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Effect of Column Shortening on the Behavior of Tubular Structures

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Abstract

This paper presents the column shortening effect on the behavior of Tubular, Tube in tube and Bundled tube structure. Frame tube buildings consist of closely spaced column connected by deep spandrel beams placed on the perimeter in plan. A Tube in tube and Bundled tube structure of 50 storeys with storey height of 4 m is considered for the study, RC columns and spandrel beams are modelled with M70 and M110 concrete mix. Models are developed using ETABS software and the effect of elastic shortening of the RC column is included in the analysis to study the behavior by calculating member forces. From the analysis, the effects due to elastic shortening in parameters such as axial force, shear force, bending moment and time period are obtained and compared between the tubular, tube in tube structure and bundled tube structure, there is a variation of about 25%, 20%, 23% and 74% and 23%, 17%, 25% and 57%. 19%, 15%, 31% and 60% respectively, which results in the reduction of member size, which ultimately reduces the dead load and the cost of construction.

Keywords: Bundled Tube Structure, Elastic Column Shortening, Tube in Tube Tall Structure, Tubular Structure

1. Introduction

The vertical city concept has been manifested due to increase in population density and demand on cultivation land. The advancement of technology and the development of economy of the world have made the vertical city concept dream become true in the way of tall buildings/towers. Fazlur Khan of Bangladesh has introduced the tall buildings concept and he had addressed many structural systems for the high-rise buildings. Some of the structural systems adopted for tall buildings are wall-frame structure, framed tube structures, outrigger-braced structures, suspended structures, core structures, space structures and hybrid structures for lateral loads supports[1].

The framed-tube of many type have being developed for lateral load resisting systems. Some of them are multiple tube systems, Bundled tube systems and tube-in-tube systems[2,3]. The Tube in tube and Bundled tube structure is being taken for the current study. A typical form of framed tube structure is shown in Figure 1.

Taranath et al. tubular system structure is a structure with closed column space between two to four meters and jointed by a deep spandrel beams at the floor level as shown in Figure 2. A group of columns perpendicular to the direction of the horizontal load is called flanged frame and a group of columns parallel to the direction of the horizontal load is called web frames[4].

Since the columns are closed to each other and the spandrel beams are deep, the structure can be considered as perforated tube and behaves as a cantilever tube. The flanged frame columns will resist the axial forces (tension and compression) and the web columns will resist the shear forces[4]. Coull et al. it has been proved that the tubular structure is an efficient structural system to resist the horizontal loads. However, in the actual tubular structure, the distribution of axial forces along the flanged frame columns at one floor is not uniform and the distribution of shear forces along the web is not linear. This is mainly due to the flexibility of the structure. This phenomenon

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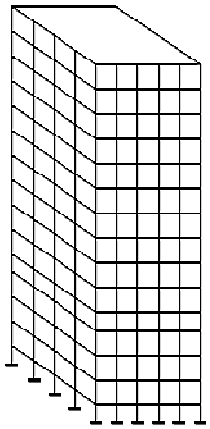

Figure 1. A typical form of framed tube structure.

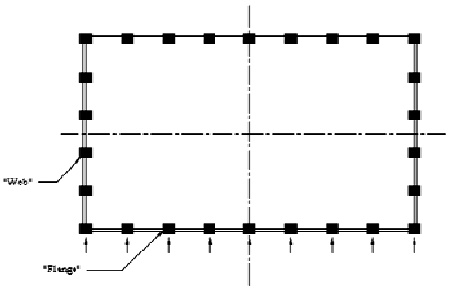

Figure 2. Components in tall structure.

reduces the efficiency of the tubular structures and it is called shear lag effect. The efficiency of the tubular structure is measured by the shear lag factor. The shear lag factor can be defined as the ratio of the stress at the centre of the flanged and the stress at the corner of the flange[5].

