ANALYSIS OF MULTIPLE TUBE-IN-TUBE SYSTEM USING ETABS

[1]Muhammad Nabeel Imtiyaz, [2]Mrs. K. Krishna Bhavani Siram
[1]M.Tech Student, [2]Assistant Professor
Department Of Civil Engineering Mahatma Gandhi Institute Of Technology, Gandipet, Hyderabad – 500 075

Abstract: Tube system of structure was introduced by Fazlur Rahman Khan and the 1st building designed using this system was the Chicago's DeWitt-Chestnut apartment in 1965. Tubular constructions have become increasingly prominent in tall buildings in recent years. The tallest building in the world: BurjKhalifa is also built using a type of tube system. A type of tube system called Tube-in-tube system of structure is particularly suitable for all tall buildings.

A tube in tube structure consists of a peripheral framed tube and a core tube that are joined by floor slabs. The entire building acts as a huge tube with a smaller tube in middle of it. Lateral loads like wind loads and earthquake loads are resisted by the inner and outer tubes. Outer tube comprises of closely spaced columns and the inner tube consists of a core shear wall. The building is made in parts. First a number of floors are constructed of the same area, then more floors are constructed of lesser area above it and then above that some more floors are constructed of even lesser area and so on.

This project involves modeling a 50-story structure in ETABS software with a multiple tube in tube system in four seismic zones in order to assess and examine deflections as well as the effects of lateral loads such as wind and earthquake loads. Also to evaluate the shears developed in the structure and displacements if any, and study its effects on multi-storey multiple tube in tube system. I expect to find out if the multiple tube in tube system of structure is capable in resisting lateral loads and check the stability of such a structure

I. INTRODUCTION

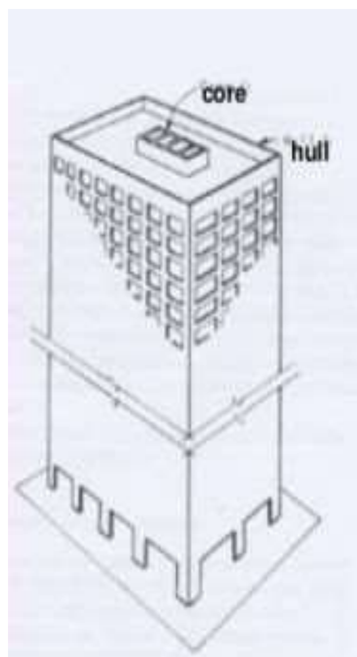
A type structural system that is utilized in constructing high-rise buildings is the tube system, this makes it possible for the building to resist loads like seismic pressures and wind loads. It behaves sort of a hollowed cylinder which is perpendicularly cantilevered to the ground. In the 1960s, engineer Fazlur Rahman Khan developed this system and since then this system was adopted to construct many high-rise buildings. Steel, concrete or a composite of these materials are often used to construct the tube system. The simplest form of tube consists of closely-spaced columns that are tied with deep spandrel beams through connections which act as part of the external perimeter of the building. The resulting frame formed leads to a dense and powerful structural 'tube' round the exterior. At the interior core, less quantity of columns can be placed as the stiff exterior frame resists the lateral loads.

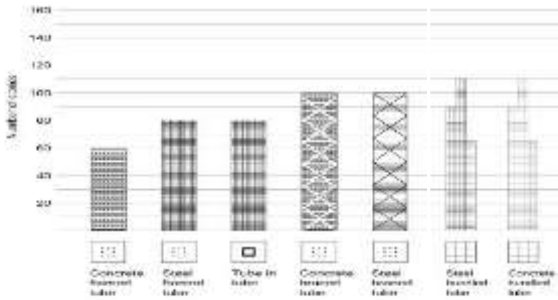
1.1 Tube in tube system:

Tube in tube frame structure consists of an outer framed tube called 'hull' together with an internal tube called 'core' that consists of service area like lift & stairwell. The outer tube is made up of closely spaced columns and the internal tube is made up of a core shear wall.

Together, these outer and inner tubes together resist gravitational and lateral loads increasing lateral stiffness. This system is more effective in high-rise structures because the bending and transverse shears are supported along the base and the height of the structure.

This project deals with Multiple tube in tube frame structure.





1.2 Analysis Techniques

Structures such as buildings are subjected to seismic loads in the event of an earthquake. IS 1893:2016 has divided India into 4 seismic zones. These zones are subdivided formulated on the severity of seismic force.
Since India is prone to strong earthquake shaking, seismic analysis is essential for the planning of earthquake resistant structures.
The basic categories for techniques of analysis are *linear static analysis*, *linear dynamic analysis*, *non-linear static analysis*, or *non-linear dynamic analysis*.

Linear static analysis: can be called additionally as Equivalent static analysis (EQS).The variation of loads with reference to time are avoided while analyzing in this method. For the complete structure we calculate the shear force at the base first and distribute it to the entire structure along side its height. This distribution of shear force gives lateral force to be distributed at each floor and then further to each individual lateral resisting element.

