

Analysis of Effects of Axial Shortening of Steel Columns in Frame Structure

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Abstract— Steel columns in frame structure always carry heavy upcoming compressive forces. As a consequence, axial shortening becomes a common phenomenon in a multistoried steel structure. A 100 storied steel structure is analyzed in SAP2000 to study the magnitude overall effects of column shortening. It was found from the study that the maximum axial shortening occurs at the columns of top storey of the steel structure and at the columns of bottom storey, the axial deformation is negligible. The increasing rate of axial shortening is significant at the initial levels. However, at the upper levels, the amount of axial shortening in steel columns differs insignificantly. In the selected rigid frame structure, the axial shortening of adjacent steel columns is found to influence significantly the differential shortening of the structure. The consequent effect of differential shortening leads to develop excessive stress in the corner joints which ultimately hamper the normal behavior of the structural systems. The results are discussed elaborately in the paper.

Keywords— Axial shortening, buckling, frame structure, differential shortening, bending stress.

I. INTRODUCTION

Steel columns are generally experienced by large axial deformation when they are subjected to massive gravity loads. In frame structure, the closely spaced columns are utilized to transfer the enormous amount of loads coming from this tall building structure. The internal columns are subjected to higher gravity loads compared to that of the external structure of any type of building. This occurrence can lead to the differential axial shortening of columns of any floor level of a building. This consequently can create problem in providing level floors and can hamper the performance of building cladding system. The problems may be more vulnerable if steel columns are used in the structure since steel members have always a tendency to buckle due to its slenderness. In the design of columns, usually the effects of axial shortening are neglected. However, the proper awareness about axial shortening can enhance the behavior of the structural system and can also make the structure free from many uncertain dangers.

II. BACKGROUND

Few studies have been conducted to determine the axial shortening of column on both concrete and steel in different structural condition. Mallick [1] initiated discussion on axial shortening in concrete structure considering creep and shrinkage as the natural phenomenon of concrete structure. Besides, Taranath [2] drew some valuable conclusions on differential settlement of tall steel building. In the study, Special attention was given on the variation of cross-sectional area of column in a general tall steel building. Moragaspitia [3] carried out research work on interactive axial shortening of column in high rise building. The study involved concrete material and long-term effects like creep and shrinkage of concrete were also taken into consideration to determine the axial shortening. Moreover, Macrae et al. [4] conducted research to observe the effect of axial shortening of column in a steel frame. Macrae et al. [4] used finite element analysis to determine the axial shortening of steel column and also proposed a few solutions to reduce the shortening effect. However, no attempt has yet been performed to get the effect axial shortening in steel structure in a simple manner. The present study has been executed to provide an idea about the magnitude of axial shortening of steel column and also to demonstrate some adverse effects of axial shortening of column in a steel structure which may be responsible to hamper the usual behavior of this type of structural system.

III. OBJECTIVES & SCOPES

The study involves the analysis of a typical high-rise steel frame structure considering all types of loading condition. It aims to focus on the variation rate of vertical axial deformation of steel column with the increase of floor height. Moreover, influences of axial shortening on the location of steel columns will also be observed. Finally, the study will analyze and demonstrate the effect of axial deformation at the beam-column joint of the selected structural system. Consequently, the probable deviation in natural behavior of the selected structure will also be discussed under the scope of this study.

IV. PROBLEM IDEALIZATION

To carry out the analysis, a 100 storied steel structure to be used in commercial purpose is selected. The plan of the