Mola et al. observed that the tubular structure was efficient if the shear lag factor of 0.7 is achieved. In the design of tall buildings the challenge for the engineer is to maximize the shear lag factor with minimum weight. When the shear lag is equal to one, the axial forces are distributed equally along the flange. In tubular structural system, there are several parameters contribute to the shear lag factors, among them all the size of the spandrel beams and columns along the flange, the bending stiffness of the web and the shape of the structures[6].

2. Modelling of Tubular Structure

Structure consists of closely spaced column connected by deep spandrel beams placed on the perimeter in plan. Tubular, Tube in tube and Bundled buildings are generally suited for story height from 40-100. Thus considering the shear lag effect and the seismic effect on the buildings, the models for this study are square in plan. Table 1 shows the details of tabular structure under study.

In this analysis of Tube in tube structure, the inner tube is assumed to be of closely spaced column. The connection of secondary beams to the core columns is hinged connection and the connection of spandrel beams to columns is rigid connection. The floor plan of tubular structure is shown in Figure 3 and Tube in tube structure is shown in Figure 4. In the case of Bundled tube structure, the closely spaced core columns are placed on the four corners of the building as shown in the Figure 5.

Table 1. Details of Structure

Number of Storey	Concrete Mix	Column size (m)	Spandrel beam size (m)	Spacing of columns (m)	Storey height (m)
50	M70	1.00×1.00	0.50×0.50	2.00	4
50	M100	1.00×1.00	0.50×0.50	2.00	4

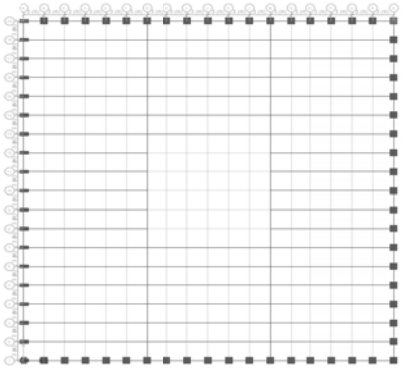

Figure 3. Floor plan of tubular structure figure

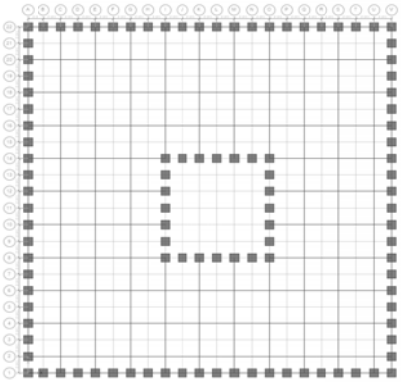

Figure 4. Floor plan of tube in tube structure.

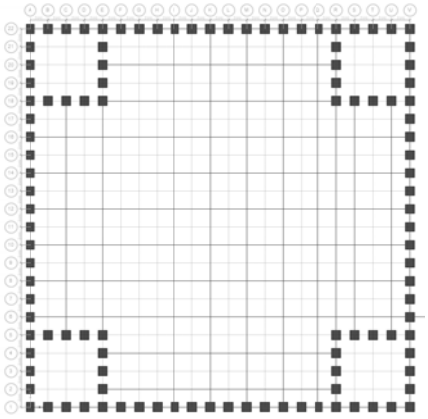

Figure 5. Floor plan of Bundled tube structure.

3. Analysis of Framed Tubular Frames

The 3D analysis of the structure is carried out using the ETABS software which is based on the stiffness approach. The calculations made are mentioned below:

3.1 Load Patterns

Dead load is calculated by taking the self weight of each members. Imposed load is taken to be as 3 kN/m^2 and wind load is calculated as per IS 875 part-3[7].

3.2. Wind Load

Wind load is calculated as per IS 875 Part- 3[7] where the location is considered as Chennai and the following parameters are calculated. The calculated wind pressure is distributed based on the height of floor and number of columns in that floor:

Design wind speed (V_z) = 70 m/s

Design Wind Pressure (P_z) = 2597 N/m^2

3.3 Analysis

The analysis is performed using ETABS. The analysis is performed with elastic shortening when the properties of the columns and beams are modelled and load is applied. The member properties like area and moment of inertia of columns and moment of inertia of spandrel beams are given as explicit input then analysis is performed for obtaining column and beam forces without effect of elastic shortening of the RC columns.