Response spectrum analysis: (RS)
This procedure takes into account load variations with respect to the modal shape. To calculate the response of a structure, we consider the values like velocity, acceleration and displacement obtained from the seismic motion. The deformations that are possible on the structure are called mode shapes or modes of vibrations. This method uses time period and modal contribution of each storey to give the modes of vibration which are then used to generate structural responses like storey shears, displacements and lateral forces.
Dynamic analysis is performed to determine the design seismic force and its distribution along all or any of the lateral load resisting elements and the building height. This analysis technique can be performed for regular buildings in zone II and zone III which have heights greater than 90 m and in zone IV and V for buildings having heights greater than 40 m.
And for irregular buildings that are in zone IV and V having height greater than 12 m and in Zone II and III having height greater than 40 m.

1.3 Objectives

1. To understand the behavior of a tall structure and their importance in resisting the lateral loads for different plan areas.
2. To study the effect of multiple tube in tube system which is subjected to earthquake forces in different seismic zones.
3. To study the displacements of tube in tube system which is subjected to earthquake loads and wind loads in different seismic zones.
4. Analyze the structures subjected to static and dynamic analysis.
5. Determine the effect on base parameter like base shears.
6. Understanding the behavior of structure and observe the changes in parameter results for all stories.

II. LITERATURE REVIEW

1) "Analytical investigation on the performance of tube in tube structures subjected to lateral loads" by Nimmy Dileep and Renjith R.

The tube type of structure is more suitable for skyscrapers. There are many types of tube constructions. A tube-in-tube structure includes a slab joined to an interior and exterior tube.
To analyze the behavior with respect to lateral loads, multiple models of this type of structure were replicated. The outer and inner columns of a tube in tube structure are positioned so as to behave like a solid barrier. This paper aimed to study the performance of a tube in tube structure on software called SAP 2000 with various configurations of the inner tube. Three models were relatively studied and the results were weighed up and plotted in terms of displacements at each storey by three methods of analysis, i.e. equivalent static analysis, response spectrum analysis as well as time history analysis.
It can be inferred here that time history analysis is better to anticipate the response of the structure as opposed to equivalent static analysis.

2) "Comparative study of tube in tube structures and tube mega frames" by Archana J and Reshmi P R.

This study aims to obtain a more suitable system of structure for tall structures. This study includes analysis of a 15 storied bare frame structure, tube-in-tube structure with tubes positioned at the centre, edge & inner tube and tube mega frame structure. The methods of analysis used in this study were response spectrum and linear static analysis.
Out of all these types of structures, the results achieved by the two methods of the analysis showed that the tube-

in-tube type of configuration with the centre tube can be proposed as a far superior structural system for high rise structures rather than tube mega frame and bare frame type of structural systems.

III. MODEL DETAILS

The building taken into consideration here is a 50 storey building, which is constructed in stages. First 25 floors are constructed of the same area, then 10 floors are constructed of lesser area and then 15 floors are constructed of even lesser area. The entire structure behaves as a unit to respond to lateral forces. The system located on the edge of the building increases resistance to wind loads. The intention of shear walls is to transfer seismic loads to the foundation. And so they are provided in the shape of two tubes within the building.

In this project a building of fifty storeys is modeled with changing the positioning of the inner tubes. 4 similar models of buildings are analyzed in 4 seismic zones (zone 2, 3, 4, 5).

The total plan area of the building at the base is 1296 m^2 (36x36 m). The model has a different plan for the three parts and the positions of the inner tubes are changed according to the floor number or part number of the building. Only the bottom storey height is 3.7m. The remaining structure has a typical storey height of 3.5 m.
The shear walls are of dimension 250x3500 mm on the ground storey and 250x3700 mm on the remainder of the superstructure. And the thickness of shear walls is 250 mm.
Concrete grade:
M40 for columns, beams
M30 for slabs,
M40for shear wall
Steel grade: HYSD 500.
Geometry:

Sl no.	Elements	External tube	1st Internal Tube	2nd Internal Tube
1	Stories	25	35	50
2	Area	36x36 m	24x24 m	18x18 m
2	Columns			
	i) Area	1000x1000 mm	-	750x750 mm
	ii) Spacing	3m	-	6 m
3	Beams Area	350x1500 mm	300x750 mm	300x750 mm
4	Shear Wall			
	i) Area	-	24x24m	18x18 m
	ii) Dimension	-	250x3700 (base storey) 250x3500 (rest of stories)	250x3700 (base storey) 250x3500 (rest of stories)
5	Slabs	8" (203.2mm)	8" (203.2mm)	8" (203.2mm)

External Tube:
Consists of closely spaced square mega columns with dimensions 1000 x 1000 mm with spacing of 3m connected by deep beams with dimension 350x1500 mm on the periphery of the building. These columns are joined with the internal shear walls by beams of dimension 300x750 mm.

1st Internal Tube (outer shear wall):
The 1st internal tube consists of shear wall of area 24x24 m (outer shear wall) connected to another internal shear wall and innermost columns by beams of dimension 300x750 mm.
2nd Internal Tube:
The 2nd internal tube includes a shear wall of area 18x18 m (inner shear wall) connected to 9 columns of dimension 750x750mm with spacing of 6m inside the building by beams of dimension 300x750 mm. Distance between shear wall and columns is 3 m.

