Comparative Analysis of Tubular Structures with Conventional Tall RC Structure

S Bhavanishankar[1], Vinod[2]

[1]*Associate Professor, Dept. of Civil Engineering, University Visvesvaraya College of Engineering, Bengaluru -560056, Karnataka, India, [1]Email-sbhavanishankar@gmail.com*
[2]*M. Tech Scholar, Dept. of Structural Engineering, University Visvesvaraya College of Engineering, Bengaluru -560056, Karnataka, India, [2]Email-vinodmj57@gmail.com*

Abstract - *Tubular structures are adopted for Tall Structures for effectively resisting the impact of lateral loads i.e., Wind load and Seismic load. Present study is made to investigate the effect of seismic loading on Tall structure and hence Response Spectrum Analysis is carried. The modeling and analysis are done using ETABS V17 software. 21-storey 3D model of Tall RC structure along with tubular structural system models in seismic zone II and seismic zone V are considered to study the time period, base shear, lateral storey displacement, storey drift. The Time Period for Tubular structures reduced considerably when compared with the Tall RC Moment Resisting Frame Structure. The Base shear for Tall Tubular structures increased when compared to Tall RC Moment Resisting Frame Structure under the seismic loading. Story displacement and Storey drift got reduced in Tubular Structures compared to Tall RC Moment Resisting Structure and the value of top story displacement and storey drifts are well within the limits. Storey accelerations increased for Tubular structures over the Tall RC Moment Resisting Structure.*

Key Words: Tall RC Structure, Tubular Structure, Seismic Analysis, Response Spectrum Analysis, ETABS V17

1. INTRODUCTION

The rapid urbanization due to economic growth and scarcity of land have accelerated the real estate development. Therefore, there is popular and pressing demand for the construction of tall buildings. In tall buildings, it is mandatory to design the for lateral loads to resist lateral effect. Hence, the knowledge of seismic performances of tall buildings become an essential part of structural engineering works. For resisting the lateral forces acting due to seismic and wind loadings the shear walls or bracings are provided to resist the lateral sway. Tubular System proves to be best alternative to this system for very Tall Structure. Tubular System with Shear core element at centre proves to be more effective in resisting Lateral sway of structure.

1.1 Tubular Structural System

Fazlur Rahman Khan is considered the "father of tubular design", who innovated this system in early 1960s. He designed Dewitt-Chestnut Apartment Building, Chicago. Tubular systems are extensively used and it is considered as a better lateral structural system for very tall buildings. The system which resists lateral loads on a building is designed to act like a three-dimensional hollow tube. System can be constructed using steel, concrete, or composite of both System. Structural system comprises of closely spaced columns and deep beams in the perimeter frame for an efficient tube action. The internal vertical elements, comprising of core or columns is primarily utilized resist gravity loads only. Effective utilization of the perimeter of the building maximizes the overall stiffness for a given building plan shape and to resist lateral loads effectively. System can be used for office, apartments and mixed-use buildings in tall structures.

1.2 Types of Tubular Structures

1.2.1 Framed Tube

Frames comprises of closely spaced columns, 2 to 4 m between centers, with deep beams joining them. 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. It can take a variety of floor plan shapes from square and rectangular, circular. This structural form provides an efficient structure appropriate for buildings with 40 to 100 Storeys. This design was first used in Chicago's DeWitt-Chestnut apartment building, designed by Khan and completed in 1963, but the most notable examples are the Aon Center and the original World Trade Center towers.

1.2.2 Tube in Tube

Also known as hull and core, 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. The majority of the gravity and lateral loads are normally taken by the outer tube because of its greater strength. It is the most commonly used structural system for high-rise building with more than 50 Storey's., 780 Third Avenue, a 50-story concrete frame office building in Manhattan, uses concrete shear walls for bracing and an off-center core to allow column-free interiors.