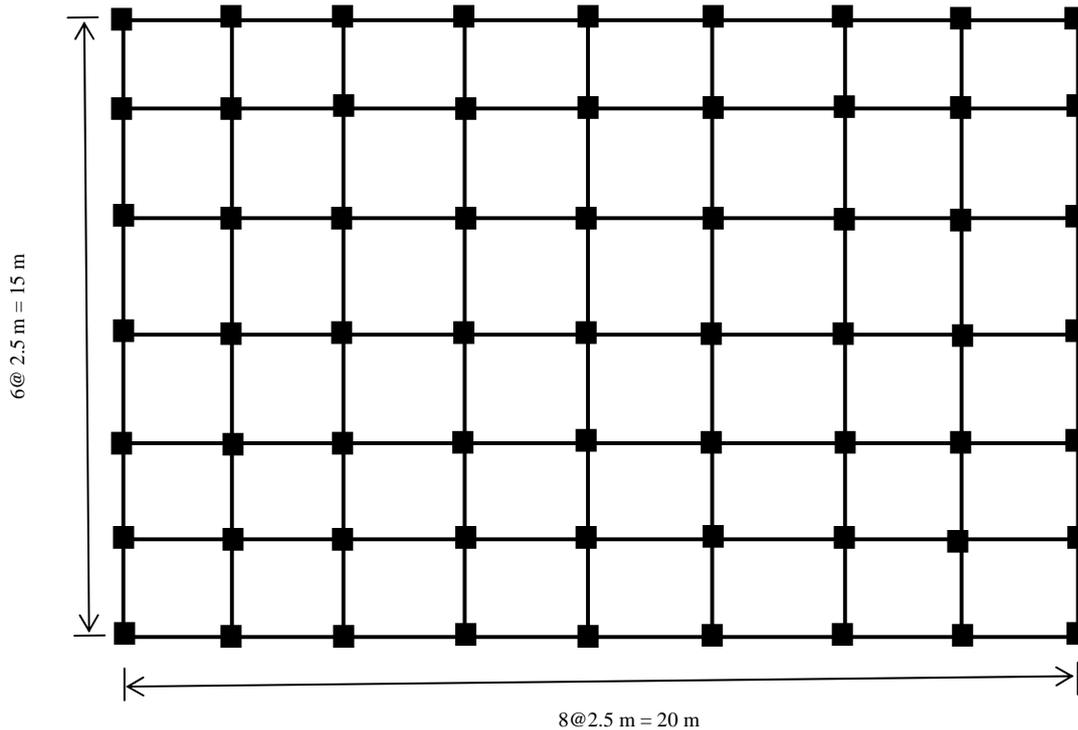


Fig 1. Plan of frame Structure

steel structure is 20 m by 15 m (Fig. 1) in dimension. The steel columns are spaced at regular intervals of 2.5 m apart in each direction. The height and area of the steel column is fixed at 3.1 m and 3.8 m². The cross-sectional area of the steel columns is taken as constant throughout the structure to make it sufficiently stiff. Fig. 1 shows the plan of the steel structure. The dead load (floor finish and partition wall) and live load on the structure is taken as 2 kN/m² and 4 kN/m² according to the specification for commercial high-rise building by Bangladesh National Building Code. The wind speed experienced by the structure is taken as 210 km/hr. To consider the dynamic action, time history analysis and also the equivalent static force analysis is conducted and the maximum values are used in the design purpose. The overall analysis is conducted in SAP 2000 by finite element method to observe the effect of axial shortening in steel column.

V. ANALYSIS RESULTS

To conduct the analysis of frame structure and to observe the influence of axial shortening on the behavior of the structural system, finite element based SAP 2000 is exploited. Few parameters are found to have significant effect in accelerating axial deformation of steel column. Consequently, some adverse conditions on structural behavior arise due to excessive axial shortening. The results from the analysis are discussed in the next sub-sections.

A. Effect of location of column

Position of column in the regular frames of steel structure has influence in the acceleration of axial shortening of steel columns. Fig. 2 illustrates the variation of axial shortening in three different locations of columns. The changing rate is studied on the bottom level, mid-level and top level of the structure.

The figure shows that the amount of axial shortening is almost same from the bottom level to mid-level for the selected three types of columns. Since, the columns are placed closely in this steel structure and consequently the three types of columns share gravity load do not vary in a large amount, this type of result can be accepted. However, the effect can be seen distinctly beyond the mid-level. At the top storey, the maximum axial deformation in steel column is found in interior column which is around 28 mm.

