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Analysis of Framed Tube Structures with Multiple Internal Tubes

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Abstract—*Modern high-rise buildings of the framed-tube system exhibit a considerable degree of shear lag with consequential reduction in structural efficiency. Despite this drawback, framed-tube structures are widely accepted as an economical system for high-rise buildings. The study presents the results by varying internal tube into multiple tubes of equivalent sizes. In this paper one internal tube of 5m x 15m is divided in to two and three tubes of equivalent sizes. Internal tubes placed at the core of the structure. External tube is formed by spacing columns at 2.5. The columns connected by the deep spandrel beams. Due to use of deep beams, tube action is achieved. The analysis is done for lateral loading. Results obtained from analysis plotted to compare and to have knowledge of actual behaviour of framed tube structures. Varying number of internal tubes reduces the shear lag effect and makes distribution of axial forces more uniform in columns. The use of three internal tubes instead of one reduced deflection shear lag.*

Keywords*: Framed tube, Shear lag, spandrel beams, Tubes, Efficiency, Lateral loading*

1. INTRODUCTION

The framed tube is one of the most significant modern developments in high-rise structural form. The frames consist of closely spaced columns, 2-4 m between centres, joined by deep girders. The idea is to create a tube that will act like a continuous perforated chimney or stack. The lateral resistance of framed tube structures is provided by very stiff moment resisting frames that form a tube around the perimeter of the building. The gravity loading is shared between the tube and interior columns. This structural form offers an efficient, easily constructed structure appropriate for buildings having 40 to100 storeys.

When lateral loads act, the perimeter frames aligned in the direction of loads act as the webs of the massive tube cantilever and those normal to the direction of the loading act as the flanges. Even though framed tube is a structurally efficient form, flange frames tend to suffer from shear lag. This results in the mid face flange columns being less stressed than the corner columns and therefore not contributing to their full potential lateral strength. Aesthetically, the tube looks like the grid-like façade as small windowed and is repetitious.

The framed-tube structure is an efficient structural system for tall buildings in steel as well as concrete. Tall building structures over a wide range of building heights. In its basic form, the system consists of closely spaced perimeter columns tied at each floor level by deep spandrel beams to form a tubular. Because of structural efficiency, modern high-rise buildings are usually built with the tube concept which places the lateral-load resisting elements on the outside perimeter. These buildings are usually equipped with a service core which may house elevators, emergency stairways, electrical and mechanical equipment, etc. The walls of the core are often designed to provide additional stiffness to the building, thus acting like a second tube within the outside tube. These buildings are called “tube in-tube” structures. Now days such structures can be equipped with multiple internal tubes. Such buildings are shows great performance for lateral loading.

Advantages to use framed tube structures with multiple internal tubes:

a) Efficient structural system: The framed tube structures with multiple internal tubes provide stability against lateral loading as well as gravity loading. Also this system provides enough opening for stairways, elevators &ducts etc.

b) Suitable for high rise structure: This system holds good for 40-100 storied structure.

c) Speedy construction: The use of framed tube structure allows speedy construction.

d) Suitable for RC, steel and composite constructions

2. SHEAR LAG

The stress distribution in the flange wall panels is not uniform and that in the web wall panels is nonlinear. These are illustrated as shown in figure. This (nonlinear) phenomenon is referred to as ‘‘shear lag’’. The shear lag can be distinguished in two types-

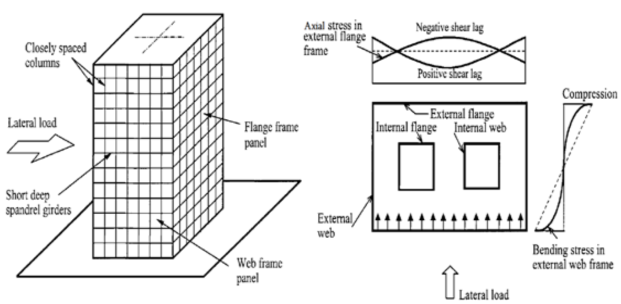
a) Positive shear lag: The stresses in the corner columns of the flange frame panels exceed those in the centre columns. The effects due to positive shear lag are- Warping of the floor slabs and deformation of the interior partitions.

b) Negative shear lag: The stresses in the centre columns of the flange frame panels exceed those in the corner columns. frame panels exceed those in the centre columns. The effects due to negative shear lag are- Local buckling on the compression side and cracking on the tension side of the flange frame.