1.2.3 Bundled Tube

The bundled tube system can be instead of one tube several tubes are connected together. A bundled tube typically consists of a number of individual tubes interconnected to form a multicellular tube, in which the frames in the lateral load direction resist the shears, while the flange frames carry most of the overturning moments. The bundle tube design was not only highly efficient in economic terms, but it was also "innovative in its potential for versatile formulation of architectural space. The bundled tube structure meant that "buildings no longer need be boxlike in appearance, they could become sculpture. Example: Sears Tower

1.2.4 Braced Tube

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 hence farther-spaced exterior columns are allowed. Steel bracings or concrete shear walls are introduced along the exterior walls to compensate for the fewer columns by tying them together. The most notable examples incorporating steel bracing are the John Hancock Center, the Citigroup Center and the Bank of China Tower.

1.2.5 Tubed Mega

Tubed Mega frame Structures contain huge vertical tubes placed at the perimeter of the building. These tubes will be the main load carrying elements in this structural system. With this structural system there will be no central core thus, no floor space has to be assigned for a central core and the building can therefore be made slenderer. The main purpose of this system is to transfer all loads to the perimeter of the building and thereby achieve higher stability since the lever arm between the load bearing components will be longer than in a core system.

1.3 Objectives

1. Comparative Analysis of Tubular Structures with Tall RC Moment Resisting Frame Structure using ETABS.
2. To study the effect of Seismic Load for Tubular Structural Systems with reference to RC Moment Resisting Frame Structure in seismic zone II and seismic zone V.
3. To study the Time Period, Base Shear, Lateral Storey Displacement, Storey Drift and Storey Acceleration for Tubular Structures with Tall RC Moment Resisting Frame Structure.

2. LITERATURE REVIEW

Nimmy Dileep et.al (2015) In this study the seismic performance of tube in tube structures. Three models were developed in SAP2000 software by varying location of the inner tubes and the structures are analysed by equivalent static, response spectrum method and time history analysis. The output of three models is evaluated to have a comparative study of their seismic performance. Study concludes that time history analysis predicts the structural response more accurately than equivalent static analysis and response analysis.

Shubham Shukla et.al (2020) An Interpretation of Seismic Behaviour of Tube in Tube Building and Moment Resisting Building with plan dimension of 30m X 30m of 40 storeys with each storey height of 3.6m. The results are compared between the models with respect to displacement, story-drift, time period and base shear. Modelling of buildings is done in ETABs. The seismic analysis results showed that, the displacement values due to seismic loads for moment resisting frame model were maximum and Tube-in-Tube model exhibited least displacement values both in equivalent static and response spectrum analysis in zone IV. The maximum seismic displacements of tube in tube got reduced by 60% in equivalent static analysis and 62% in response spectrum analysis respectively when compared with moment resisting frame. The time period of tube in tube building had reduced by 36% compared with RCC building. This study also concludes that the Tube in Tube structures are comparatively more efficient in resisting the seismic loads than that of a conventional moment resisting frame structures.

3. METHODOOGY

1. For the study Tall RC Moment Resisting Frame Structure with plan dimension of 30mx30m of height 63m is considered, with each storey of 3m height for 21 storeys. The floor height is kept constant for all models in order to get consistent results
2. For the reference base model, a regular reinforced concrete moment resisting frame model is considered.
3. Moment Resisting Frame with Core, Framed Tube, Tubed Frame, Tube-in-Tube and Bundled Tube structure are modelled with reference to base model by using ETABS Software.
4. To understand the behavior under lateral loads (seismic load), the loads as per IS 1893: 2016 are used.
5. Based on the results and responses from applied gravity and seismic loads, conclusion will be made.

4. MODELING AND ANALYSIS

Table 1: Models considered for the Analysis

Model	Nomenclature
RC Moment Resisting Frame Structure	**MRF**
RC MRF Structure with core	**MRFC**
Framed Tube Structure	**FTS**
Tubed Frame Structure	**TFS**
Tube in Tube Structure	**TTS**
Bundled Tube Structure	**BTS**