3.4 Elastic Shortening of RC Columns

A column in a tall building undergoes axial shortening considerably more than its lower brethren required that special attention be paid in column design[8]. A related problem, by no means unique to tall buildings, but one that gets aggravated to a great extent, is the levelness of floors[9,10]. Similarly, the problem of human response to transient vibration of floors is not unique to tall buildings but needs careful study because the cost of correcting the problem in a tall building with several floors is phenomenally more expensive than correcting the relatively fewer floors of a low-rise building. Column in tall building subjected to larger axial displacement due to the accumulated load from a large number of floors and also from the larger length is known as axial elastic shortening[11]. It depends on material properties of columns and the stress induced strains due to axial load[11,12].

4. Results and Discussion

The models for this study are square in plan having 50 storeys. The parameters like axial force, shear force, bending moment and time period is considered and compared and the variation in these parameters due to column shortening is discussed below. The change in axial force due to column shortening in Tubular, Tube in tube and Bundled tube structure are shown in Figure 6. The column shortening effect in structure with M70, M110 grades and structure without column shortening is compared.

The result shows a variation of about 20%, 23% and 19% decrease in the axial force in the Tubular, Tube in tube and Bundled tube structure respectively with column shortening to the structure without column shortening.

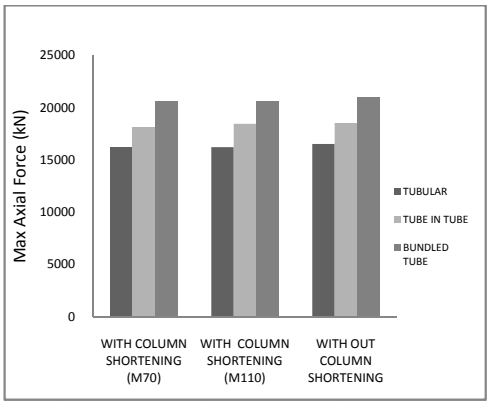

Figure 6. Comparison of Max Axial force.

The change in shear force due to column shortening in Tubular, Tube in tube and Bundled tube structure are shown in Figure 7. The column shortening effect in Tube in tube and Bundled tube structure with M70, M110 grades and structure without column shortening is compared. The result shows a variation of about 23%, 17% and 15% decrease in the shear force in the Tubular, Tube in tube and Bundled tube structure respectively with column shortening to the structure without column shortening.

The change in bending moment due to column shortening in Tube in tube and Bundled tube structure are shown in Figure 8. The column shortening effect in Tube in tube and Bundled tube structure with M70, M110 grades and structure without column shortening is compared. The result shows a variation of about 24%, 27% and 31% decrease in the bending moment in the Tube in tube and Bundled tube structure respectively with column shortening to the structure without column shortening.

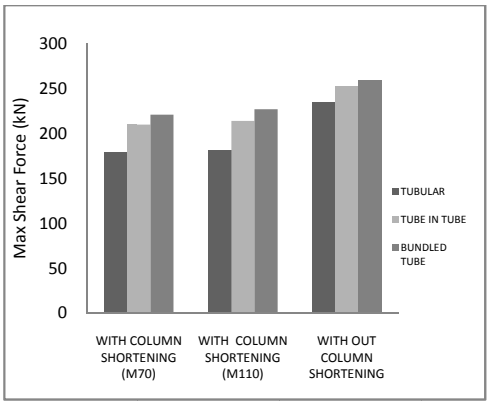

Figure 7. Comparison of Max Shear force.

