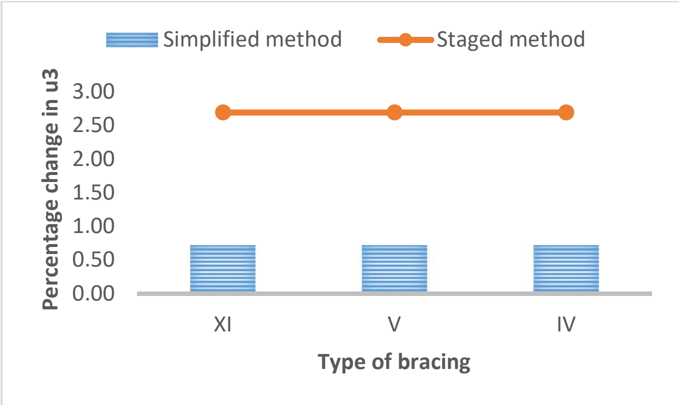


Figure 13: Axial shortening for dead load and live load in pattern 2

Figure 14 shows the Axial shortening of building in Zone III with bracings placed at the exterior and interior in the alternate storey. It demonstrates that the Axial shortening for all 3 bracings i.e., X, V, Inverted V was 1.12% in Simplified method and 1.47% in Staged method which are less efficient compared to Bare frame.

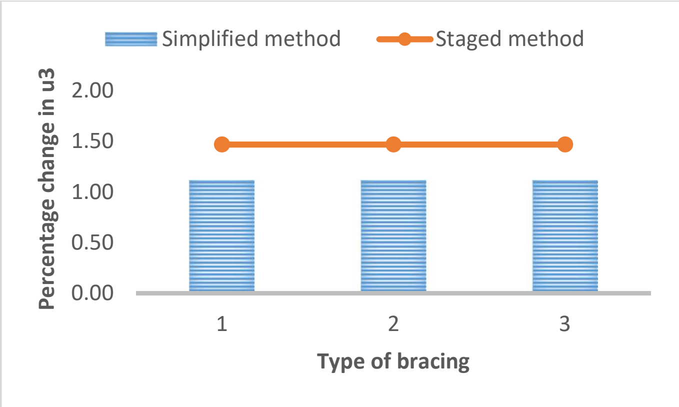


Figure 14: Axial shortening in Zone III for pattern 2

PATTERN 3

Figure 15 shows the Axial shortening of 60 storied building with bracings arranged in pattern 3 for dead load case. In this pattern, the bracings are placed at exterior and interior in the alternate storey and Axial shortening for the X and V bracing are found to be equally efficient with Bare frame. For Inverted V bracing it is 0.42% less efficient in simplified method and 0.86% in Staged method compared to Bare frame.

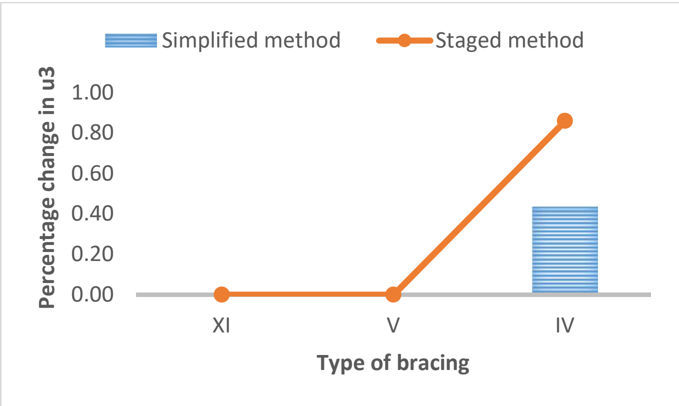


Figure 15: Axial shortening for dead load in Pattern 3

Figure 16 shows Axial shortening of dead load and live load in pattern 3. It is found that the efficiency of X and Inverted V bracing is equal to Bare frame and for V bracing it is -0.36% more efficient compared to Bare frame for both Simplified and Staged method. This is due to bracings placed in the middle bay of the structure (between grids CD).