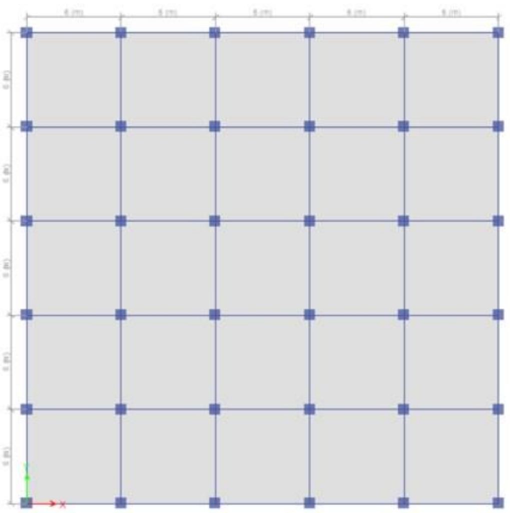

Figure 1: Plan view of Conventional MRF Structure

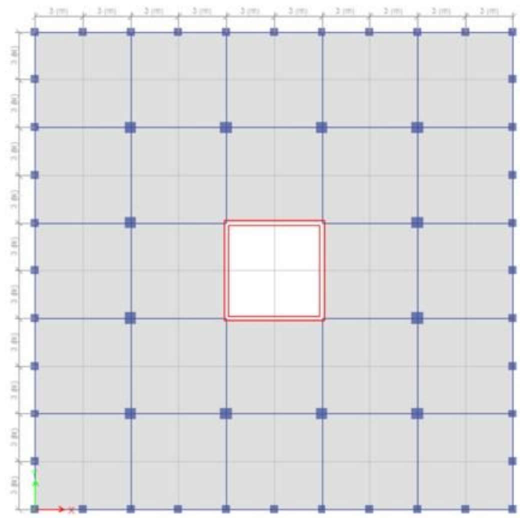

Figure 4: Plan view of Tubed Frame Structure

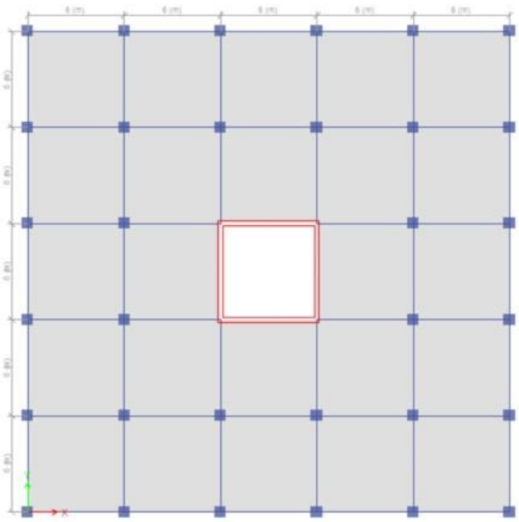

Figure 2: Plan view of MRFC Structure

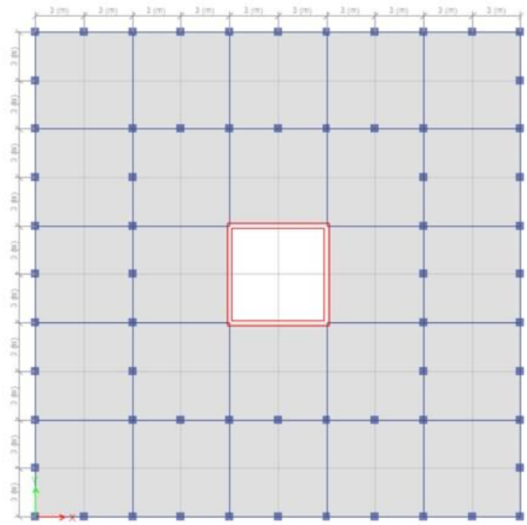

Figure 5: Plan view of Tube in Tube Structure

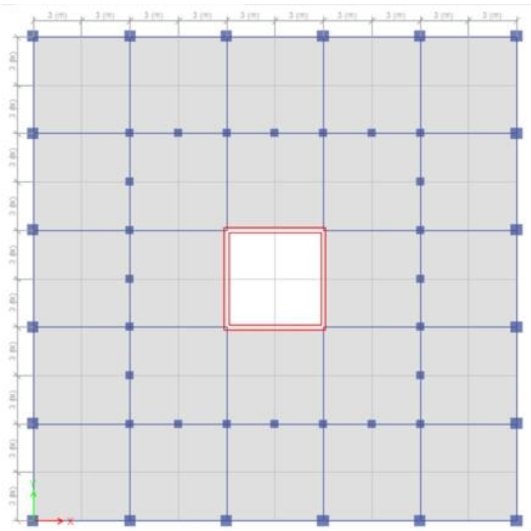

Figure 3: Plan view of Framed Tube Structure

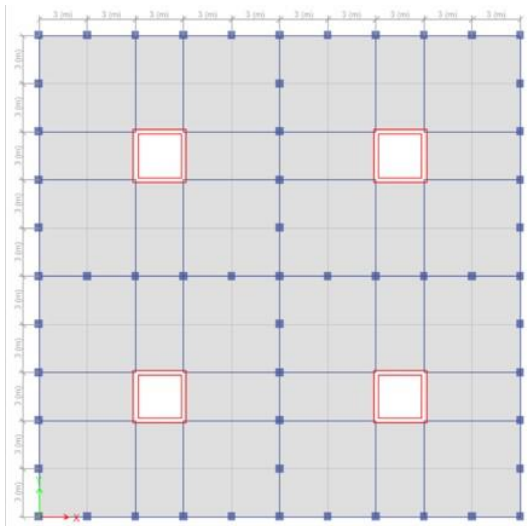

Figure 6: Plan view of Bundled Tube Structure

Table 2: Parameters considered for the Analysis

Design Data for All Buildings	
Details of Building	
Number of stories	21
Type of building	Commercial
Storey height	3m
Building Plan Dimension	30m x 30m
Location of Structure	Bangalore, Imphal
Number of stories	21
Material Properties	
Grade of Concrete	M30
Grade of Steel	Fe500
Member Properties	
Thickness of Slab	150 mm
Size of Beam	300 x 650 mm
Size of Column	700 x 700 mm 500 x 500 mm
Thickness of Shear Wall	300 mm
Thickness of Brick Wall	230 mm
Loads and Intensities	
Live Load on all the floors	4 KN/m^2
Live Load on terrace	1 KN/m^2
Floor Finish	1 KN/m^2
Terrace Finish	1 KN/m^2
Wall load	10.5 KN/m^2