The figure shows that about 5% excessive axial shortening occurs in interior column compared to that of the corner column. This type of phenomenon leads to differential shortening of columns in the same floor level. The effects of this condition have considerable influence on the behavior of structure are discussed latter in the study.

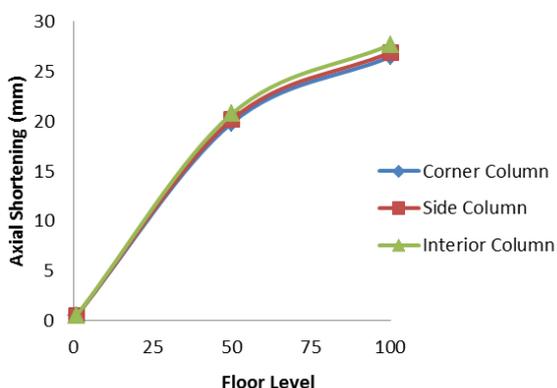


Fig 2. Effect of location of column on axial shortening

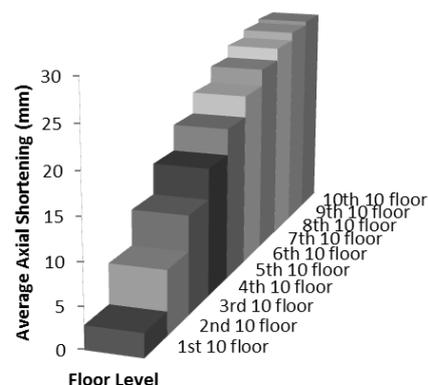


Fig 4. Effect of axial shortening on side column

B. Effect of location of column

The height of the structure is also considered as a selected parameter to observe the effect of axial deformation in steel column. The column charts (Figs. 3 to 5) shown for corner column, side column and interior column respectively demonstrates the variation rate of axial shortening with increasing the level of floors. The variation of axial shortening follows the similar trend for all of the columns.

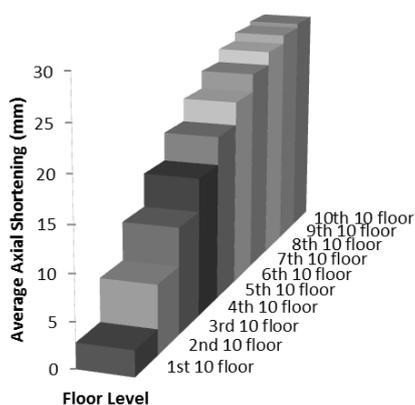


Fig 3. Effect of axial shortening on corner column

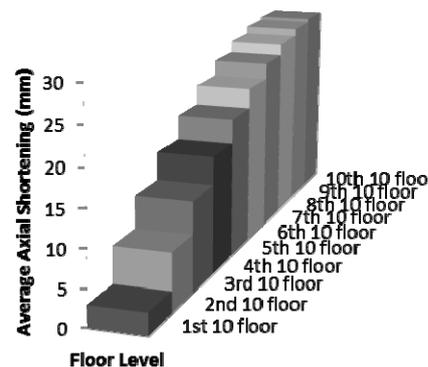


Fig 5. Effect of axial shortening on interior column

The maximum value of axial shortening in steel column is found at the top storey of the steel. At structure the same time, the axial deformation of column becomes zero at the bottom of the structure.

The average value of axial shortening is taken in every ten floors of the 100 storied structure. The variation of axial shortening is significant at the initial stage and at the upper levels changing rate of axial deformation becomes nearly constant. The amount of shortening of steel columns increases almost 170% from the first ten floors to the second ten floors. At the next higher floors, the slope of the increment of axial shortening becomes less steep. Finally, the steel columns of top ten floors are subjected to only 2% excessive axial shortening compared to the bottom ten floors.

C. Effect of axial shortening on beam-column joint

The probable effect of axial shortening of steel column on beam-column joint is studied here.

