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ANALYTICAL INVESTIGATION ON THE PERFORMANCE OF TUBE-IN-TUBE STRUCTURES SUBJECTED TO LATERAL LOADS

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***Abstract*— Over the past few years tubular structures are becoming a common feature in tall buildings. Tube in tube structures is particularly suitable for all tall buildings. A tube - in – tube structure comprises of a peripheral framed tube and a core tube interconnected by floor slabs. The entire building act as a huge tube with a smaller tube in middle of it. Lateral loads are shared between the inner and outer tubes .In order to study the seismic performance of tube – in – tube structures three different models were developed in SAP2000 software by varying the location of the inner tubes. The structures are analyzed using continuum approach in which the horizontal slabs and beams connecting vertical elements are assumed as continuous connecting medium having equivalent distributed stiffness properties. Equivalent static, Response spectrum analysis and Time history analysis is done and the output of three models are evaluated to have a comparative study of their seismic performance.**

***Index Terms*— Tube in- Tube, Static analysis, Time history analysis.**

I. INTRODUCTION

Nowadays, the advancements in structural systems, increase in building height and slenderness, use of high strength materials, reduction of building weight etc has necessitated the consideration of lateral loads such as wind and earthquake in the design process. Lateral forces resulting from wind and seismic activities are now dominant in design considerations. Lateral displacement of such buildings must be strictly controlled, not only for occupants comfort and safety, but also to control secondary structural effects. Currently, there are many structural systems such as rigid frame, braced frame, shear-walled frame, frame-tube, braced-tube, bundled-tube and outrigger systems that can be used to enhance the lateral resistance in tall buildings.

Tubular structures have been successfully utilized and are becoming a common feature in tall buildings. Basic forms of tubular systems are the framed tube, core tube, tube-in-tube and bundled tube. A tube-in-tube structure comprises of a peripheral framed tube and a core tube interconnected by floor slabs. For each of these vertical components, various simplified models have been developed that analyze structure's behavior under lateral loads. Approximate techniques for a single tube and multi-tube systems have been developed by many researchers over the past decades.

The exterior and interior columns of a tube-in-tube structure are placed so closely together that they not only appear to be solid, but they act as a solid surface as well. The entire building acts as a huge hollow tube with a smaller tube in the middle of it. Lateral loads are shared between the inner and outer tubes.

II. LITERATURE RIVEW

Peter C. Chang[(1)] (1985) analyzed Tube-in-tube structures using a continuum approach. Flexural deformation, shear deformation, and shear-lag effects are studied. The beams are forced to have equal lateral deflections, and the amount of load carried by each beam is a function of its relative stiffness The analyses are performed using the Minimum Potential Energy principle, and the results are compared with results of finite element analyses. An efficient method for determining the global deflection behavior of a tube-in-tube structure was presented.. Displacement compatibility of lateral deflections between the two tubes is enforced, thereby reducing the two sets of differential equations to a set of 10 first-order differential equations.

J. J, Connor and C. C. Pouangare(2) (1991) proposed a very simple model for the analysis and design of framed-tube structures subjected to lateral loads. The structure is modeled as a series of stringers and shear panels. The analytical expressions for the stresses and displacements are done to attain the desired results. The model can be used directly for the analysis of structures that incorporate different materials and different properties along the height of the structure

M. R. Jahanshahi, R. Rahgozar, M. Malekinejad (3)(2012) They presents parametric functions for static analysis of tall buildings with combined system of tube in- tube and outrigger-belt truss system subjected to three separate load cases of concentrated load at top of the structure, uniformly and triangularly distributed loads along the height of the structure. The formulas proposed here have been validated by comparing them to the computer static analysis results obtained from three-dimensional studies using the finite element method. It has been shown that results computed by the energy method correlate well with those obtained by means of SAP2000 analysis.

Kang-Kun Lee, Yee-Chaye Loo, Hong Guan(4) (2001) A simple mathematical model is proposed for the approximate analysis of framed-tube structures with multiple internal tubes. The accuracy, simplicity, and reliability of the proposed method are verified through the comparisons with the two existing simplified methods and a 3D frame analysis program. The additional lateral stiffness due to the tube-tube interaction is also accounted for in the analysis. The additional bending stresses are observed to have significant effect on the shear-lag phenomenon. In comparison with the 3D frame analysis program, the only other approach available for the tubes-in-tube system, the proposed method provides similarly accurate results in predicting the deflection response and the column axial stress distributions.