Parapet Wall load	2.85 KN/m^2
Seismic Properties from IS: 1893-2016	
Zone factor	0.10 (Zone II) 0.36 (Zone V)
Importance factor	1.5
Response Reduction Factor	5
Soil Type	Medium

4.1 Load Combination

- 1.5 (DL+RSx) …… Response Spectrum Analysis

Analysis results are taken for above load combination for the parameters like Base Shear, Storey displacement, Storey drift.

5. RESULTS AND DISCUSSIONS

5.1 Time Period

The fundamental time period for all models obtained from the modal analysis.
As per IS 1893(Part 1)- 2016:
$T_a = 0.075h^{0.75}$ - RC frame building without brick infill.

Table 3: Time Period for different Models

Modes	TIME PERIOD (sec)						
	IS 1893 2016	MRF	MRFC	FTS	TFS	TTS	BTS
1	1.67	2.77	1.98	1.94	1.86	1.83	1.96
2		2.77	1.97	1.93	1.86	1.82	1.94
3		2.46	1.77	1.73	1.56	1.52	1.59

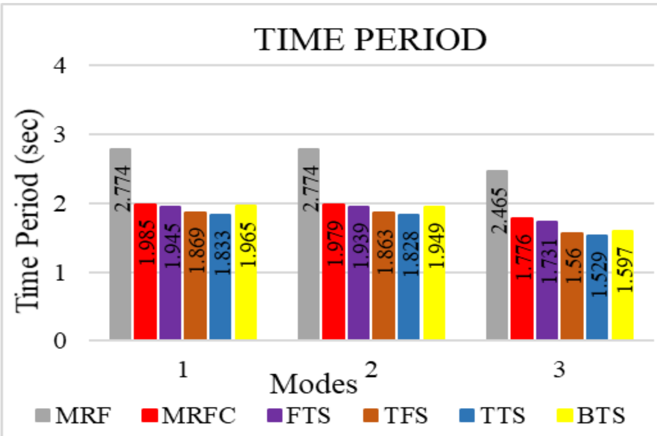

Figure 7: Bar chart showing Time Period for different models for first 3 Modes

From all the models, TTS shows the minimum time period of 1.833sec which indicate most stiffer and MRF shows the maximum time period of 2.774sec which indicate least stiff in 1st mode. Tube in Tube Structure (TTS) is showing the best results among all Tubular Structures.