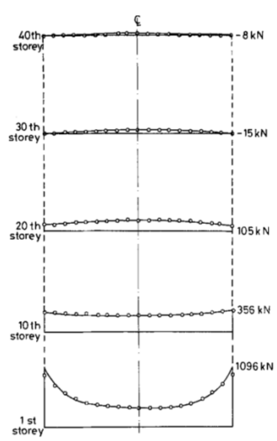
Due to increase in the natural flexibility of the spandrel beams, which tie the closely spaced columns at each floor level the positive and negative shear lag phenomenon is more prominent in framed tube structure. Following are the structural parameters affecting the shear lag behaviour:

i. Number of internal tubes.
ii. Ratio ‘g’ i.e. - The number of stories to the number of bays in the external flange frame panel.
iii. Stiffness ratio S_r- The ratio of bending stiffness of the column and that of the beam.
iv. Stiffness factor S_f – representing the ratio of the shear rigidity and the column bending stiffness.

To investigate the shear lag phenomenon in the front columns in the external flange panel, the ratio P is introduced as the ratio of axial force in the corner column and that in centre column. A value of p greater than unity suggests a positive shear lag. Otherwise negative shear lag indicated. Also by plotting the axial forces in the columns of external flange at a particular storey we can get idea about the shear lag.



Following figure shows the axial force distribution pattern of framed tube structure with internal tube for a lateral loading.



3. PROBLEM

To study effect on shear lag by varying number of internal tubes in framed Tube structure. Forty storied framed tube structures with single, two and three internal tubes having following properties.

Plan Dimension: 15m x 30m

Effective size of internal tube / tubes: 5m x 15m

Height of each story: 3m

Column spacing of external tube: 2.5m

Internal tube: RCC 250mm Thick

Live load: i) 1 to 39 Stories= 3 kN/ m^2

ii) 40 Storey= 1.5 kN/ m^2

Floor finish: 1 kN/ m^2

Wind speed, V_b = 39 m/sec

Terrain category= 4

Structure class = C

Risk coefficient K_1= 1

Topography k_3= 1

Terrain factor k_2= 1.07

(As per IS 875: 1987 (Part 3))

Concrete= M30, Steel= Fe415

Following are the sizes of various structural members used for modelling the desired structure.

Structural Members	**Tube structure with one internal tube**	**Tube structure with two internal tubes**	**Tube structure with three internal tubes**
Size of columns in external tube	1000mm X 750mm	1000mm X 750mm	1000mm X 750mm
Size of beams in external tube	1200m X 750mm	1200m X 750mm	1200m X 750mm
Size of internal columns	900mm X 750mm	900mm X 750mm	900mm X 750mm
Size of internal beams	900mm X 750mm	900mm X 750mm	900mm X 750mm
Size of external tube	15m X 30m	15m X 30m	15m X 30m
Size of internal tubes	5m X 15m	5m X 7.5m	5m X 5m

4. MODELLING

Framed tube structure is modelled with software ETABS V9.7.4. The following figures show the schematic diagram of models to be analysed.

