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Differential Settlement in Various Tubular Structural Systems

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Abstract: Tubular structural system is a 3 dimensional space structure comprises of 3, 4 or possibly more frames, braced frames or shear walls joined at or near their edges to form a vertical tube like structural system which is capable of resisting lateral forces in any direction by cantilevering from the foundation. Tubular tall building structures have started becoming an integral part of the building scenario in developed countries. They provide various advantages over a conventional tall building in terms of flexibility of interior spacing, better utilization of material and hence lesser cost of construction. Therefore studies on various parameters that influence the serviceability of such structure is beneficial in the long run. One such parameter is the differential settlement of tubular structures is studied under this work. This research work will shed some light on the influence of differential settlement on the tubular structures. The differential settlement that would occur on four separate G+60 tubular tall structures under different framed conditions is determined using a structural analysis and design software and thereby observed that there was a gradual increase from zero at the base of structure in fixed supports whereas in spring supports there was a settlement at the base of structure. From the analysis of different tube structures like framed tube, braced tube, bundled tube and tube in tube structures, it was observed that there was a certain percentage increase in the settlement of top storey with spring support when compared to that of fixed support. Compared to other tube structures, the framed tube structure exhibited a better performance in settlement under both the support conditions.

Key words: Tubular Structure, supports, differential supports.

I. INTRODUCTION

The advancement of technology and the increased economic development of the countries have brought about a new era in construction of high-rise buildings. With the significant improvement in construction technology it is witnessed that new structural systems being adopted in the design of high-rise buildings. One among them is the tubular structural system. Tubular structural system resists lateral loads (wind, seismic etc.). This system was first introduced by Fazlur Rahman Khan in the 1960s. The first example of a tube system being used was the 43-storey Khan designed Dewitt-chestnut apartment building in Chicago.

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Fazlur Khan defined a framed tube structure as “a 3 dimensional space structure comprises of 3,4 or possibly more frames, braced frames or shear walls joined at or near their edges to form a vertical tube like structural system which is capable of resisting lateral forces in any direction by cantilevering from the foundation”. This laid the foundation for tube structural design of many skyscrapers including John Hancock Centre, Wilis tower, W.T.C, and the Petronas tower.

In a tube structure, the exterior consists of closely spaced columns that are tied together with deep spandrel beams through moment connections. This assembly of columns and beams forms a rigid frame that amounts to a dense and strong structural wall along the exterior of the building. This exterior framing is designed sufficiently to resist all lateral loads on the building, thereby allowing the interior of the building to be simply framed for gravity and loads. Interior columns are comparatively few and located at the core. The distance between the exterior and the core frames is spanned with beams or trusses and intentionally left column-free. This maximizes the effectiveness of theexterior tube by transferring some of the gravity loads within the structure to it and increases its ability to resist overturning due to lateral loads. The group of columns perpendicular to the direction of horizontal load is called flanged frame and group of columns parallel to the direction of horizontal load is called web frames. Since the columns are close to each other and the spandrel beams are deep, the structure can be considered as perforated tube and behaves as cantilevered tube. The flanged frame columns will resist the axial forces (tension and compression) and web will resist the shear forces. The different types of structures are shown in fig 1.

1.2 Types of tubular system

1.2.1 Framed Tube Structures

Frames consist of closely spaced columns,generally 2 to 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 structure is provided by stiff moment resisting frames that form a tube around the exterior of the building. The gravity loading is shared between tube and the interior columns. This structural form offers an efficient, easily constructed structure appropriate for buildings having 40 to 100 storeys. When lateral loads act, the exterior frames aligned in the direction of loads acts as the webs 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 restrict from contributing their full potential lateral strength.

1.2.2 Braced Tube Structures

Further improvement of tubular structures can be made by cross bracings the frame with X-bracings over many storeys. As the diagonals of the braced tube are connected to the column at each intersection, they virtually eliminate the effects of shear lag in both flange and web frames. As a result, the structure behaves under lateral loads more like a braced frame reducing bending in the members of the frame. Hence spacingof columns can be increased and the depth of girders will be less, thereby allowing large size windows than in conventional framed tube structures. In braced tube structures, the braces transfer axial load from highly stressed columns to least stressed columns and eliminates difference between load stresses in columns. E.g.: Chicago's John Hancock building, The Citigroup Centre, Bank of China Tower.