5.2 Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of the structure.

Table 4: Base Shear for different models under different seismic zones

Seismc Zones	BASE SHEAR (KN)					
	MRF	MRFC	FTS	TFS	TTS	BTS
Zone 2	2689	3731	3809	3962	4026	4112
Zone 5	9680	13430	13711	14262	14492	14845

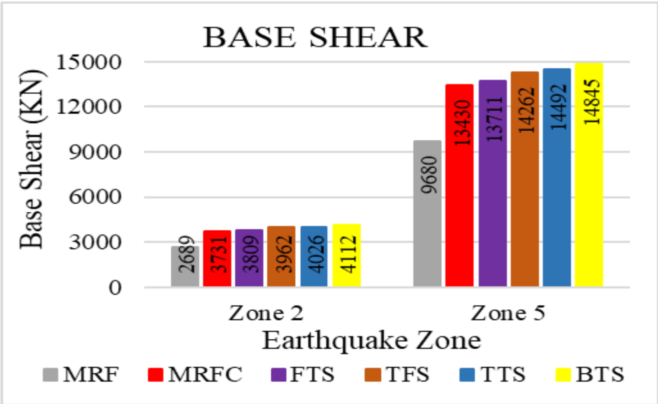

Figure 8: Bar chart of Base Shear for different Models under different seismic zones

Base shear value of Tube structures increased due to increase in the seismic weight.
BTS shows maximum value of base shear compared to all models of tubular structures and to MRF structure in seismic zone 2 and seismic zone 5. Hence the BTS will have highest Rigidity among all tubular structures.
The base shear of MRF structure is least compared to all structural models due to less seismic weight which indicates the MRF structure is least stiff.
Base shear is enhanced by 52.91% in BTS over MRF structure and by 49.72% in TTS over MRF structure and by 47.34% in TFS over MRF structure and by 41.65% in FTS over MRF structure and by 38.75% in MRFC over MRF structure in seismic zone 2.
Base shear is enhanced by 53.35% in BTS over MRF structure and by 49.71% in TTS over MRF structure and by 47.33% in TFS over MRF structure and by 41.64% in FTS over MRF structure and by 38.73% in MRFC over MRF structure in seismic zone 5.

5.3 Storey Displacement

Displacement is the distance of element (beam, column, frame, etc.) moved from its original location.

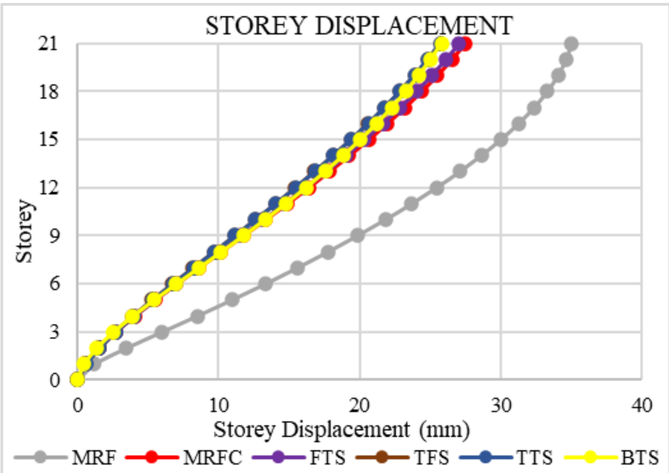

Figure 9: Storey Displacement for different Models from RSAx in seismic zone 2

The displacement of tubular structural models is less compared to moment resisting frame structure under seismic loading. MRF has displacement of 35.01mm at its top storey level in seismic zone 2. Tubular models having displacement of around 26mm at their top storey levels.