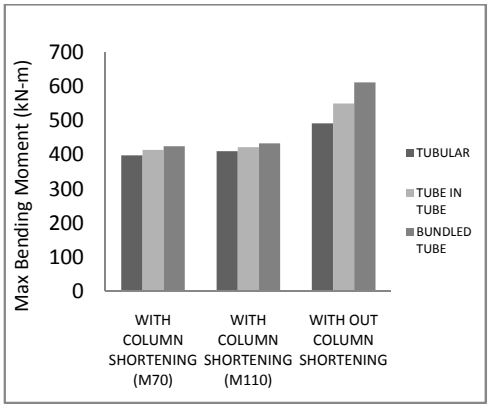

Figure 8. Comparison of Max bending moment.

The change in time period due to column shortening in Tubular, Tube in tube and Bundled tube structure with column shortening with M70, M110 and without column shortening are shown in Figures 9, 10 and 11 respectively. The column shortening effect in Tube in tube and Bundled tube structure with M70, M110 grades and structure without column shortening is compared. The result shows a variation of about 62%, 57% and 60% increase in the time period of the Tubular, Tube in tube and Bundled tube structure respectively with column shortening to the structure without column shortening.

The change in Storey drift in Tubular, Tube in tube and Bundled tube structure with column shortening and without column shortening is shown in Figures 12, 13 and 14 respectively and the result shows a variation

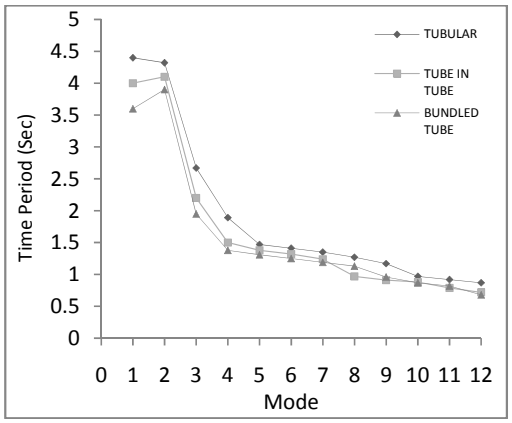

Figure 9. Comparison of time period. With Column shortening (M70).

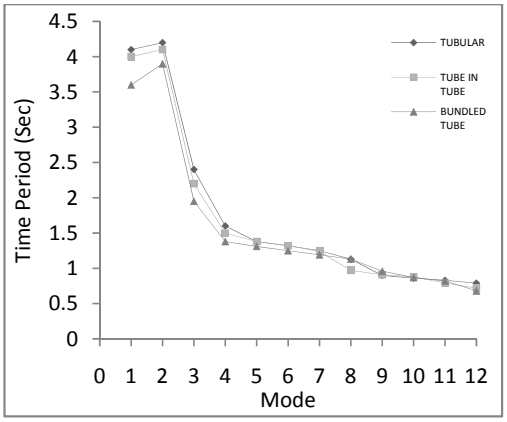

Figure 10. Comparison of time period. With Column shortening (M110).

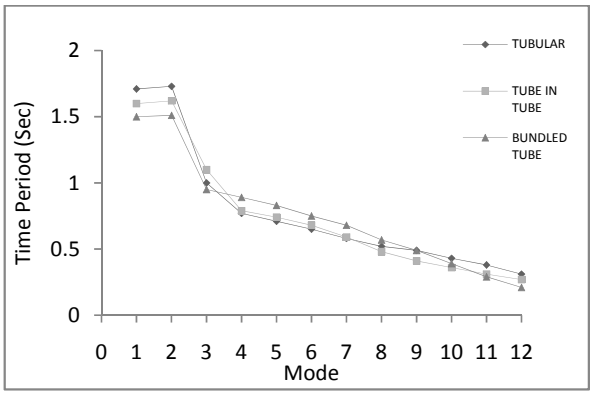

Figure 11. Comparison of time period - without column shortening.

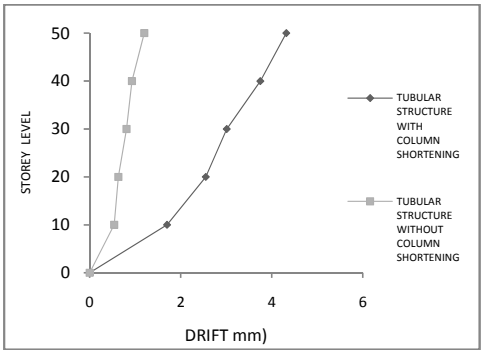

Figure 12. Comparison of storey drift in tubular structure with and without column shortening effect.