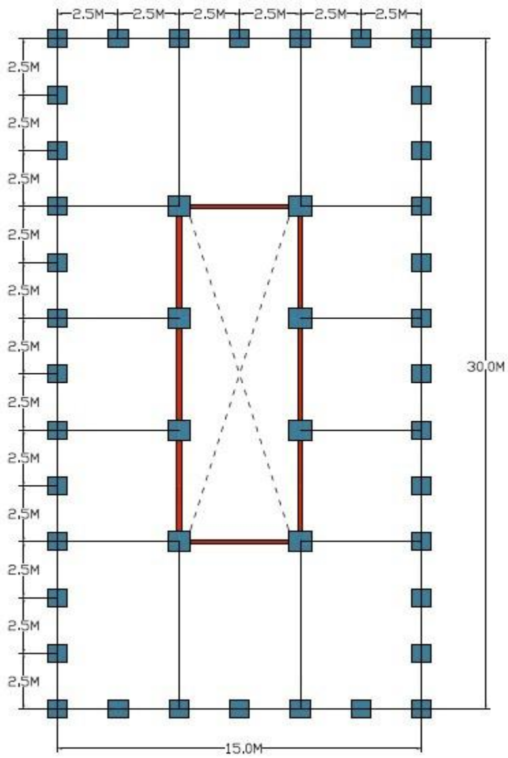


Figure 1 Framed tube structure with one internal tube

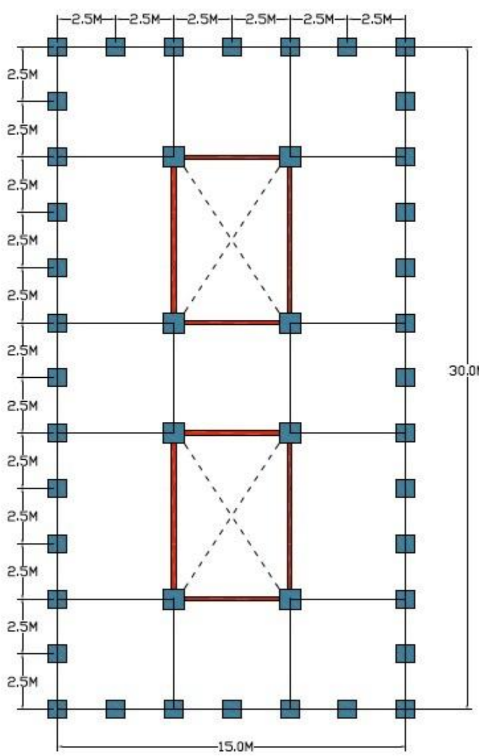


Figure 2 Framed tube structure with two internal tubes

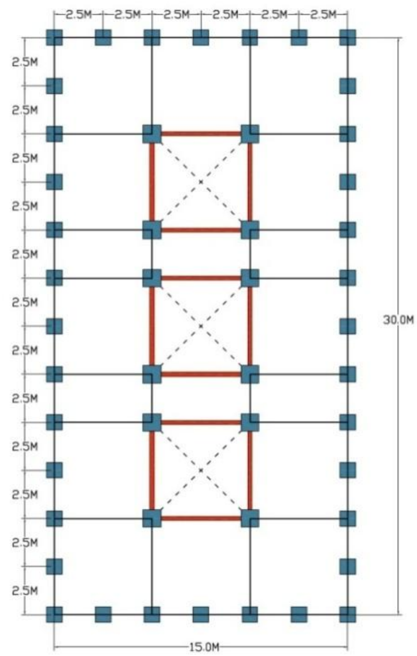
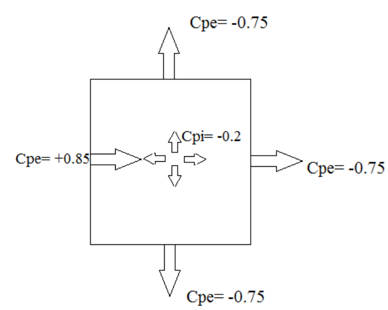


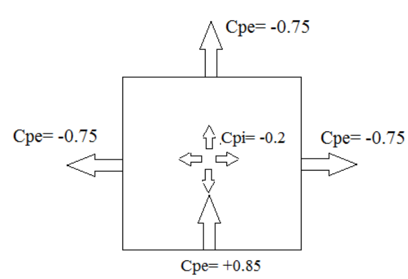
Figure 3 Framed tube structure with three internal tubes

5. LOADS

The modelling is done as considered above problem statement. The lateral loading considered is wind load. To apply wind load on the models in ETABS we need the various coefficients such as K1, K2 & K3. Also we need to apply external and internal coefficients of pressure. For the given structure the coefficients of wind pressure are-



a) Wind in X-direction (Wx):

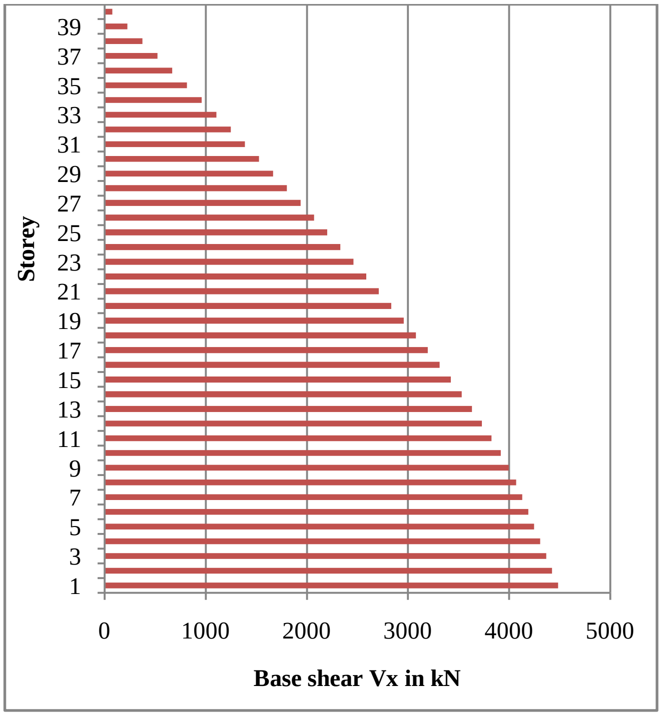


b) Wind in Y-direction (Wy):