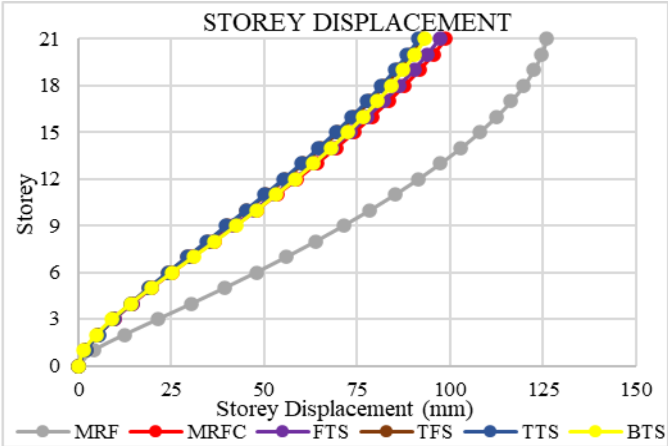

Figure 10: Storey Displacement for different Models from RSAx in seismic zone 5

The displacement of tubular structural models is less compared to moment resisting frame structure under seismic loading. MRF has displacement of 126.04mm at its top storey level in seismic zone 5. Tubular models having displacement of around 93mm at their top storey levels in seismic zone 5.

Table 5: Maximum Storey Displacement for different Models under different seismic zones

Seismic Zones	MAXIMUM STOREY DISPLACEMENT (mm)					
	MRF	MRFC	FTS	TFS	TTS	BTS
Zone 2	35.01	27.47	27.01	26	25.72	25.80
Zone 5	126.0	98.88	97.24	93	91.64	93.33

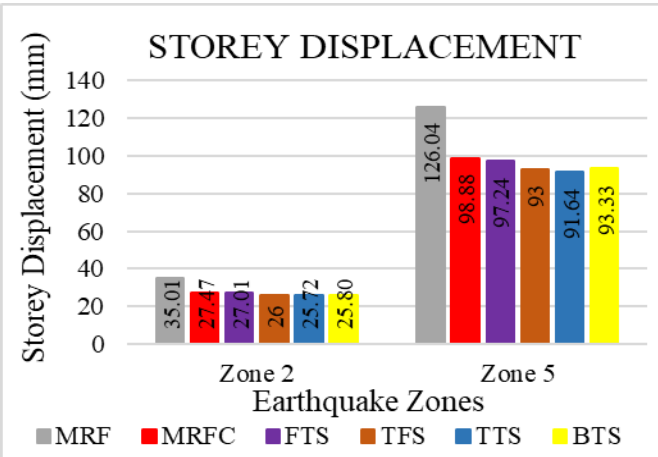

Figure 11: Bar chart showing Maximum Storey Displacement for different Models under different seismic zones

TTS gives the least displacement among the tubular models and hence it is most effective in resisting lateral displacements in structure.
TTS shows maximum reduction in displacement by 26.53% and 27.29% over the MRF structure in seismic zone 2 and seismic zone 5 respectively.

5.4 Storey Drift

Storey drift is the difference of displacements between two consecutive stories w. r. t. height of that storey.
As per IS 1893 (Part 1): 2016, the storey drift in any storey due to specified lateral force, shall not exceed 0.004 times the storey height.

