International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 04 | Apr -2017 www.irjet.net p-ISSN: 2395-0072

DYNAMIC ANALYSIS OF TUBE-IN-TUBE TALL BUILDINGS

Lavanya.T[1], Sathyanarayana Sridhar.R[2]

[1] *Post Graduate student, M.E. Computer Methods and applications in Structural Engineering*
[2] *Associate Professor, Department of Civil Engineering,*
Coimbatore Institute of Technology, Coimbatore-04, Tamilnadu, India.

* * *

Abstract - *One of the important dynamic characteristics of tall buildings namely, the Natural Frequency (ω, radians/sec) or Fundamental Time Period (T, seconds) is obtained analytically for a range of tube-in-tube tall buildings using transfer matrix method. In this paper, an approximate procedure is generated to perform the free vibration analysis of tube-in-tube tall buildings. In the absence of a rational method for determining the Fundamental Time Period of Tube-in-Tube High Rise Buildings in the Codes, in order to provide a new approximate method for the preliminary design, the tube-in-tube structure is simplified as a prismatic cantilever flexural shear beam with fixed base. In this Transfer Matrix method, the dynamic response of structure such as displacement, rotation angle, bending moment and shear force are expressed in the form of a transfer vector. The method suggested here enables us to calculate the natural frequency of tube-in-tube tall buildings accurately with the aid of computer programming.*

Key Words: Dynamic characteristics, Transfer Matrix Method, Flexural rigidity, Prismatic cantilever flexural shear beam, Transfer vector, Computer Programming

1.INTRODUCTION

Tall buildings are usually flexible and are sensitive to dynamic loads. Therefore, estimating the natural frequency for tall buildings is highly important for evaluation of building response due to Wind or Earthquake. Forced vibration response of tall buildings due to these loads always involves natural frequency as a key parameter. The accuracy of solution of free vibration and its natural frequencies depends on the selection of the mathematical model. The exact dynamic behavior of structures could be obtained through three-dimensional analyses such as Finite Element Analysis (FEM).Even simple models require large computational effort in FEM analysis.

1.1 Common Types of Structural Systems in Tall Buildings

1 Rigid Frame System (Moment Resisting Frame System)
2 Braced frame system
3 Shear Wall System
4 Coupled Wall System
5 Advanced Structural forms- Tubular Systems

1: Rigid Frame System: It is a system that utilizes the moment resisting connection between columns and beams along its total perimeter to resist the applied lateral loads. It can be utilized to provide lateral load resistance for low-rise buildings.

2: Braced frames: To resist lateral deflections, the simplest method from the theoretical standpoint is an intersection of full diagonal bracing or X-bracing. It works well for 20 to 60 storey height but does not give room for opening such as door and windows.

3: Shear Walls: The lateral loads are assumed to be concentrated at floor levels. The rigid floors spread these forces to the columns or walls in the building. Specially designed reinforced concrete walls parallel to directions of load are used to resist a large part of the lateral loads caused by winds or earthquakes by acting as deep cantilever beams fixed at the foundation. These elements are called shear walls.

4: Coupled Wall System: When two or more shear walls are connected by a system of beams or slabs, total stiffness exceeds the summation of individual stiffness. This is due to the beam connecting them that caters the individual cantilever action.

5:Tubular systems: The tubular system is to arrange the structural elements in such a way that the system can resist the imposed loads on the structure efficiently especially the lateral loads. This system comprises of various elements i.e. slabs, beams, girders, columns. The walls and cores are engaged to resist the lateral loads, in the tubular system the horizontal loads are resisted by column and spandrel beams at the perimeter level of the tubes.