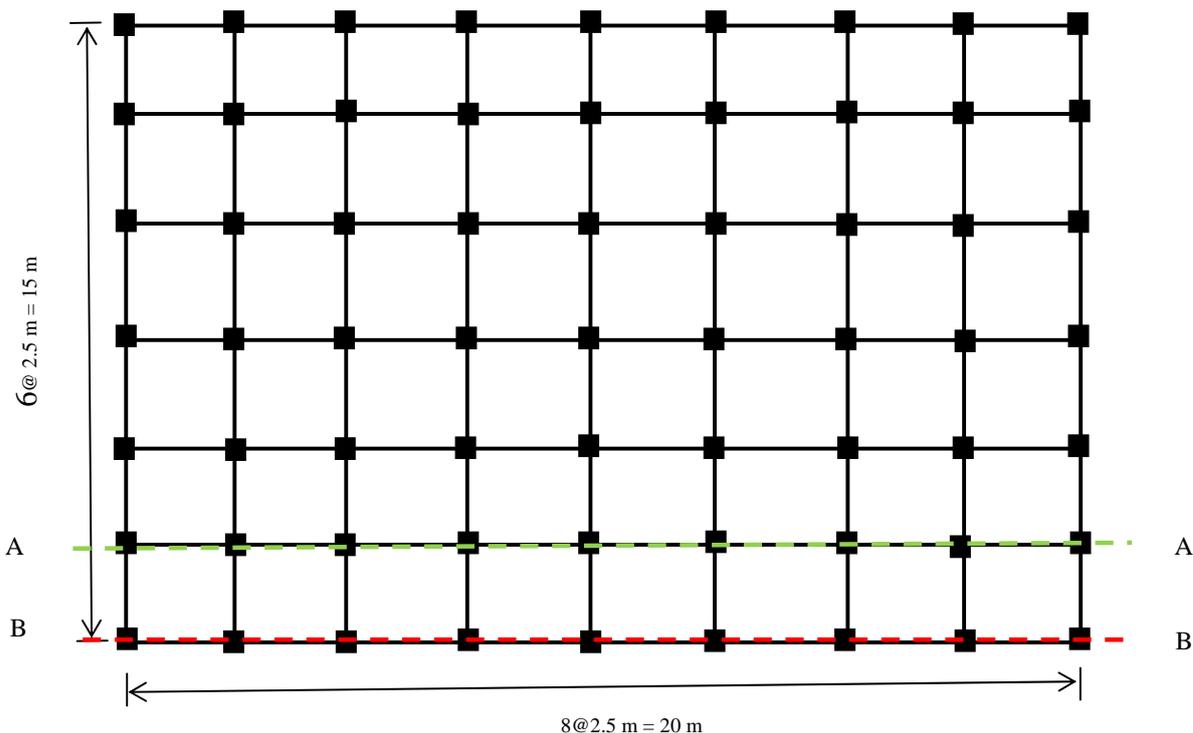


Fig 6. Plan of steel structure with selected frames

Fig. 6 shows two selected frame A-A and B-B. Frame A-A includes corner and side column while frame B-B include side and interior column of the selected steel structure. Effects of axial deformation of steel columns are studied on the beam-column joint of the two frames.

Fig. 7 illustrates the condition of axial deformation at different column points of Frame A-A and B-B. At the similar location, Fig. 8 and 9 show the beam-column joint moments at the top level and bottom level of the structure. It can be seen that due to the distinct difference in the amount of axial shortening in a steel frame, differential axial shortening results. The trend is similar for both of the selected frames.