1.2.3 Tube in Tube Structures

This is a type of framed tube consisting of an outer-framed tube together with an internal elevator and service core. The inner tube may consist of braced frames. The outer and the inner tubes act jointly in resisting both gravity and lateral loading in steel framed buildings. However, outer tube usualy plays a dominant role because of its much greater structural depth. This type of structure (tube in tube structure) is also called as hull and core structure.

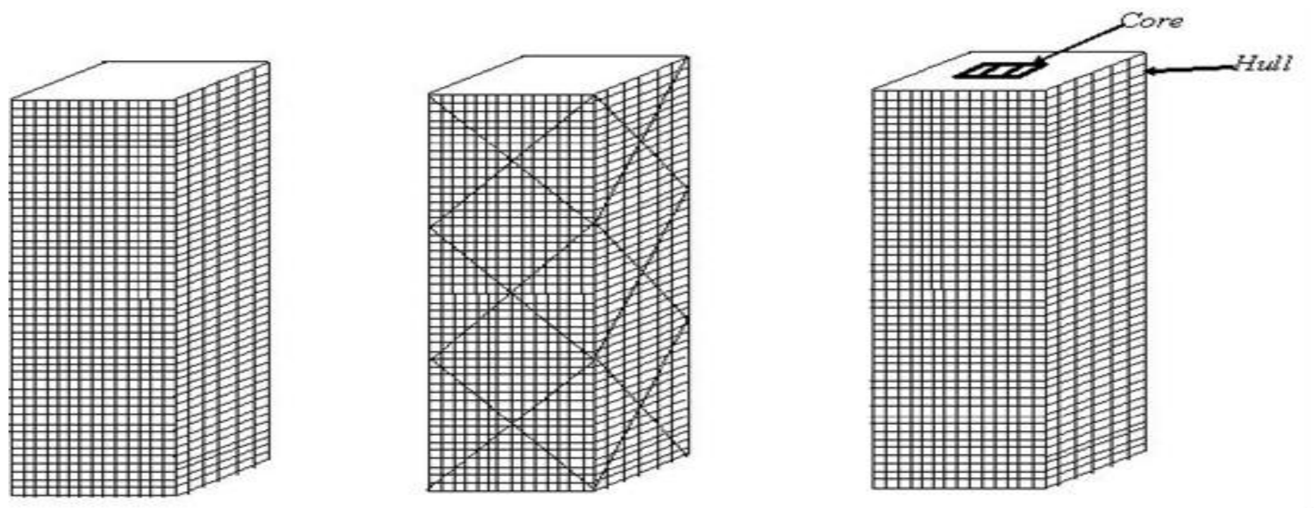


Fig. 1 (a) Framed tube (b) Braced Tube (c) Tube in Tube

1.2.4 Bundled Tube

The bundled tube system can be visualized as an assemblage of individual tubes resulting in multiple cell tube. System allows for greater height and cover more floor area. E.g.: Sears Tower. In this system, introduction of internal webs greatly reduces the shear lag in the flanges. Hence their columns are more evenly stressed than in the single tube structures and their contribution to the lateral stiffness is greater.

1.3 Objective

The objective of this project is to determine the differential settlement that would occur on four separate G+60 tubular tall structures using a structural analysis and design software and thereby to study the influence of the settlement on the tall structures.

II. METHODLOGY

2.1 Methodology

A thorough review of literature was carried out to understand the previously carried out studies on tubular structures and the effect of settlement on them. To begin with, the modeling of four separate types of tubular structures were done by using the computer software ETABS. Analysis of these buildings for settlement under different support conditions namely fixed and spring support.The different outputs are then studied and compared with each other.

III. MODELING

3.1Model 1 – Framed tube structure

In this model,the structure is 180m tall and has 60 storey each one being 3m high. The dimension of the plan at the base is 9mx9m. The deep beams that connect the columns on the exterior are of size 1300mmx250mm and all other beams are of size 500mmx250mm. Theexterior columns of the structure are of 1000mmx1000mm size. The slab is of thickness 150mm and the concrete used is of grade M80. Both fixed and spring supports are used alternately to find the displacement in the vertical direction wherein the stiffness of the springs used are36000kN/m. The plan and 3D view of the building are shown in fig. 2 and fig. 3 respectively.