The master plan and arrangement of columns & shear walls for structure are shown in AutoCAD in fig below

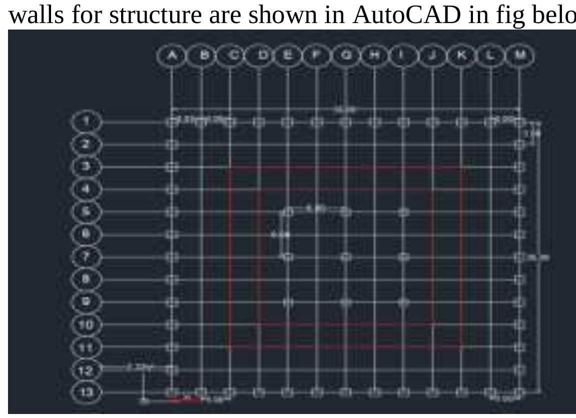


Fig-1: shows the plan view of the structure. The red lines represent the shear walls. The white squares represent the columns, and the white lines represent beams.

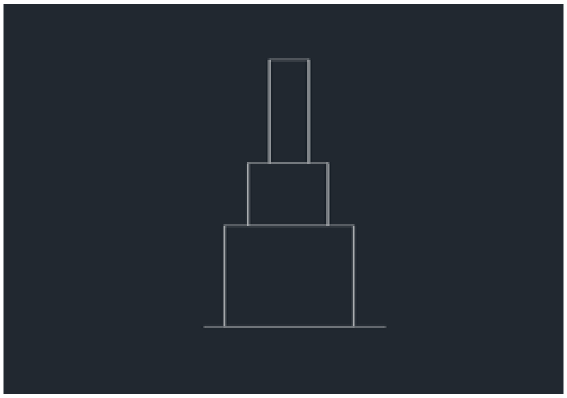


Fig-2: shows the elevation of the structure. The bottom part consists of 25 stories, middle part consists of 10 stories and the top part consists of 15 stories

Geometry in Etabs

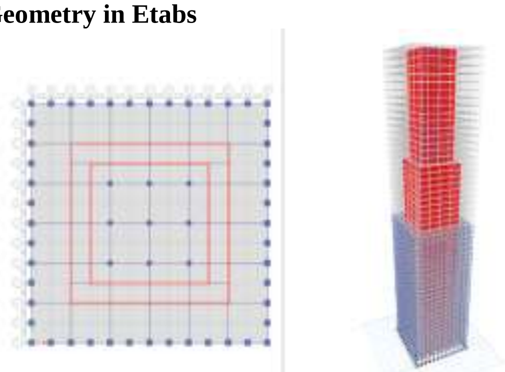


Fig-3: shows the outer mega columns, inner columns and the tube in tube type of shear walls which is continued until 25th storey

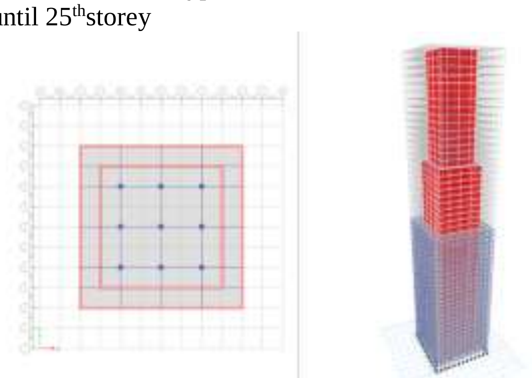


Fig-4: shows the inner columns and the tube in tube type of shear walls which is continued until 35th storey

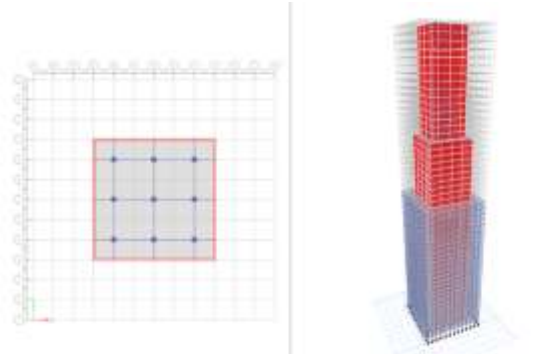


Fig-5: shows the inner columns and shear walls which is continued until 50th storey

Loads:

1. Dead load:
   i) The self weight of the beams, columns (frame elements), slab (area element) and shear walls are automatically taken into account by the software itself.

   ii) Wall load:
   The wall loads are calculated individually and applied as uniformly distributed load on the beams.