1.2 Types of Tubular Systems:

(a) Framed tube structure
(b) Braced tube structure
(c) Tube in tube structure
(d)Bundled tube structures

(a) Framed Tube Structures: Frames comprises of closely spaced columns, 2 to 4 m between centers, with deep girders joining them. The ideology is to develop a tube like structure which acts like a continuous perforated chimney or stack. The lateral resistance of this structure is provided by stiff moment resisting frames which form a tube throughout the periphery of the building. The gravity loads are distributed between the tube and the interior columns. This structural form provides an efficient structure appropriate for buildings with 40 to 100 storeys. When the horizontal loads act, the boundary frames arranged in the load direction acts as the webs of massive tube cantilever while those normal to the direction of the loading act like flanges. Although framed tube is the most structurally efficient system, flange frames will suffer from shear lag. This causes the mid face flange columns subjected to less stress than that of corner columns and so they won't contribute to their full potential strength. Example: Aon Centre and W.T.C Towers

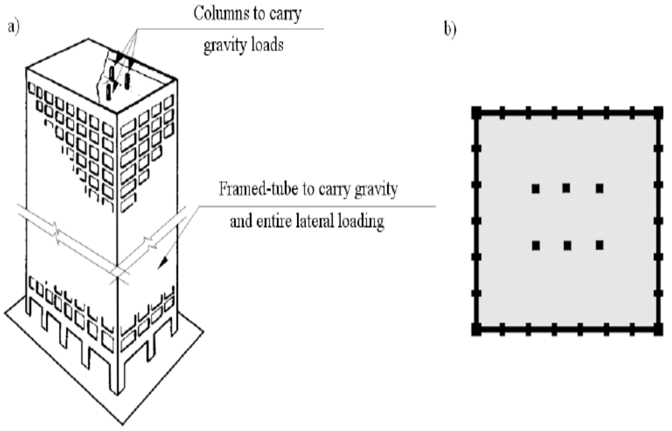


Fig.-1: a) 3D view of Frame tube structure and b) sectional plan

The framed tube structure is shown in Fig. 1.3 can be considered to be composed of: (1) Two web panels parallel to the direction of the lateral load; (2) two flange panels normal to the direction of the lateral load. These structural components are interconnected to each other along the panel joints and connected to the floor slabs at each floor level. The high in-plane stiffness of the floor slabs will restrict any tendency for the panels to deform out-of-plane and it may, therefore, be assumed that the out-of-plane actions are insignificant compared to the primary in-plane actions. If the sizes and spacings of the frame members are assumed uniform, as is usually the case in practice, then each framework panel may be replaced by an equivalent uniform orthotropic membrane.

(b)Braced Tube Structures: The tubular structure is further improved and can be done by cross bracing the frame with X-bracings throughout the entire building. As the braced tube diagonals are connected to the column at each and every intersection, they virtually erase the shear lag effects in flange and web frames together. As a result, the structure behaves like a braced frame under lateral loads by reducing bending in the frame members. Example: John Hancock Building

Hence spacing between the columns shall be increased and the depth of girders can be made less, which facilitates large size windows unlike in conventionally framed tube structures. In braced tube structures, the braces are provided to share the axial load from more highly stressed columns to less highly stressed columns and this phenomenon helps to lower the difference between load stresses in columns. Example: Chicago's John Hancock building, The Citigroup Center, Bank of China Tower

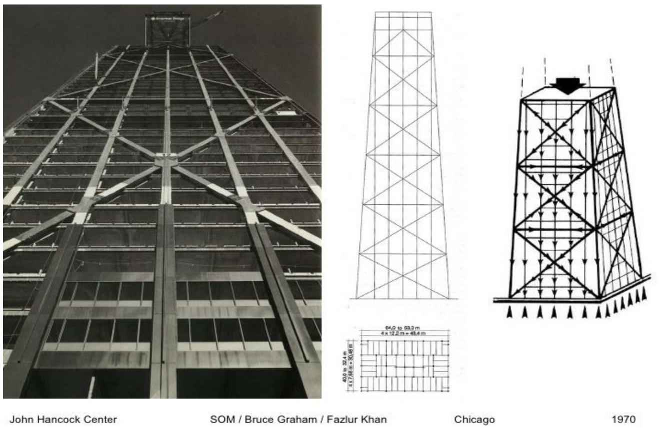


Fig-2: 3D view of Braced tube structure and sectional plan

(c) Tube- in -Tube Structures: This is another type of framed tube consisting of an outer-framed tube along with an internal elevator and service core. The inner tube consists of braced frames. The outer and the inner tubes act together to resist both gravity and lateral loads in steel framed buildings. However, outer tube always plays an important role because of its greater structural depth. This type of structures is also referred as hull and core structures.