3.3 Model 2 – Tube in tube structure

Here, the structure is 180 m tall and has 60 storey each one being 3 m high. The dimension of the exterior tube is taken as 12 m x 10 m and the dimension of the inner core is taken as 4 m x 2 m.

The deep beams that connect the columns on the exterior are of size 1200 mm x 400 mm and all other beams are of size 600 mm x 400 mm. The columns of the structure are of 1500 mm x 1500 mm size.

The slab is of thickness 150 mm and the concrete used is of grade M80.

Both fixed and spring supports are used alternately to find the displacement in the vertical direction wherein the stiffness of the springs used are 36000 kN/m. The plan of the tube in tube in structure is shown in fig. 4.

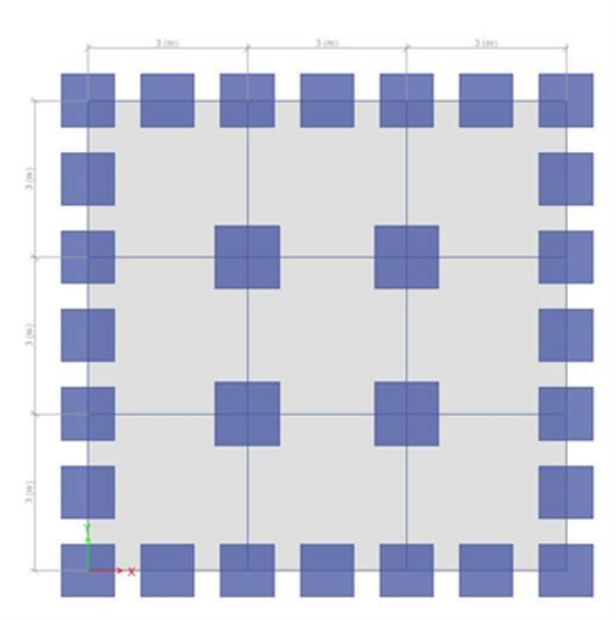


Fig. 2 Plan of a framed tube structure

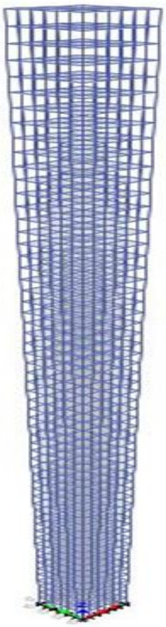


Fig. 3. 3D view of a framed tube

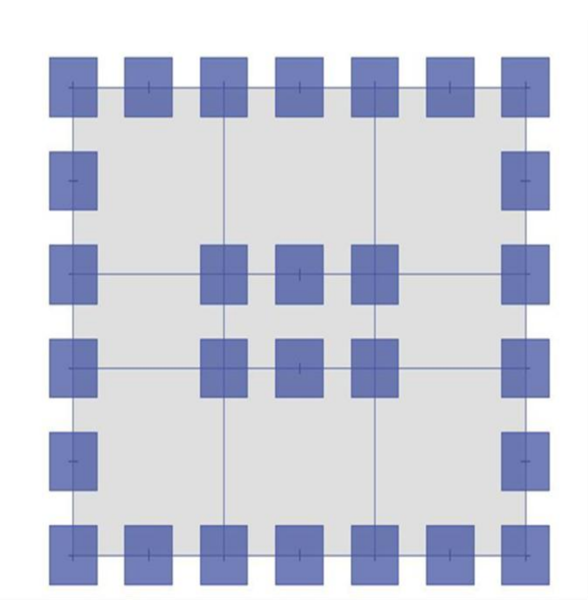


Fig. 4 Plan of a tube in tube structure

Fig. 5 3D view of a tube in tube

The 3D view of tube in tube structure is shown in fig.5. In this structure a tube is designed inside a tube making for an exterior tube and a core.

3.4 Model 3 – Bundled Tube

In this model, the structure is 180m tall and has 60 storeys each one being 3m high. The dimension of the plan at the base is 18mx18m. The deep beams that connect the columns on the exterior are of size 1200mmx250mm and all other beams are of size 500 mm x230mm. The columns of the structure are of 1500mmx1500mm size. The slab is of thickness 150mm and the concrete used is of grade M80. Both fixed and spring supports are used alternately to find the displacement in the vertical direction wherein the stiffness of the springs used are 36000kN/m. The plans at various sections of the bundled tube are shown in fig. 6, fig. 7, fig. 8 and fig. 9.The 3D view of the bundled tube is displayed in fig. 10. The plan dimension decreases as it goes from the bottom to the top.