Density of red brick =19.20 kN/m^2 from IS 875 part1
Height of wall = floor height – beam depth
= 3700-750 = 2950 mm or 2.95 m
Thickness of wall = 300 mm
Wall load on beam = Volume x Density
=1x0.30x2.95x19.20 =17 kN/m

   iii) Floors finish is taken as 1.5 KN/ m2.
2. Live load:
   Live load on the slabs taken is 4 KN/ m2. As per IS 875 Part-2.
3. Seismic loads:
   The seismic loads are calculated for the 4 seismic zones from IS 1893 part 1-2016

Seismic load factors

	Zone 2	Zone 3	Zone 4	Zone 5
Location	Ajmer	Vijayawada	Delhi	Guwahati
Zone Factor	0.10	0.16	0.24	0.36
Site Type	Medium	Medium	Medium	Medium
Importance Factor	1.5	1.5	1.5	1.5
Response reduction Factor	5	5	5	5

4. Wind loads:
   The wind loads are calculated for the 4 cities according to IS 875 part 3- 2015

Wind load factors

Location	Ajmer	Vijayawada	Delhi	Guwahati
Vb (wind speed) m/s	47	50	47	50
K1	1.07	1.08	1.07	1.08
K2	1	1	1	1
K3	1	1	1	1
K4	1	1	1	1

Load combinations:
The load combinations were automatically taken by Etabs software.
Provisions according to IS 16700:2017:

1. Max Deformations:

According to IS 16700:2017 maximum deformations at top storey is given by
= H/250
So we have height of max storey =175.2 m= 175200 mm
So 175200/250 = 700.8 mm
Therefore the max displacement at top storey in zones 2,3,4 and 5 is 67.737 mm, 108.34 mm, 162.5 mm and 243.7 mm respectively.
Which is less than 700.8 mm

2. Slenderness ratio:

According to Table 2 of IS 16700 2017, maximum slenderness ratio (H/B) for structural wall+ framed tube for zones II,III,IV,V are 10,10,9,9 respectively.
And the maximum slenderness ratio of buildings according to this project is =H/B =172.5/36 = 4.79 m in zones II,III,IV,V.

3. Plan Aspect Ratio

According to clause 5.2.2 of IS 16700 2017, the maximum plan aspect ratio (Lt/Bt) of the overall building shall not exceed 5.0.
And maximum plan aspect ratio for buildings considered in project is
L/B = 36/36 =1

IV. RESULTS & DISCUSSION

1. Base shears:

Table-1

	BASE FORCES	
	load case	kN
Zone-2	EQS-X	8145.96
	EQS-Y	8143.03
	RS-X	8406.56
	RS-Y	8400.72
Zone-3	EQS-X	13034
	EQS-Y	13029
	RS-X	13450.5
	RS-Y	13441.15
Zone-4	EQS-X	19550
	EQS-Y	19543
	RS-X	20177.13
	RS-Y	20163.1
Zone-5	EQS-X	29325
	EQS-Y	29315
	RS-X	29326.11
	RS-Y	29316.06

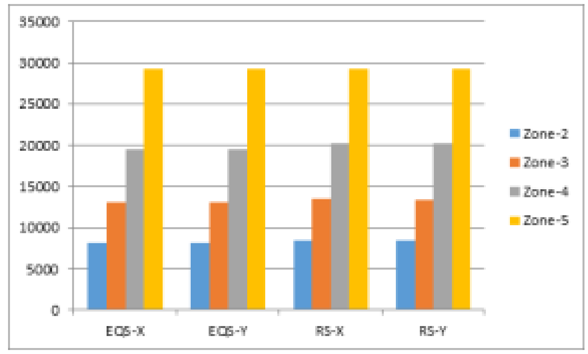


Fig-6: shows the shear force acting on the base of the structure in 4 zones from equivalent static analysis and response spectrum analysis.

Discussion:

The base shear values determined by *equivalent static* method for zone II is 8146kN. Base shear values for zone III, IV, V are 60%, 49.99%, 50% more than zone II respectively.
The base shear values determined by method of *response spectrum* for zone II is 8406.56 kN. Base shear values for zone III, IV, V are 60%, 50%, 45.34% more than zone II respectively.

2. Displacements due to loads EQS and RS:

ZONE-2:

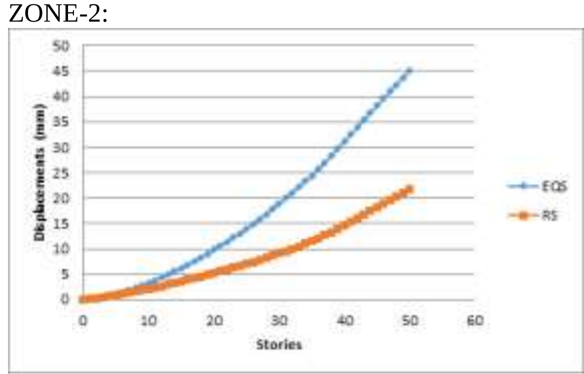


Fig-7: Maximum displacement that occurs at the top storey is 45.154 mm by EQS method of analysis and 21.675 mm by RS method of analysis.

ZONE 3:

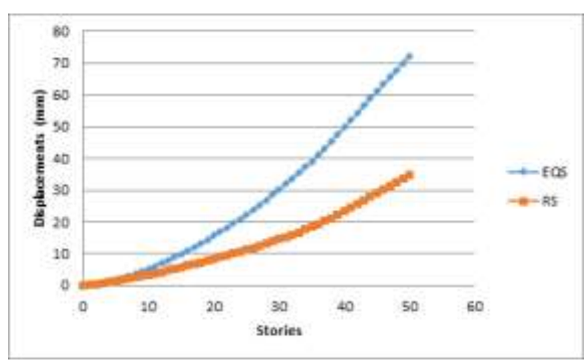


Fig-8: Maximum displacement that occurs at the top storey is 72.247 mm by EQS method of analysis and 34.681 mm by RS method of analysis.