Tube-in-Tube Building generally consists of an inner tube to aid vertical transportation demand and an outer tube which comprises of dense columns and deep beams. It is the most commonly used structural system for high-rise building with more than 50 storeys. In order to facilitate the computational efficiency in the preliminary design, a numerous approximate analysis approaches were proposed to substitute the Finite Element Method which is elaborate but too exhaustive to calculate. Most of the approximate analysis for horizontal vibration analysis considers that the tube-in-tube structure is a double cantilever beam system with acceptable deformation between the two tubes. On the basis of continuum parameter technique, accurate solution of the double beam system is obtained, especially when structural parameters are assumed to be the same along the height of structure.

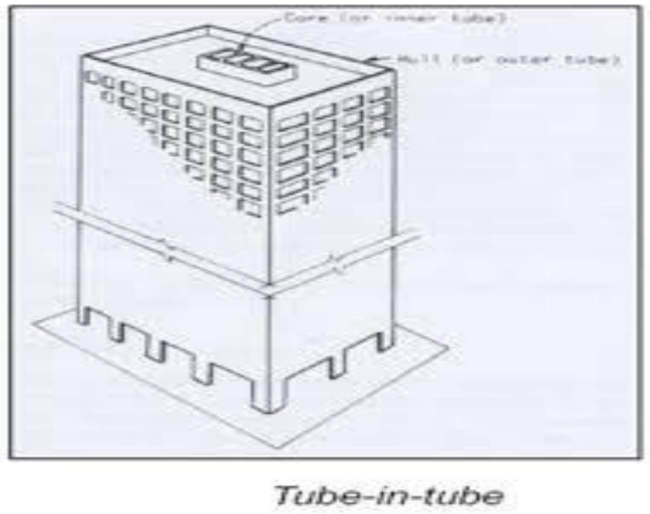


Fig-3: 3D view of Tube in Tube structure

(d) Bundled Tube: The bundled tube system can be characterized as an assemblage of individual tubes which results in multiple cell tube. This System allows for great heights and large floor area.

In this system, internal webs if introduced will greatly reduce the shear lag in the flange beams. Hence their columns are more uniformly stressed than in the single tube structures and they contribute more to the lateral stiffness. Example: Sears Tower

Advantages: Offers some clear advantage from materials standpoint. Designed well, tubular forms have been known to utilize the same amount of material as would have been employed for a structure that is half as large or framed conventionally. • Allows greater flexibility in planning of interior space since all the columns and lateral system is concentrated on the perimeter of structure. This allows a column-free space in the interior • Regularity in the column schedule allows off-site fabrication and welding where speed can be achieved while still confronting to quality • Wind resisting system since located on the perimeter of the building meant that maximum advantage is taken of the total width of the building to resist overturning moment • Identical framing for all floors because floor members are not subjected to varying internal forces due to lateral loads

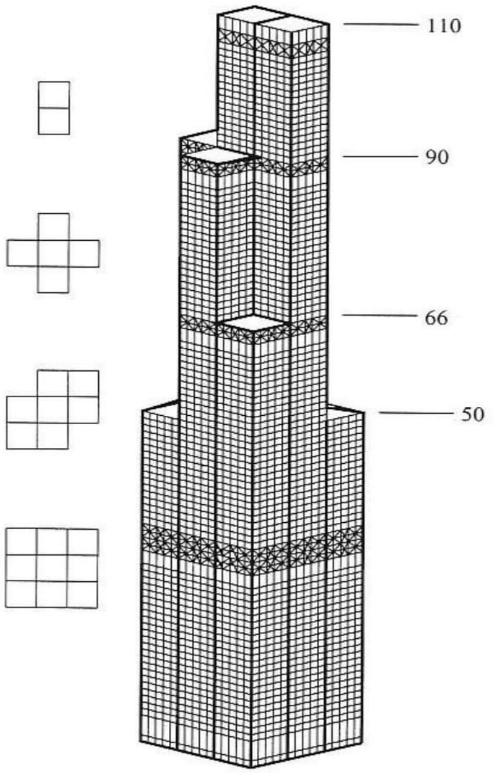


Fig-4: 3D view of Bundled Tube structure

2. LITERATURE SURVEY

1) Heidbrecht and Stafford Smith (1973) Obtained natural frequencies from the solution of a governing differential equation for a range of values of the structural parameters affecting the behaviour.