6. RESULTS

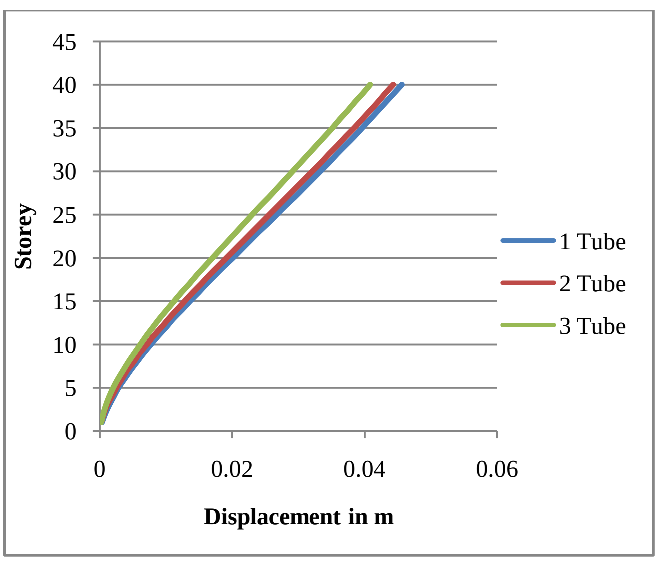
The results found plotted to get actual behaviour of structure and to judge the objectives of study. The results and their significance discussed here briefly.

a) Base shear



Graph 1: Shows Storey shear against storey level

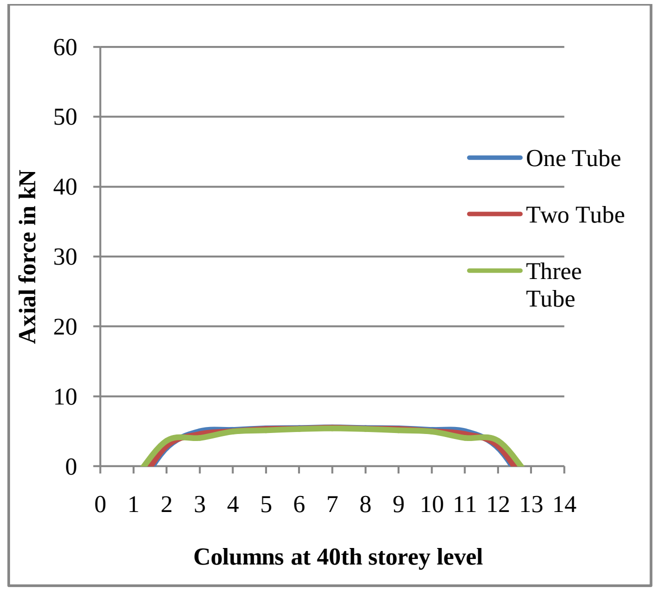
b) Displacement



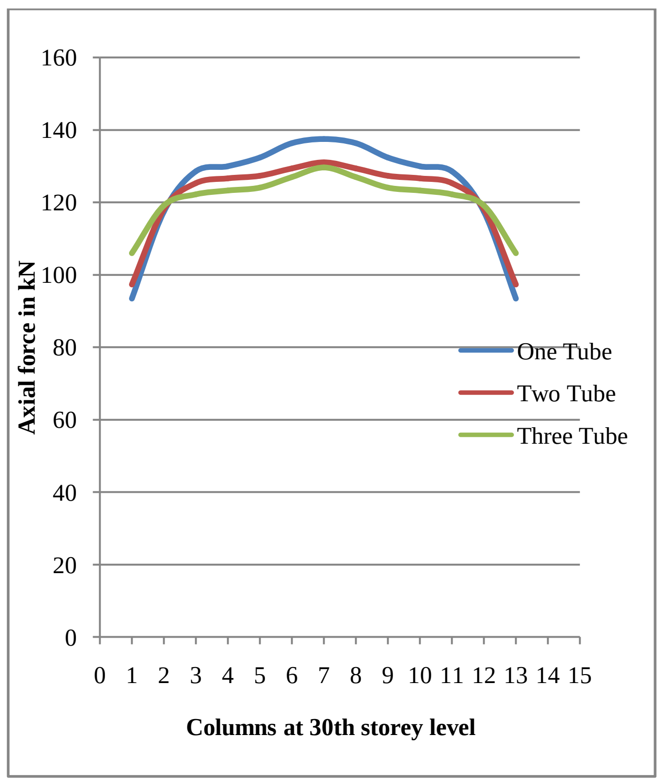
Graph 2: Shows Displacement against storey level

c) Shear lag:

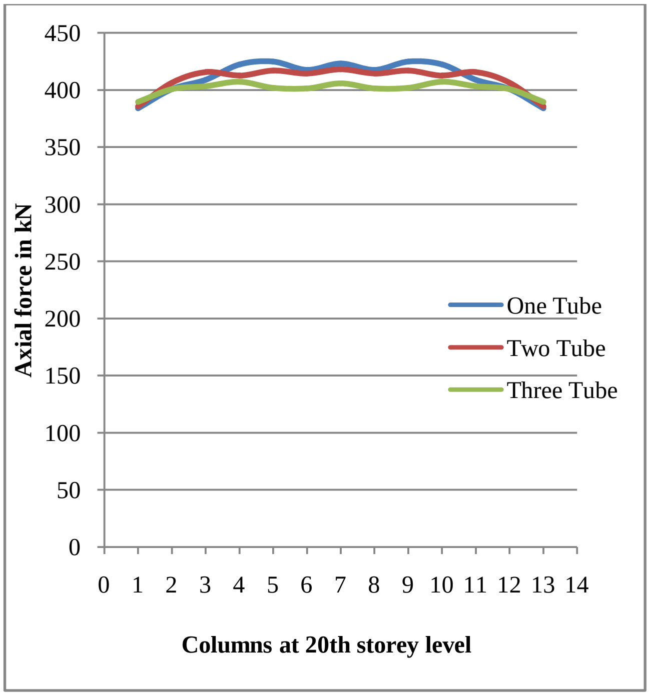
The axial force distribution in the front flange of the building due to wind loading is as follows:



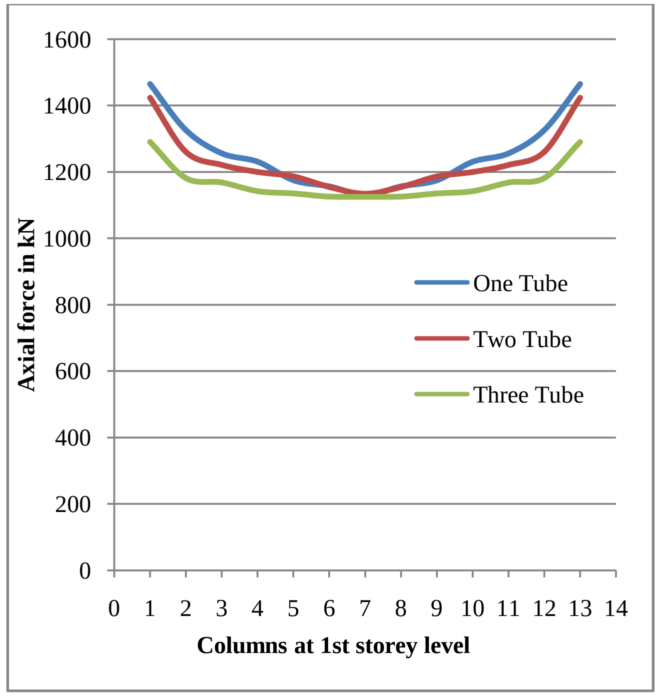
Graph 3: Shows axial force distribution against columns at 40th storey