ZONE 4:

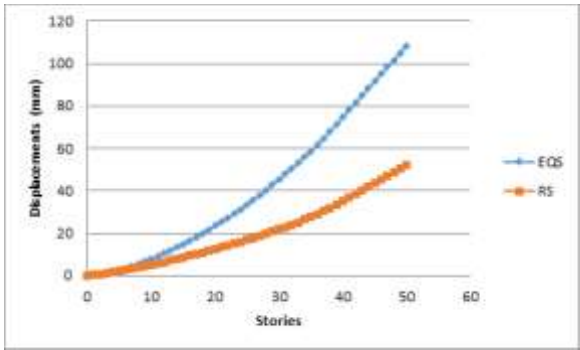


Fig-9: Maximum displacement that occurs at the top storey is 108.371 mm by EQS method of analysis and 52.024 mm by RS method of analysis.

ZONE 5:

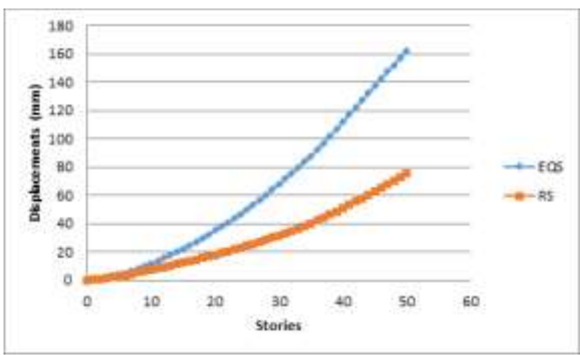


Fig-10: Maximum displacement that occurs at the top storey is 162.556 mm by EQS method of analysis and 75.641 mm by RS method of analysis.

Discussion:

The displacements increase along the peak of the structure with the maximum displacement occurring at the top storey.

The maximum displacement values when the structure is subjected to only seismic loads and analyzed by equivalent static (EQS) and Response spectrum (RS) methods are:

Load case	Zone II	Zone III	Zone IV	Zone V
EQS	45.154	72.247	108.371	162.556
RS	21.675	34.681	52.024	75.641

(values are in mm)

Since maximum displacements in all zones is less than H/250 (IS 16700-2017, Cl 5.4)

=172500/250

=700.8 mm

Hence the structure is safe in displacements due to seismic loads

3. Displacements due to wind loads:

ZONE 2:

Fig-11: Maximum displacement that occurs at top storey is 43.484 mm

ZONE 3:

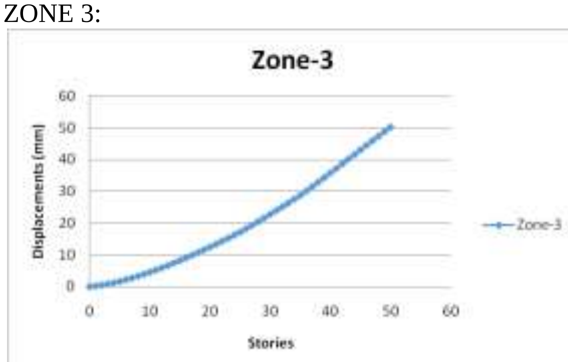


Fig-12: Maximum displacement that occurs at top storey is 50.137 mm

ZONE 4:

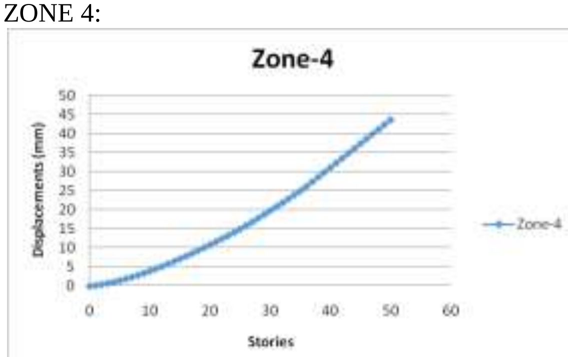


Fig-13: Maximum displacement that occurs at top storey is 43.484 mm

ZONE 5:

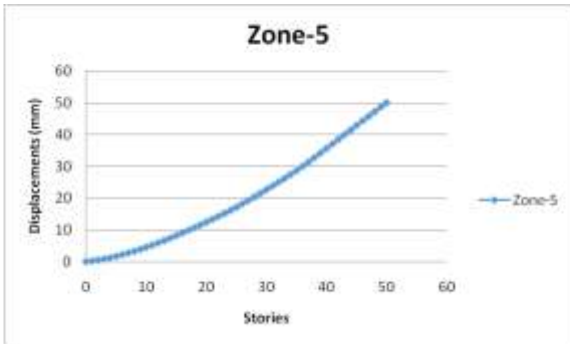


Fig-14: Maximum displacement that occurs at top storey is 50.137 mm

Discussion:

The displacements increase along the peak of the structure with the maximum displacement occurring at the top storey.