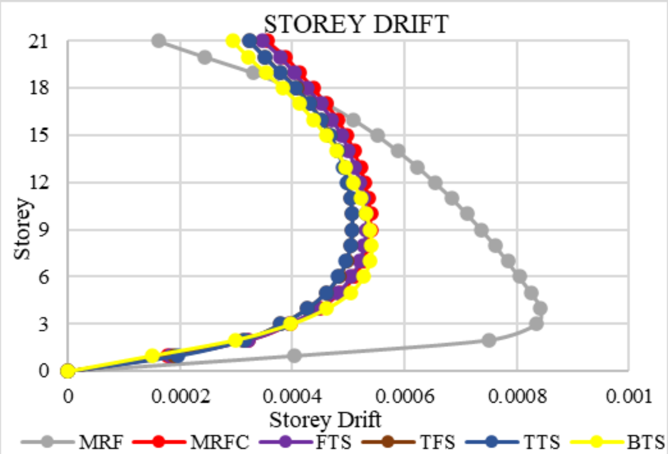

Figure 12: Storey Drift for different Models from RSAx in seismic zone 2

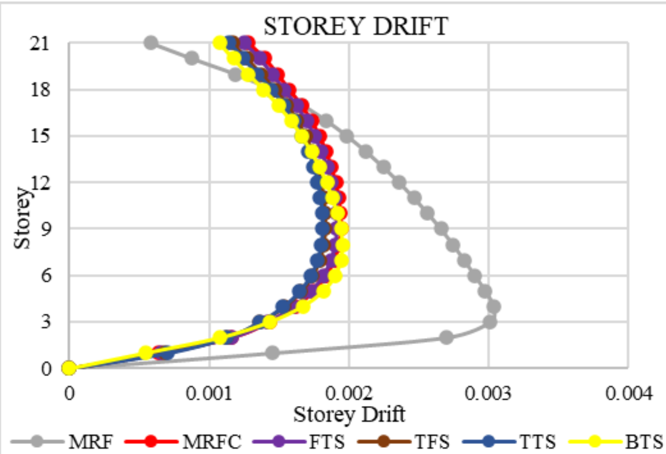

Figure 13: Storey Drift for different Models from RSAx in seismic zone 5

The storey drift of TTS structure is less compared to other models and hence stiffness of TTS structure is more among all tubular models and over MRF structure in seismic zone 2 and seismic zone 5.
The storey drift values got reduced for the Tubular Structural Systems considerably when compared with Moment Resisting Frame Structure under seismic loading.

Table 6: Maximum Storey Drift for different Models under different seismic zones

Seismic Zones	STOREY DRIFT ($*10^{-6}$)					
	MRF	**MRFC**	**FTS**	**TFS**	**TTS**	**BTS**
Zone 2	843	540	532	510	510	540
Zone 5	3034	1943	1914	1827	1809	1956

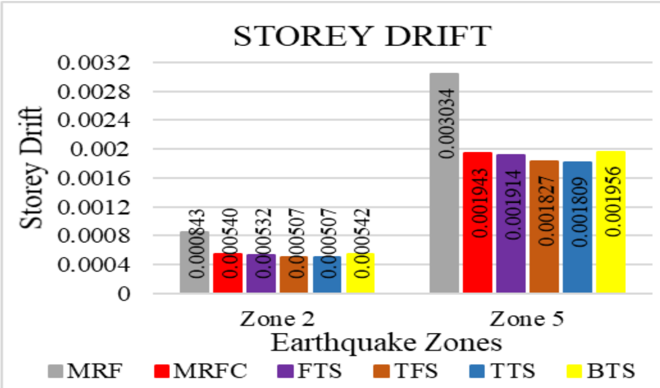

Figure 14: Bar chart showing Maximum Storey Drift for different Models under different seismic zones

TTS shows maximum reduction in storey drift by 39.85% over the MRF structure having storey drift of 0.000843 at storey 4 under seismic zone 2 and by drift by 40.37% over the MRF structure having storey drift of 0.003034 at storey 4 under seismic zone 5.

5.5 Storey Acceleration

The acceleration or the rate of change of the velocity of the building in motion.

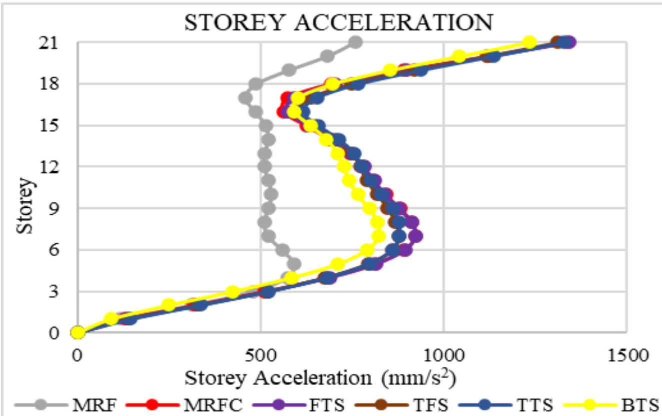

Figure 15: Storey Acceleration for different Models from RSAx in seismic zone 2

The storey acceleration of TTS structure is more compared to other models and hence stiffness of TTS structure is more among all tubular models and over MRF structure. But at storey level 7, the FTS is having higher storey acceleration compared to TTS structure in seismic zone 2 and seismic zone 5.