III. SCOPE OF WORK

The main objective of this thesis is to investigate the performance of a tube in tube structure with different positioning of the internal tube. The study is done in 3D models developed in SAP 2000. Static and Time history analysis of each sets of models and the comparison of these two methods is done. The effect of different positions of the internal tube during the seismic loading is included in studied.

The displacement parameters at each floor level for Equivalent static, Response spectrum and Time history are plotted and a comparative study is conducted which is expected to present the effect of torsion and pounding gap of adjacent building.

IV. MODEL DETAILS

Three sets of 15 storied building are modeled with story height 4m. the total base area of the building is 51 x 51 m^2. All models have the same plan but the interior positioning of the inner tubes are varied to compare the result of their seismic performance. The building consists of rectangular columns with dimensions 1200 x 600 and beams with dimension 600 x 250. The floor slabs are of 280mm thick and the tube side walls are of 250mm thick. The modulus of elasticity (E) and the shear modulus (G) are taken as 2.73x 10^7 KN/m^2 and 1.14 x 10^7 KN/m^2.

In the present study a commercial building under seismic zone V is adopted with varying the positioning of the internal tube. The base plan and various positioning are shown in Fig. 1and 2.

The gravity loads include beam, column, slab, wall and other permanent members. The self weight of the beams, columns (frame members) and slab (area element) is automatically considered by the program itself. The wall loads are calculated separately and applied as uniformly distributed load on beams. Live loads are assigned as uniform area load on slab element as per IS 1893 (Part 1) 2002. Live load on roof is taken as 4 KN/ m^2 and that on floors are taken as 5 KN/ m^2.

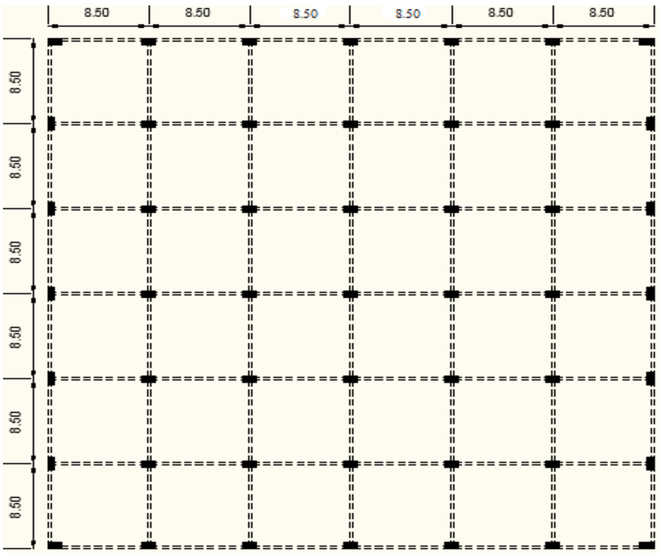

Fig. 1. Base plan

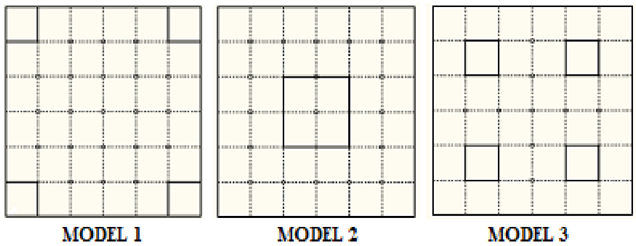

Fig.2. Positioning of internal tubes

V. v. ANALYSIS DONE

Two types of analysis procedures are carried out to determine the behavior of the structure under the effect of seismic loads.

The analyses carried out are

A. Equivalent static analysis
B. Time history analysis
C. Response spectrum analysis
D.

Analysis type	*Usual name*	*Dynamic effect*	*Non linearity*
Linear static	Equivalent static analysis	No	No
Non linear dynamic	Time history analysis	Yes	Yes
Linear dynamic	Response spectrum analysis	Yes	No

A. Equivalent static analysis:

This procedure is carried according to IS 1893 (Part 1) 2002. First the design base shear is computed for the building and then it is distributed along the total height. Thus the lateral force at each floor level is distributed to individual lateral load resisting element. Since the live load coming in each floor is greater than 3 KN/m^2 the seismic weight is taken as dead load plus 50% live load. Hence the lateral load resisting system adopted is ductile shear wall with SMRF accordingly response reduction factor is adopted is 5.