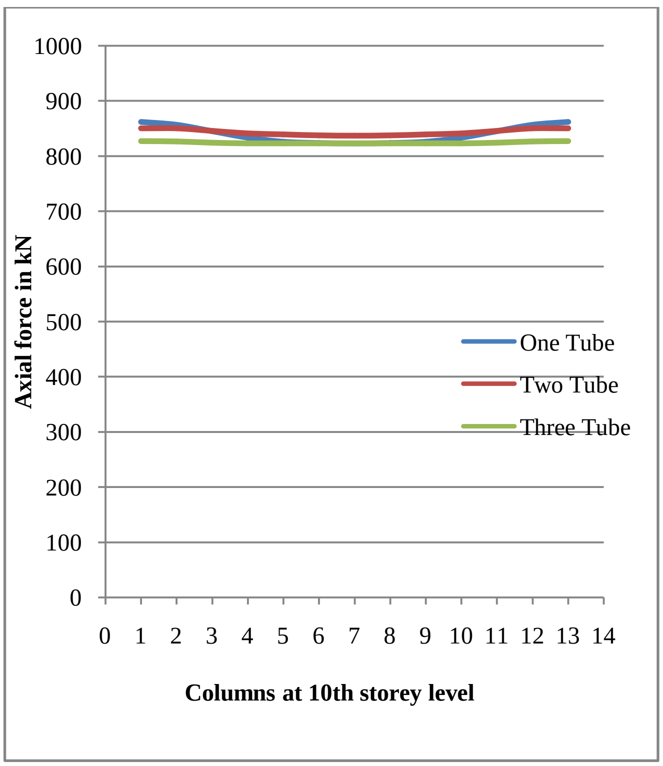
Graph 4: Shows axial force distribution against columns at 30th storey



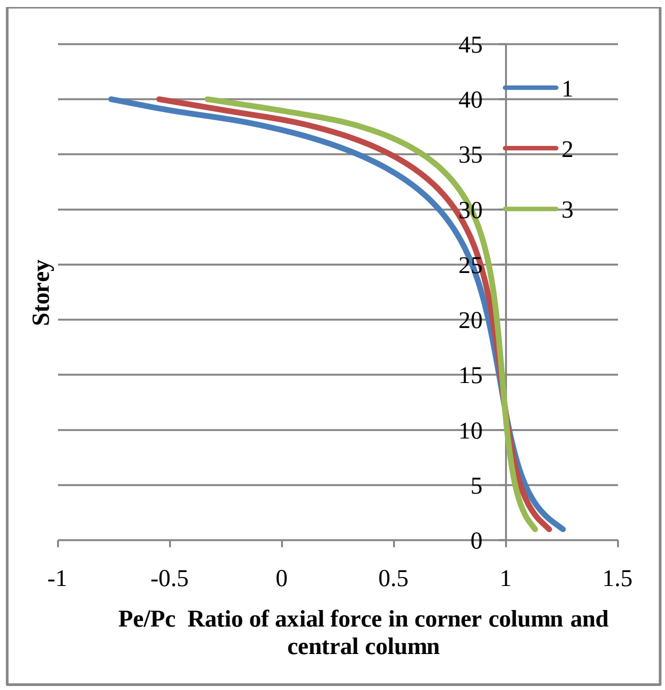
Graph 5: Shows axial force distribution against columns at 20th storey



Graph 6 shows axial force distribution against columns at 1st storey



Graph 6: Shows axial force distribution against columns at 10th storey



7. DISCUSSIONS

The graph of base shear shows that the base shear of all the three models is equal. The value of base shear is 4483.34kN. In case wind loading there is no change of base shear for the changing number of internal tubes.

The graph of displacement against storey level is different for each model. The displacement of the structure with three internal tubes is less than two tube structure and displacement of two tube structure is less than one tube structure. This because of increase in stiffness of structure due to increase in internal tubes.

From the graph of 40th storey it clears that the axial force distribution of all the three models is such that the negative shear lag is present. The graph is almost same for all models.

The distribution of axial forces for 30th storey is such that there is negative shear lag is present. Graph for three tube structure is flatter than other two models. At 20th storey level slight shear lag is present for all three models but axial force distribution is more uniform in case of three tube structure.

The axial force distribution for 10th storey level is such that there is slight positive shear lag for two tube and one tube structure. The force distribution is uniform in case of three tube structure. At first storey level, axial forces are non-uniformly distributed for all models but in case of three tube structure distribution is slightly flatter than two tube structure and in case of two structure the distribution of axial forces is flatter than one tube structure.

The shear lag reversal point is present in between 15th and 10th storey level.

8. CONCLUSION

- In case of wind loading negative shear lag is present in top 2/3rd of the structure height.
- For one tube structure, at 1st storey level the axial force in corner column of the front flange of the building is more than middle column by 29.57%.
- For two tube structure, at 1st storey level the axial force in corner column of the front flange of the building is more than middle column by 22.55%.
- For three tube structure, at 1st storey level the axial force in corner column of the front flange of the building is more than middle column by 14.73%.
- The multiple internal tubes must adopt for framed tube structures since these gives better performance in case of lateral loading.
- The use of multiple internal tubes provides structural safety and stability against lateral loading.
- For framed tube structures shows better performance when used with multiple internal tubes.

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