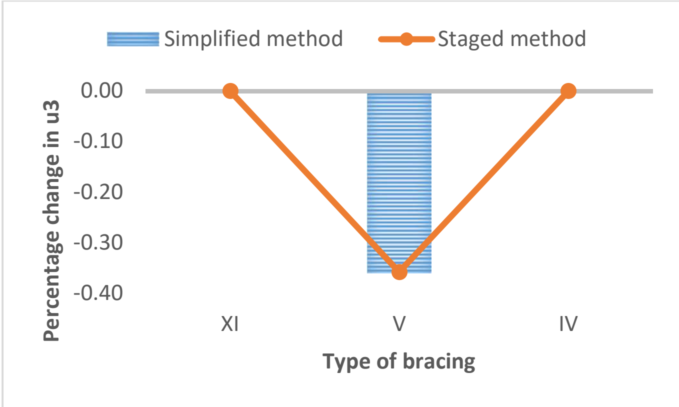


Figure 16: Axial shortening for dead load and live load in pattern 3

Figure 17 shows the Axial shortening of the building in Zone III having bracings at exterior and interior bays in the alternate storey. It is observed that the Axial shortening for bracings X and Inverted V are 0.37% and 1.12% less efficient and V bracing is equally efficient in Simplified method and Staged method compared to Bare frame.

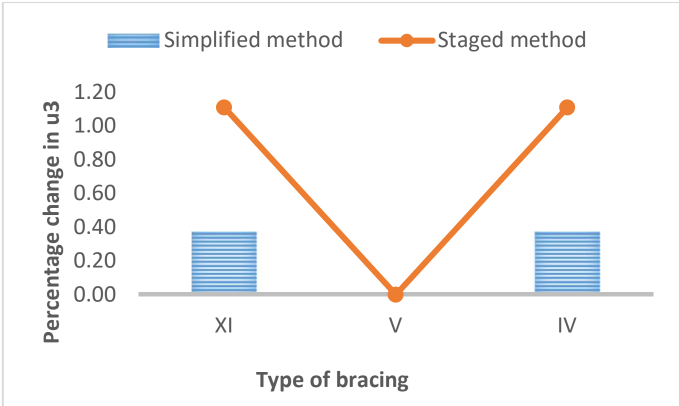


Figure 17: Axial shortening in Zone III for pattern 3

The reliability and consistency of different bracing types were determined by the variance analysis.

Figure 18 shows the variance of Axial shortening of building in all the Zones with bracings at both exterior and interior. It demonstrates that the variance of Axial shortening for V interior bracing is performing consistently under different conditions both in Simplified method and Staged method and hence is the most reliable.

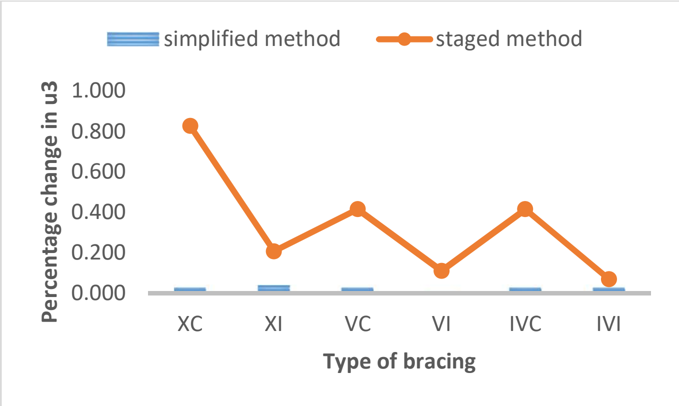


Figure 18: Variance of Axial shortening considering all the Zones

IV.CONCLUSION

The analytical study on the effect of Bracing systems in high rise structures has been done by modelling in SAP 2000. The parameters like Axial shortening has been compared with and without any bracing for 3 bracing types in 4 patterns. Following conclusions are made on the performance of bracing system upon insistence of diaphragm action of the slabs

- The arrangement with bracings provided at interior bays of the structure is found to be more effective than the bracings at exterior bays of the structure.
- For the bracings arranged in alternative bays and in alternative bays after two floors for the dead load case X bracing has less efficiency compared to Bare frame model.
- For the bracings arranged in alternative bays and in alternative bays after two floors for dead load and live load case and in Zone III all the three bracings are less efficient compared to Bare frame model.
- The V bracing at interior bays is performing consistently with least variation compared to other bracing types under different conditions and hence it is most reliable.
- For the construction purpose, analysing the structure in the Staged method is preferable than Simplified method to reduce the effect of Axial structure in the structure.
- With the bracing bay varied in successive levels, for dead load case X & V bracing has no effect on axial shortening when compared with the Bare frame model.
- With the bracing bay varied in successive levels, for dead load and live load case V bracing has more efficiency compared to Bare frame model.
- With the bracing bay varied in successive levels, in the Zones V bracing has equal efficiency to that of Bare frame model.

V. REFERENCES

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