The maximum displacement values when the structure is subjected to wind load:

Load case	Zone II	Zone III	Zone IV	Zone V
WL-x	43.438	50.084	43.438	50.084
WL-y	43.484	50.137	43.484	50.137

(values are in mm)

Since maximum displacements in all zones is less than H/500 (IS 16700-2017, Cl 5.4)

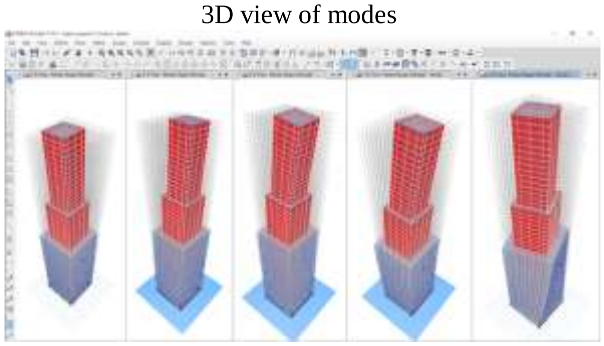
=172500/500

=345 mm

Hence the structure is safe in displacements caused by wind loads

4. Time period:

3D view of modes



Mode-1 Mode-2 Mode-3 Mode-4 Mode-5

Mode	Period sec	Sum UX	Sum UY
1	1.946	0.0372	0.4737
2	1.945	0.5111	0.5108
3	0.684	0.5223	0.7689
4	0.683	0.7803	0.7801
5	0.584	0.7803	0.7801
6	0.314	0.7904	0.8639
7	0.314	0.8741	0.874
8	0.225	0.8741	0.874
9	0.191	0.8976	0.8989
10	0.191	0.9225	0.9224
11	0.165	0.9225	0.9224
12	0.129	0.9333	0.9343

Discussion:

1. First two modes should be translational, that is higher amount of mass should participate in Ux and Uy direction. Rz should be less than Ux & Uz.
   Clause satisfied (IS 1893 2016 table 5)

2. Number of modes taken here is 12 since, in the analysis for earthquake shaking, it should be such that the total sum of modal masses of these modes is at least 90% of total seismic mass within total number of modes considered. Clause satisfied
   (IS 1893 2016 Cl 7.7.5.2)

5. Lateral loads:

ZONE 2:

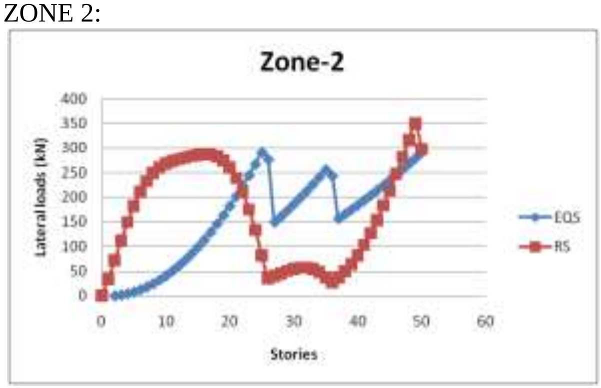


Fig-15

Discussion:

EQS		
Storey	Lateral loads (kN)	% of decrease in lateral load
25	276.871	45.858 %
26	149.903	
35	243.483	35.339 %
36	157.437	

RS		
Storey	Lateral loads (kN)	% of decrease in lateral load
25	81.488	56.074 %
26	35.794	
35	36.531	26.00 %
36	27.032	

When analyzed by EQS method there is 45.858% decrease in lateral loads where the planar area decreases and the tube structure changes from storey 25 to 26 and 35.339% decrease from storey 35 to 36.

When analyzed by RS method there is 56.074% decrease in lateral loads where the planar area decreases and the tube structure changes from storey 25 to 26 and 26.00% decrease from storey 35 to 36.

Maximum amount of lateral loads act at storey 49 for the structure in all seismic zones.

ZONE 3:

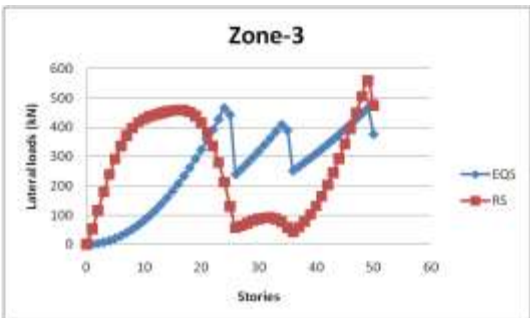


Fig-16

Discussion:

RS		
Storey	Lateral loads (kN)	% of decrease in lateral load
25	195.586	56.074 %
26	85.912	
35	87.680	26.002 %
36	64.881	

EQS		
Storey	Lateral loads (kN)	% of decrease in lateral load
25	442.994	45.858 %
26	239.845	
35	389.572	35.339 %
36	251.899	

When analyzed by EQS method there is 45.858% decrease in lateral loads where the planar area decreases and the tube structure changes from storey 25 to 26 and 35.339% decrease from storey 35 to 36.

When analyzed by RS method there is 56.074% decrease in lateral loads where the planar area decreases and the tube structure changes from storey 25 to 26 and 25.992% decrease from storey 35 to 36.