2) ***Coull and Bose (1975) and Coull and Ahmed (1978)*** developed an orthotropic membrane analogy of transforming the framework panels into equivalent orthotropic membranes each with elastic properties so chosen to represent the axial and shear behavior of the actual framework. They analyzed the equivalent membrane tubes by assuming the bending stress distributions to be cubic and parabolic on the web and flange panels respectively and using energy formulation to derive the governing differential equations.

3) ***Khan and Stafford Smith (1976)*** have also developed an orthotropic membrane analogy for simplified analysis of framework panels by using finite element analysis.

4) Wang.Q (1996) obtained a formula for calculating the natural frequencies of tube-in-tube structures in tall buildings directly from the fourth-order Sturm-Liouville differential equations. In another study, numerical solutions of eigenvalues for free vibration of tube-in-tube structures by using modified ODE solver for eigen value problem was presented by him based on an existing Ordinary Differential Equation (ODE) solver.

5) ***Wen-Hae Lee (2007)*** proposed a simple mathematical model for approximate analysis of framed tube structures with multiple internal tubes using the minimum potential energy principle in conjunction with the variational approach. Lee presented an approximate solution that was formulated for free vibration analysis of tube-in-tube tall buildings. The governing partial differential equation of motion has been reduced to an ordinary differential equation with variable coefficients on the assumption that the transverse vibration is harmonic. A power-series solution was used to obtain mode shape functions for the tube-in-tube structures.

6) ***H. Ghasemzhadeh and H.R. Samani (2010)*** In this paper, based on the principle of conservation of energy, approximate formulas are proposed to find out the fundamental frequency. Tubular structures including tube and tube-in-tube structures are idealized as a prismatic cantilever flexural-shear beam assuming the lower most elevation to be fully fixed and natural frequency expressions are subsequently derived by means of energy method. Using the proposed formulas it is possible to calculate the natural frequencies of tubular tall buildings, having any number of point masses subjected to concentrated and/or distributed axial loads with negligible loss of accuracy. Moreover, natural frequencies are calculated conveniently without any finite element modeling complications. The effect of soil structure interaction has not been considered in this study, and the lower-most elevation of the structure is assumed to be fully fixed.

3. STRUCTURAL IDEALISATION

Consider a tubular tall building which is subjected to uniformly distributed gravity loads at storey levels.

3.1 Assumptions:

1) The building is assumed to be doubly symmetric in plan.

2) It is also assumed that both beams and columns are of uniform section throughout the height of the building.

3) The floor slabs are considered as rigid diaphragms in their own plane so that the relative displacements between tubes in tube-in-tube buildings are restricted.

The entire building is idealized as a prismatic cantilever beam with shear rigidity *GA*, flexural rigidity *EI*, mass per unit length *m* and axially distributed compression force *N*. Floor masses and gravity loadings at storey levels are replaced by concentrated masses m_i, and concentrated forces N_i, respectively.

4. TRANSFER MATRIX METHOD

The transfer matrix method is a method for finding the static and dynamic properties of an elastic system. The basic principle behind this method is that of breaking up a complicated system into individual parts with simple elastic and dynamic properties that can be expressed in matrix form. The matrix is then solved by using the FORTRAN programming. The details of the method are explained in the reference [5]

5. .RESULTS AND ANALYSIS

Calculation for Moment of inertia of equivalent beam:

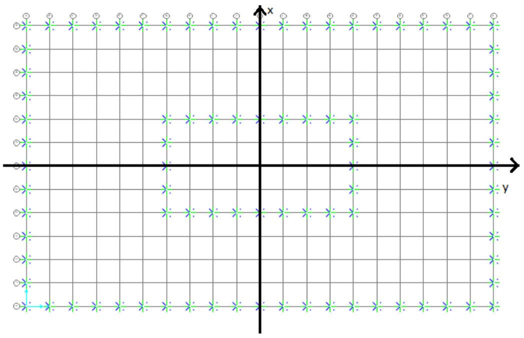


Fig-5.: Sectional plan view of tube-in-tube tall building

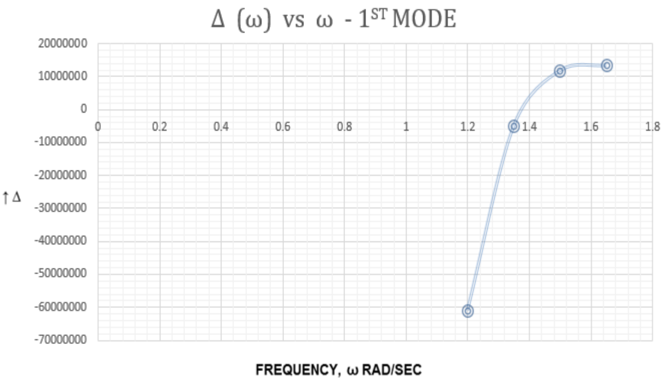
Parameters	Values
No. of storeys	50
Height of each storey	3 m
Bay length of tube	2.5 m
Width of building	30 m
length of building	50 m
Column dimensions	0.8m *0.8m
Beam dimensions	0.8m*0.8m
E	2×10^7 k N/m^2
Mass per unit run	582.279 T

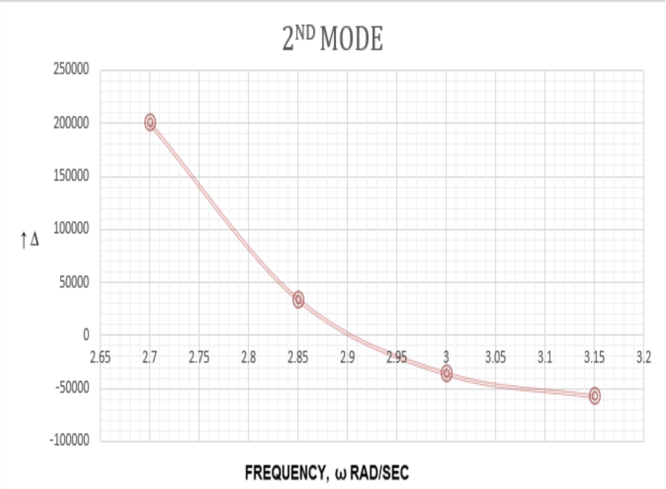
A × h^2	**Inner tube**
9 x area of column x distance 'h' 5×5 =	**144**
2 x area of column x 2.5×2.5 =	**8**
total EI (2×sum) for 2 webs and 2 flanges =	**304**
A × h^2	**Outer tube**
21 x area of column(0.8*0.8) x distance 'h' (15*15) =	**3024**
2 x area of column x 12.5×12.5 =	**200**
2 x area of column x 10×10 =	**128**
2 x area of column x 7.5×7.5 =	**72**
2 x area of column x 5×5 =	**32**
2 x area of column x 2.5×2.5 =	**8**
total EI (2×sum) for 2 webs and 2 flanges =	**6928**

The data given is taken from the reference [13]. The values obtained in this Transfer Matrix method are compared with [13]

EI	1.407×10^{11} k N-m^2
GA/μ	3.75×10^{7} kN

The values obtained above got validated with the reference[13] values.Later the problem is solved using TM method with the aid of computer programming and the resultant residue values are plotted to find out the first five frequencies.The graphs are as shown below. Graphs/Charts helps us for estimating the first natural frequency or fundamental time period