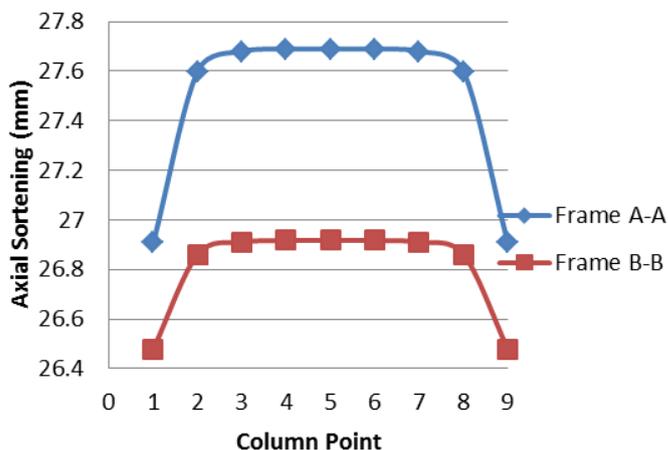


Fig 7. Axial shortening at column points

Fig. 8 and 9 show that significant moment is developed at the corner joint due to the difference in axial shortening in the adjacent corner and side columns and also the adjacent side and interior column of the frames. The variation of moment in the selected frames at the bottom and top level of the structure follows the same pattern. However, the beam-column joint moment at top floor level is much higher than that of the bottom level.

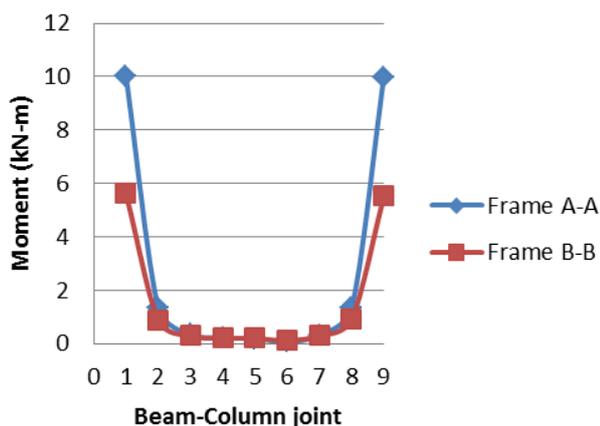


Fig 8. Moment at joint at top level

At the top storey, around 8 kN-m moment varies from corner to side column whereas about 5 kN-m moment varies within side to interior column. The difference between the amounts of developed moment can induce excessive stress at the end joint of tubular structure which is not usually anticipated. As a result, crack may develop due to this phenomenon which ultimately leads to aggravation in the behavior of the high rise building.

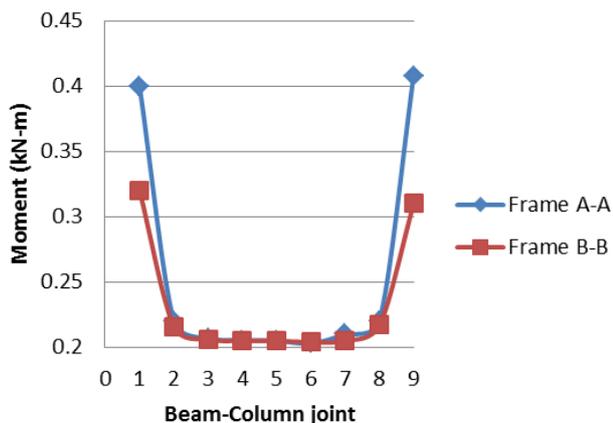


Fig 9. Moment at joint at bottom level

VI. CONCLUSION

The study is conducted to observe the intensity of axial shortening in the steel columns of frame structure and also to analyze the probable consequence related to the axial deformation of steel column. It is found that the maximum axial shortening occurs in the top storey of the structure and almost zero magnitude at the bottom level. The increasing rate of axial deformation of steel column is quite high from ground level to the mid floor levels and finally it becomes moderate from the mid floor level to the top floor. Interior columns experience higher axial shortening compared to side and corner columns which is responsible for the development of differential shortening in steel columns. Additional moment develops at end joint and consequently additional stress is introduced. These occurrences are responsible to hamper the natural behavior of the structure. So, in design of steel framed structure, the effect of axial shortening must be considered.

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