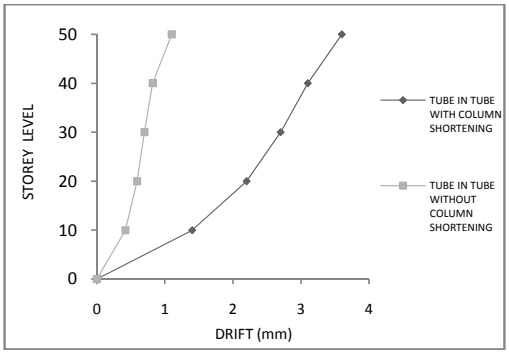

Figure 13. Comparison of storey drift in Tube in tube structure with and without column shortening effect.

of about 74%, 70% and 60% decrease in Tubular, Tube in tube and Bundled tube structure with column shortening and without column shortening. The change in Storey drift in Tubular, Tube in tube and Bundled tube structure with column shortening is shown in Figure 15.

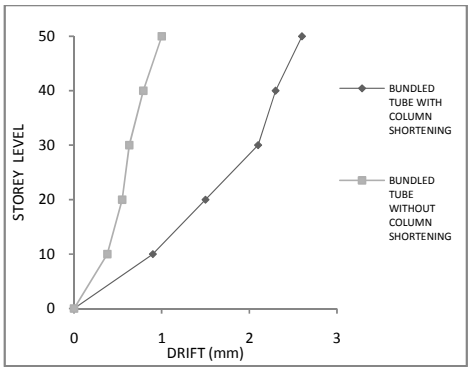

Figure 14. Comparison of storey drift in Bundled tube structure with and without column shortening effect.

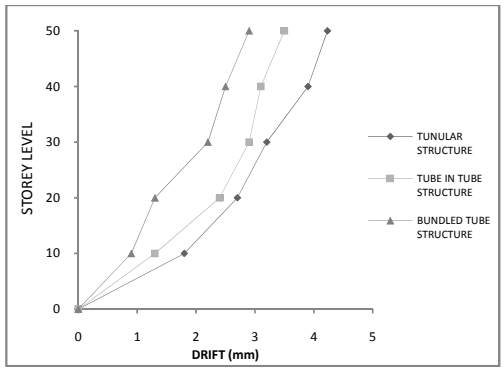

Figure 15. comparison of storey drift in Tubular, Tube in tube and Bundled tube structure with column shortening effect.

5. Conclusion

The columns in a tall building undergoes axial shortening considerably more than columns in the low and medium rise buildings. This leads to the uneven settlement of the floor levels. In this paper, the Tubular, Tube in tube and Bundled tube structure are analysed and the following conclusions are drawn:

- Decrease in the maximum bending moments, Axial force, Shear Force of about 25%, 20% and 23% respectively while comparing the Tubular structure without column shortening to the structure with column shortening.
- Decrease in the maximum bending moments, Axial force, Shear Force of about 23%, 17% and 25% respectively while comparing the Tube in tube structure without column shortening to the structure with column shortening.

- Decrease in the maximum bending moments, Axial force, Shear Force of about 19%, 15% and 31% respectively while comparing the Bundled tube structure without column shortening to the structure with column shortening.
- Increase in the time period of about 62%, 57% and 60% while comparing the Tubular, Tube in tube structure and Bundled tube structure without column shortening to the structure with column shortening.
- Decreases in Storey Drift of about 74%, 70% and 60% in the Tubular, Tube in tube structure and the Bundled tube structure without column shortening to the structure with column shortening.
- Due to reduction of forces the dimension of the structural elements can be reduced which directly reduces the dead load of the structure and also the cost of construction.

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