3.5 Model 4 – Braced tube

The structure is 180 m tall and has 60 storeys each one being 3 m high. The dimension of the plan at the base is 12 m x 12 m. The deep beams that connect the columns on the exterior are of size 1250 mm x 230 mm and all other beams are of size 500 mm x 230 mm. The columns of the structure are of 1200 mm x 1200 mm size.

The bracings provided are steel angles of total depth and total width of 203.2 mm and having horizontal and vertical leg thickness of 25.4 mm. The area of each bracing would be 96.8 cm^2.

The slab is of thickness 150 mm and the concrete used is of grade M80. Both fixed and spring supports are used alternately to find the displacement in the vertical direction wherein the stiffness of the springs used are 36000 kN/m.

The 3D view is shown in fig 11. In this structure bracings are provided on two opposite faces to provide increased resistance to the structure against lateral loads.

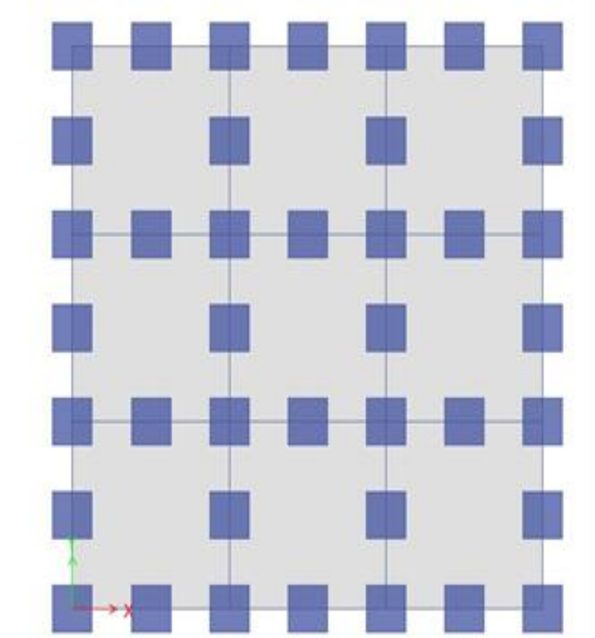
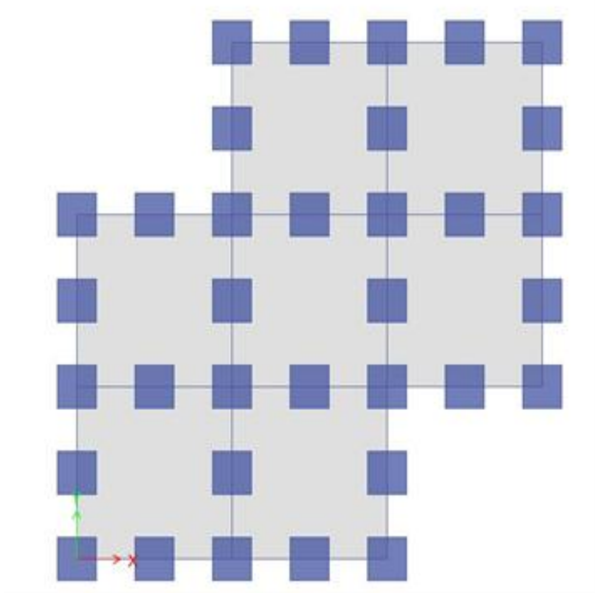


Fig. 6 Plan of a bundled tube structure Fig.
(Floors 1-30)