ZONE 4:

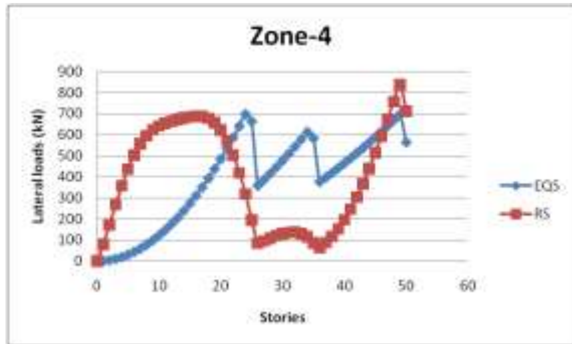


Fig-17:

Discussion:

EQS		
Storey	Lateral loads (kN)	% of decrease in lateral load
25	664.491	45.858 %
26	359.767	
35	584.359	35.331 %
36	377.848	

RS		
Storey	Lateral loads (kN)	% of decrease in lateral load
25	130.382	56.074 %
26	57.271	
35	58.441	25.992 %
36	43.251	

When analyzed by EQS method there is 45.858% decrease in lateral loads where the planar area decreases and the tube structure changes from storey 25 to 26 and 35.331% decrease from storey 35 to 36.

When analyzed by RS method there is 56.074% decrease in lateral loads where the planar area decreases and the tube structure changes from storey 25 to 26 and 26.002% decrease from storey 35 to 36.

ZONE 5:

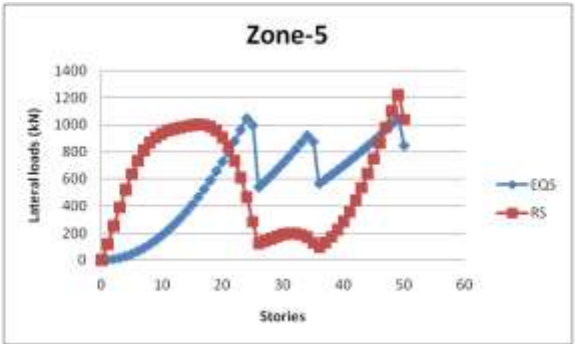


Fig-18:

Discussion:

EQS		
Storey	Lateral loads (kN)	% of decrease in lateral load
25	996.734	45.858 %
26	539.651	
35	876.538	35.339 %
36	566.773	

When analyzed by EQS method there is 45.858% decrease in lateral loads where the planar area decreases and the tube structure changes from storey 25 to 26 and 35.339% decrease from storey 35 to 36.

When analyzed by RS method there is 56.055% decrease in lateral loads where the planar area decreases and the tube structure changes from storey 25 to 26 and 26.002% decrease from storey 35 to 36.

6. Storey Drifts:

ZONE 2:

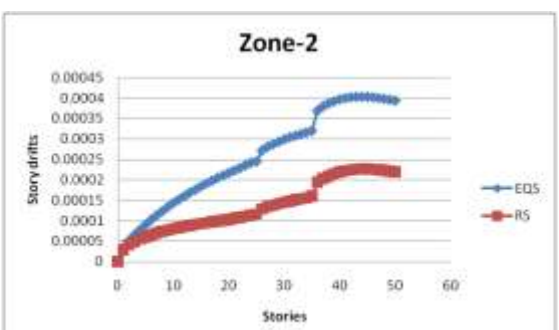


Fig-19:Maximum storey drift in zone-II is 0.0004 by EQS method and 0.00023 by RS method.

ZONE 3:

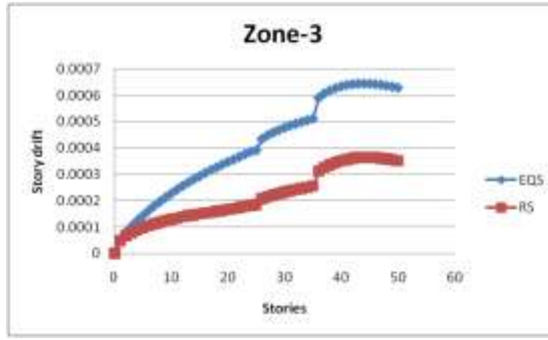


Fig-20:Maximum storey drift in zone-III is 0.000647 by EQS method and 0.000364 by RS method.

RS		
Storey	Lateral loads (kN)	% of decrease in lateral load
25	284.271	56.055 %
26	124.867	
35	127.438	26.002 %
36	94.301	

ZONE 4:

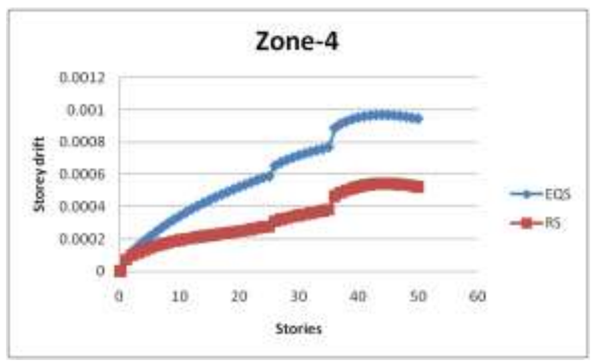


Fig-21:Maximum storey drift in zone-IV is 0.00097 by EQS method and 0.000546 by RS method.