B. Time history analysis

Mathematical models of the building are developed and they are subjected to accelerations from previous earthquake records. The method consist of step by step direct integration over a time interval: equations of motion are solved with displacement, velocities and accelerations of previous step serving as initial functions. The equation of motion is represented in equation 1.

$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) = p(t) \quad (1)$$

Where m is the diagonal mass matrix, k is the stiffness matrix and c is the damping matrix. $\ddot{x}(t)$, $\dot{x}(t)$, $x(t)$, p are the acceleration, velocity and displacement and applied load respectively.

The analysis is carried out using Lacc North 1 earthquake for obtaining various floor responses. Ritz vector model is assigned and modal analysis is done to get the response.

C. Response spectrum analysis

There are computational advantages in using the response spectrum method of seismic analysis for prediction of displacements and member forces in structural systems. The method involves the calculation of only the maximum values of the displacements and member forces in each mode of vibration using smooth design spectra that are the average of several earthquake motions.

Here the peak response of a structure during an earthquake is obtained directly from the earthquake response spectrum. This procedure gives an approximate peak response, but is quite accurate for structural design applications. In this approach, the multiple modes of response of a building to an earthquake are taken in to account. For each mode, response is read from the design spectrum, based on modal frequency and the modal mass.

The responses of different modes are combined to provide an estimate of total response of the structure using modal combination methods such as complete quadratic combinations (CQC), square root of sum of squares (SRSS) or absolute sum (ABS) method.

VI. RESULTS

The results of equivalent static and time history analysis for all the 3 models are listed below:

A. Table 1 and Fig.3 illustrates the comparison of story displacements with respect to story height done in static analysis.

B. Table 2 and Fig.4 illustrates the comparison of story displacements with respect to height done in time history analysis.

C. Table 3 and Fig.5 illustrates the comparison of story displacements with respect to height done in response spectrum analysis.

The comparison results are tabulated in tables 1 to 3.

TABLE 1 Story Displacements With Respect To Story Height Done In Static Analysis.

Height (m)	Deflections (mm)		
	MODEL 1	MODEL 2	MODEL 3
4	0.773	0.714	0.839
8	1.471	1.369	1.562
12	2.188	2.049	2.298
16	2.927	2.795	3.061
20	3.678	3.567	3.847
24	4.4307	4.364	4.646
28	5.175	5.161	5.451
32	5.903	5.973	6.25
36	6.608	6.766	7.0355
40	7.281	7.54	7.7991
44	7.918	8.285	8.5333
48	8.444	8.995	9.23
52	9.061	9.664	9.884
56	9.562	10.284	10.696
60	10.019	11.012	12.031
64	10.449	12.35	13.51

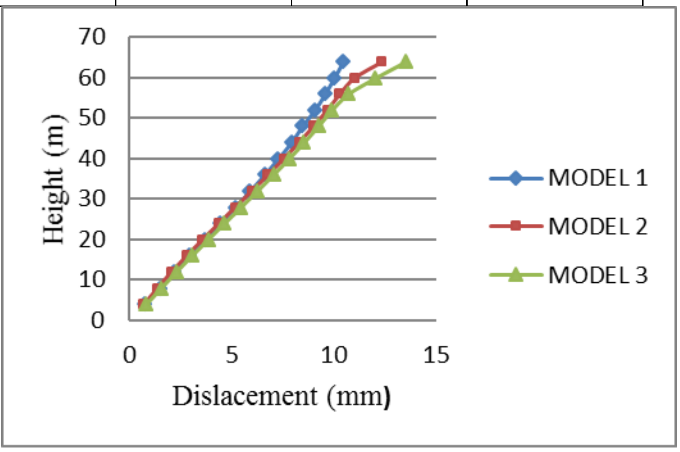

Fig.3. Variation of story displacement with respect to story height in static analysis

TABLE 2 Story Displacements With Respect To Height Done In Time History Analysis.