7 Plan of a bundled tube structure
(Floors 31-44)

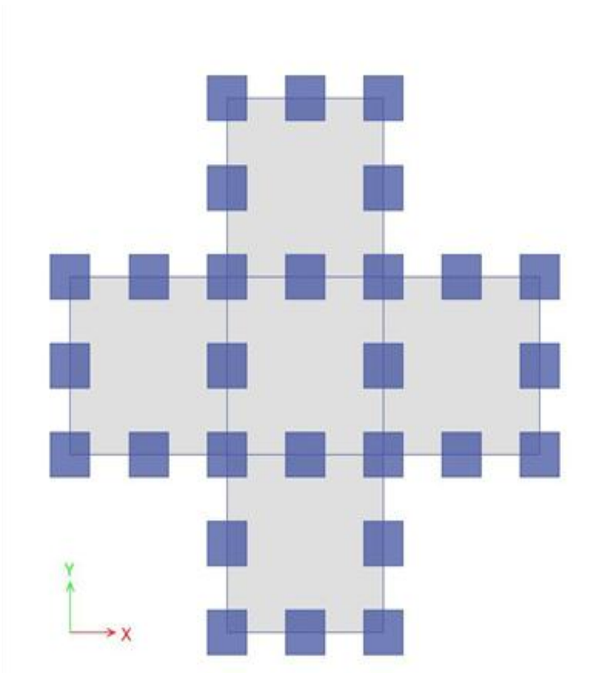
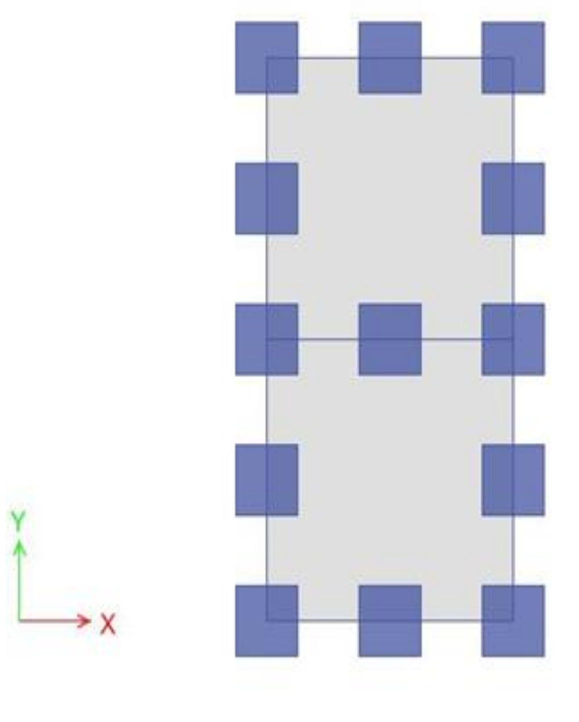


Fig. 8 Plan of a bundled tube structureFig.
(Floors 45-54)



9 Plan of a bundled tube structure
(Floors 55-60)

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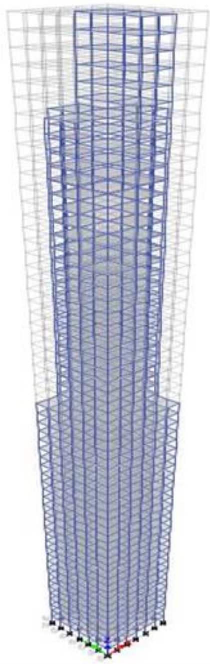

Fig.10 3D view of a bundled tube structure

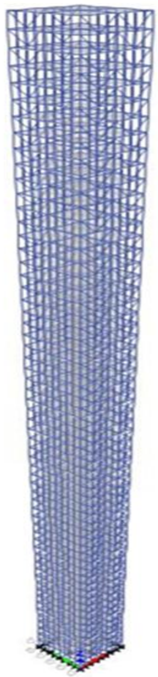

Fig. 11 3D view of a braced tube structure

IV. RESULTS AND DISCUSSIONS

4.1 Framed tube

From the settlement values under both fixed and spring supports a graph is plotted depicting the variation of settlement with each storey. The graph plotted using the results depicts two curves, one showing the settlement under fixed support and the other the settlement under spring support. The settlement for fixed support at the base is zero whereas the settlement for spring support at the base gives a definite value. The graph obtained from plotting the settlement under different supports namely the fixed support and the spring support versus the storey numbers are shown in fig. 12. It is clear from the graph that for the framed tube structure, the settlement for the base under fixed support is zero while the settlement at base under spring support gives a value of 38.5 mm. There is 35.90% increase in the settlement of the top storey of the structure with spring support when compared to the fixed support.