ZONE 5:

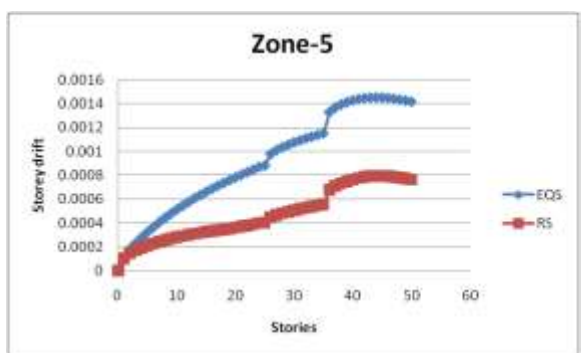


Fig-22:Maximum storey drift is 0.00145 by EQS method and 0.00079 by RS method.

Discussion:
Maximum storey drifts in each zone by both EQS and RS analysis are:

Load case	Zone II	Zone III	Zone IV	Zone V
EQS	0.0004	0.000647	0.00097	0.00145
RS	0.00023	0.000364	0.000546	0.00079

Storey drift in any storey in all the zones is less than 0.004 according to clause 7.11.1 of code IS 1893-2016.
Hence the maximum storey drift of structure in each zone is within permissible limits, this shows that the multiple tube-in-tube system of structure is a good system to minimize max storey drift.

V. CONCLUSION

1. Base shear values by EQS method for zone II,III,IV,IV are 8145.96 kN, 13034 kN, 19550 kN, 29325 kN. And by RS method for zone II,III,IV,IV are 8406.56 kN, 13450.5 kN, 20177.13 kN, 29326.11 kN.
   Therefore EQS method gives values greater than RS values in all seismic zones except in zone-3.

2. Maximum displacement due to seismic loads is 165.556 mm occurring in zone-V by EQS method.
   And therefore this satisfies the clause 5.4 given in code IS16700-2017, i.e. displacement is less than H/250=172500/250=700.8 mm.
   The displacements due to seismic loads analyzed by equivalent static method and response spectrum method are within permissible limits. This shows that the multiple tube-in-tube system of structure is a good system to minimize displacement due to seismic loads.

3. Maximum displacement due to wind loads is 50.137 mm occurring in zone-III & zone-V.
   And therefore this satisfies the clause 5.4 given in code IS16700-2017, i.e. displacement is less than H/500=172500/500=345 mm.
   The displacements due to wind loads are within permissible limits. This shows that the multiple tube-in-tube system of structure is a good system to minimize displacement due to wind loads.

4. The modes of vibration should be translational within the first two modes, i.e. the higher amount of mass must participates in Ux and Uy direction than in Rz direction. This shows that torsion does not occur in the first 2 modes of vibration and hence satisfies table 5 of the code IS 1893 2016.
   Within the 12 modes considered, the total sum of modal masses is at least 90% of the total seismic mass, i.e. 93% of the total seismic mass is considered in the 12th mode. Hence satisfies clause 7.7.5.2 of code IS 1893 2016.

5. Maximum decrease in percentage of lateral loads due to sudden decrease in planar area along height of structure for all seismic zones was found between stories 25& 26 as 45.858% and between stories 35 &36 as 35.337% when analyzed by EQS analysis.
   And for all seismic zones between stories 25 & 26 as 56.069% and between stories 35 &36 as 25.999% when analyzed by RS analysis.

6. The maximum storey drift of the structure is 0.00145 mm & occurs in zone-V and is within permissible limits, i.e. within 0.004 mm as given by clause 7.11.1.1 of code IS 1893-2016. This shows that the multiple tube-in-tube system of structure is a good system to minimize max storey drift.

VI. Scope of further studies

This project deals with multiple tube in tube system with varying plan areas and elevations and then its analysis by method of static linear analysis (equivalent static analysis) and dynamic linear analysis, (response spectrum analysis).
This model or this type of geometric model can be further studied by method of
Static non-linear analysis, which is pushover analysis and dynamic non-linear analysis, which is time history analysis.

REFERENCES

1) Duggal, S.K. - Earthquake Resistant Design of Structures-Oxford University Press (2007)
2) “Analytical investigation on the performance of tube in tube structures subjected to lateral loads” by NimmyDileep and Renjith R.
3) “Comparative study of tube in tube structures and tube mega frames” by Archana J and Reshmi P R.
4) “Performance of Tube in Tube Structures: A Review” by Adil G. Khatri, RupaliGoud, Gaurav Awasthi
5) “Dynamic Analysis of Hybrid Tall Tube Structural system” by Pavithra, Dr. S Vijaya, Kavya
6)IS 875 part-1 Code of practice for design loads, Dead loads
7) IS 875 part-2 Code of practice for design loads, Imposed loads
8) IS 875 part-3 Code of practice for wind loads
9)IS 16700-2017 Criteria for structural safety of tall concrete buildings
10) IS 456: 2000- Indian Standard plain and reinforced concrete code of practice
11) IS 1893 Part-1: 2016 Criteria for earthquake resistant design of structures s