Height (m)	Deflections (mm)		
	MODEL 1	MODEL 2	MODEL 3
4	2.242	2.011	2.007
8	3.439	3.905	3.534
12	4.731	4.883	4.999
16	5.699	6.224	6.82
20	6.883	7.977	8.499
24	8.441	9.459	10.249
28	9.943	10.998	12.931
32	11.76	13.117	14.844
36	13.224	14.426	16.21
40	14.454	15.538	17.488
44	15.553	16.557	18.645
48	16.624	17.659	19.454
52	17.465	18.569	20.288
56	18.136	19.248	21.222
60	18.936	20.116	22.132
64	19.488	21.045	23.022

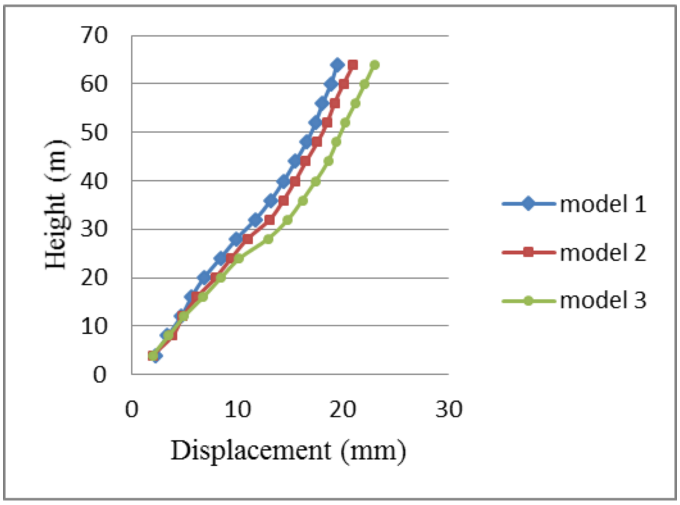

Fig.4. Variation of story displacement with respect to story height in time history analysis

TABLE 3 Story Displacements With Respect To Story Height Done In Response spectrum Analysis.

Height (m)	Deflections (m)		
	MODEL 1	MODEL 2	MODEL 3
4	0.942	1.035	0.9017
8	1.819	1.955	1.7534
12	2.731	2.903	2.999
16	3.689	3.905	3.82

TABLE 3 Cont………

Height (m)	Deflections (mm)		
	MODEL 1	MODEL 2	MODEL 3
20	4.683	4.958	5.01
24	5.701	6.049	6.635
28	6.731	7.167	7.931

32	7.76	8.297	9.08
36	8.777	9.425	10.21
40	9.768	10.538	11.368
44	10.721	11.621	12.475
48	11.624	12.659	13.54
52	12.465	13.636	14.548
56	13.236	14.538	15.482
60	13.936	15.346	16.32
64	14.588	16.048	17.1

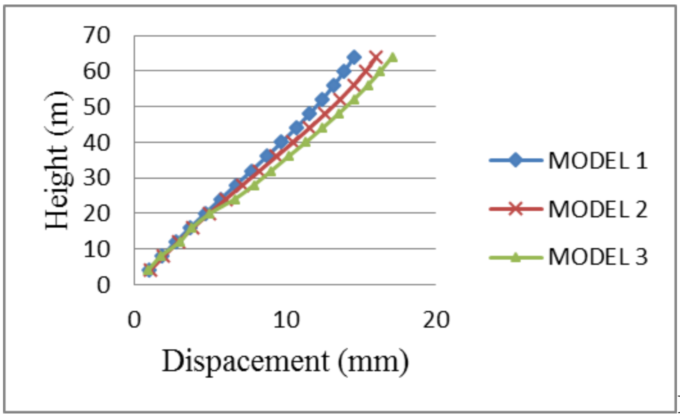

Fig.5. Comarison of results of static and dynamic analysis

VII. Conclusion

The results of three methods of analysis are compared between the three sets of models to study the effect of lateral load pattern on displacements of buildings. From the above study it is concluded that time history analysis predicts the structural response more accurately than equivalent static analysis. It is seen that for a regular structure with seismic loading, the model with core located at the corners (model 1) yielded better results. Large displacements are seen in model 3 in which the positioning of the inner cores are are not exactly at middle nor at corner hence this type of arrangement is least recommended.

VIII. Acknowledgment

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