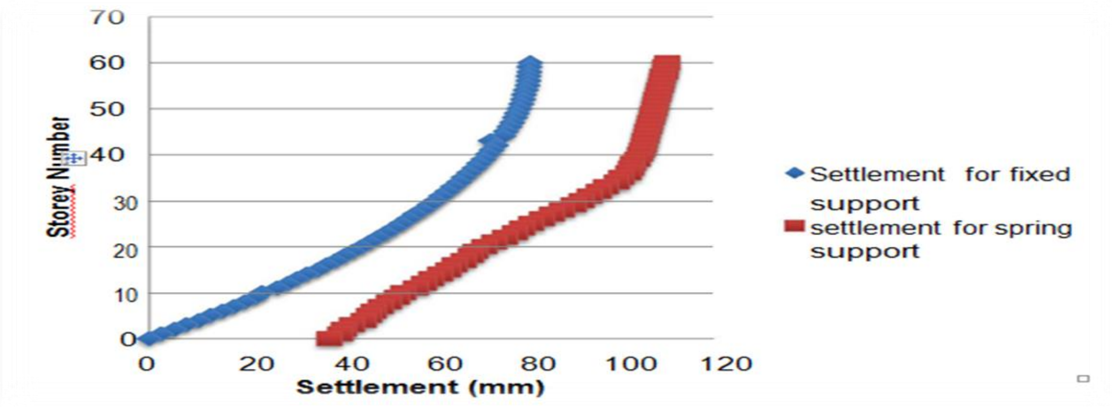

Fig 12.Graph plotting the settlement of framed tube

4.2 Tube in tube structure

A graph is plotted using the results depicts two curves, one showing the settlement under fixed support and the other the settlement under spring support. The settlement for fixed support at the base is zero whereas the settlement for spring support at the base gives a definite value. The graph obtained from plotting the settlement under different supports namely the fixed support and the spring support versus the storey numbers are shown in fig. 13. It is clear from the graph that the settlement for the base under fixed support is zero while the settlement at base under spring support gives a value of 51.6 mm. And there is a 67.73% increase in settlement of the top storey with the spring supports when compared to the top floor of the same tube in tube building with spring support.

4.3 Bundled Tube

From the settlement values under both fixed and spring supports a graph is plotted depicting the variation of settlement witch each storey. The graph obtained from plotting the settlement under different supports versus the storey numbers is shown in fig. 14. The graph plotted using the results depicts two curves, one showing the settlement under fixed support and the other the settlement under spring support. It is clear from the graph that there is 57.46% increase in the settlement of the top storey of the structure with spring support when compared to the building with fixed support.

4.4 Braced tube

The graph is plotted using the results that depicts two curve, one showing the settlement for the fixed support which is zero at the base and a definite value for the