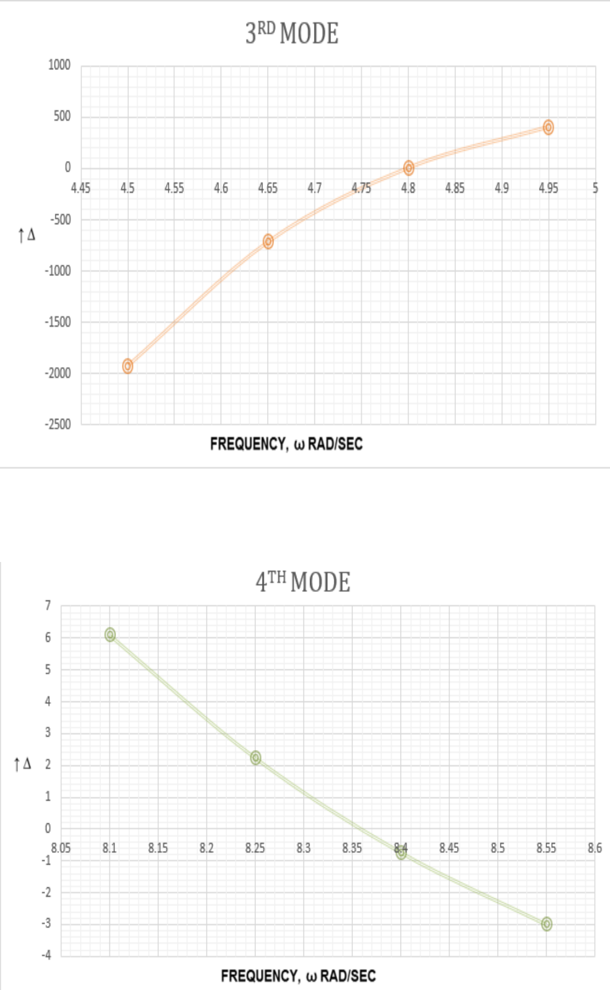


Chart-1 : Residue(Δ) vs frequency (ω) graphs

Thus, as shown above the graphs are plotted between residue values(Δ) along y-axis and the frequency values along x-axis.The point of intersection of the curve and the x-axis is considered as the frequency value.

Type of the Model	**SAP2000**	**Energy method from [13]**	**TMM method**
	ω_1(rad/sec)	ω_1(rad/sec)	ω_1(rad/sec)
Value	1.2546	1.3980	1.3946

From the above validation table,we can notice that the values obtained from the energy method of [13] almost coincides with the TMM calculation.This proves that the method is so accurate.

6.CONCLUSION

The fundamental Time period is the one important dynamic character of tall building. No appropriate provision for the new class of tubular tall buildings is mentioned in the standard Codes. The code formulas fully do not represent the calculated time period based on stiffness and mass. In the present work, it is aimed at developing simple methodology for the free vibration analysis of tall buildings based on Transfer Matrix Approach with the aid of FORTRAN programming to solve the complex problems with ease and develop simplified solutions in the form of Design.

7. REFERENCES

1) Khan, F.R. & Amin, N.R. (1973). Analysis and Design of Fame Tube Structures for Tall Concrete Buildings, Struct. Engg. 51(3), 85-92.
2) Coul, A. & Bose, B. (1975). Simplified Analysis of Framed-Tube Structures. Journal of the structural Division-ASCE, 101(11), pp. 2223-2240.
3) Schueller, W. (1977). High Rise Building Structures, John Wiley & Sons Inc., U.S.A.
4) Clough, R.W. & Penzien. (1982). Dynamics of Structures. McGraw-Hill Book Co., Singapore.
5) T.Lavanya(2017), M.E thesis(to be submitted to CIT college)
6)Khan, F.R. (1985). Tubular Structures for Tall Buildings, Handbook of Concrete Engineering, Editors: Fintel, M., Van Nostrand Reinhold, N.Y., pp. 399-410.
7) Taranath, B. S. (1988). Structural Analysis and Design of Tall Buildings, McGraw-Hill Inc., U.S.A.
8) Stafford Smith, B. & Coul, A. (1991). Tall Building Structures: Analysis and Design. Wiley, New York.
9) Kwan, A.K.H. (1994). Simple Method for Approximate Analysis of Framed Tube Structures. Journal of the Structural Division-ASCE, 120 (04), pp. 1221-1239.
10) Wang, Q. (1996). Sturm-Liouville Equation for Free Vibration of a Tube-in-Tube Tall Building. Journal of Sound and Vibration, Vol. 191, No. 9, 349-355.
11) Bureau of Indian Standards IS 1893-2002, Part- 1, Criteria for Earthquake Resistant Design of Structures.
12) Lee, W.H. (2007). Free Vibration Analysis for Tube-in-Tube Tall Buildings. Journal of Sound and Vibration, Vol. 303, 2007, 287-304.
13)Ghasemzhadeh, H. & Samani, H.R. (2010). Estimating Frequency of Vibration for Tubular Tall Buildings. Fourteenth ECEE.