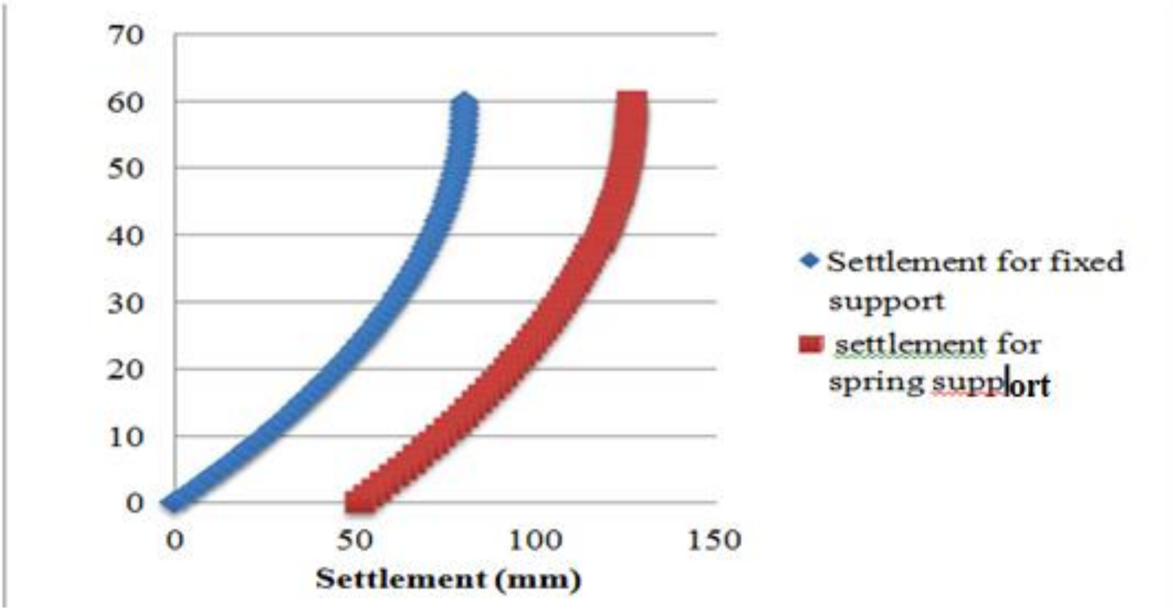

Fig 13. Graph plotting the settlement of tube in tube structures

spring support. The graph obtained from plotting the settlement under different supports namely the fixed support and the spring support versus the storey numbers are shown in fig. 15. It is clear from the graph, the settlement for the base under fixed support is zero while the settlement at base under spring support gives a value of 34.7mm. And there is 43.08% increase in the settlement of the top storey of the structure with spring support when compared to the building with fixed support.

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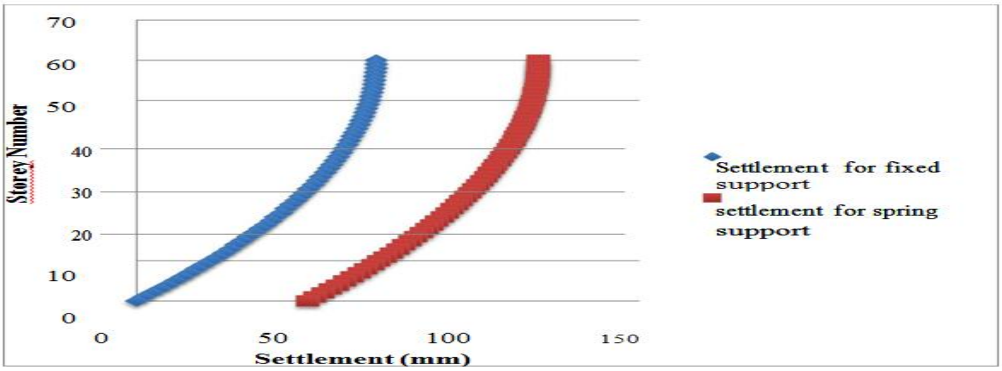

Fig 14. Graph plotting the settlement of bundled tube

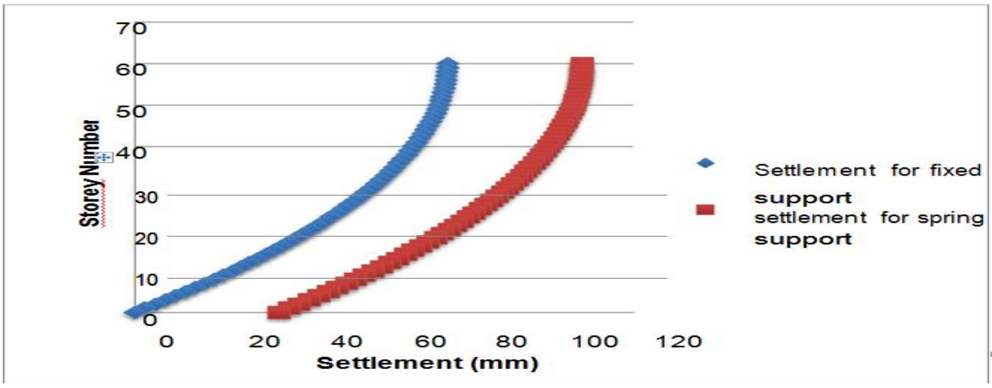

Fig.15 Graph plotting the settlement of braced tube

V. CONCLUSIONS

5.1 General

The analysis of four different types of tubular structures were carried out using the software ETABS. The results obtained from the analysis of the structures were then compared for two different support conditions, namely, the fixed support and the spring support. The following conclusions were obtained from the settlement analysis for each of the four buildings under different support conditions:

- For a framed tube structure, there is a 35.90% increase in the settlement of the top storey of the structure with spring support when compared to the building with fixed support.
- For a tube in tube structure, there is a 67.73% increase in the settlement of the top storey of the structure with spring support when compared to the building with fixed support.
- For a bundled tube structure, there is a 57.46% increase in the settlement of the top storey of the structure with spring support when compared to the building with fixed support.
- For a braced tube structure, there is a 43.08% increase in the settlement of the top storey of the structure with spring support when compared to the building with fixed support.
- The framed tube structure exhibited a better performance when compared to that of other tube structures

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