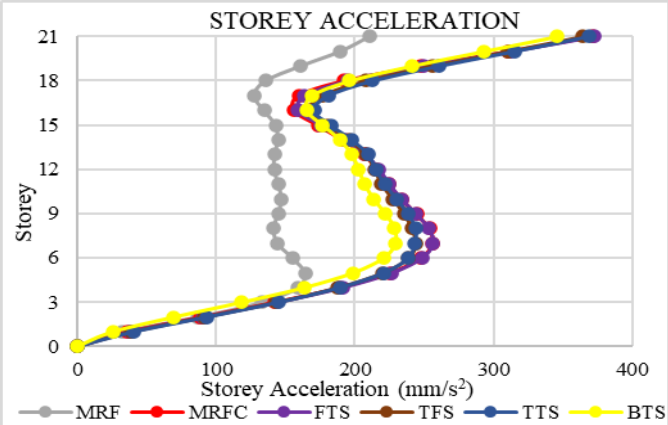

Figure 16: Storey Acceleration for different Models from RSAx in seismic zone 5

Table 7: Maximum Storey Acceleration for different Models under different seismic zones

Seismic Zones	STOREY ACCELERATION (mm/s²)					
	MRF	MRFC	FTS	TFS	TTS	BTS
Zone 2	211	371	373	364	369	346
Zone 5	758	1337	1341	1311	1327	1232

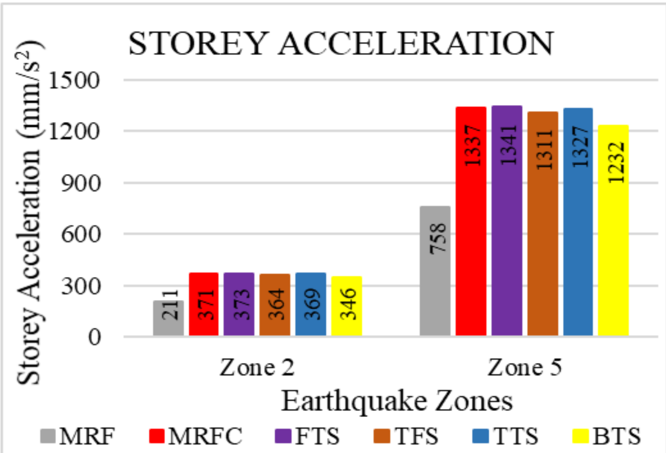

Figure 17: Bar chart showing Maximum Storey Acceleration for different Models under different seismic zones

FTS shows maximum storey acceleration of 373 mm/s² over the MRF structure having storey acceleration of 373 mm/s² under seismic zone 2.

FTS shows maximum storey acceleration of 1341 mm/s² over the MRF structure having storey acceleration of 758 mm/s² under seismic zone 5.

6. CONCLUSIONS

- Time period got reduced for the Tubular structures compared to Tall RC Moment Resisting Frame Structure. TTS shows maximum reduction in time period by 33.92% over MRF structure having maximum time period of 2.774 in its first mode. Hence TTS is most effective structure. BTS shows the least reduction in time period by 29.16% over MRF structure. Hence BTS is most vulnerable among all tubular models.
- Base Shear value goes on increases as the number of storeys increases in structure, because of the addition of inner tube, column rings increased the seismic weight which in turn resulted in increase of Base shear for Tube in Tube structure.
- BTS shows maximum value of base shear compared to all models of tubular structures and to MRF structure in seismic zone 2 and seismic zone 5. Hence BTS is more effective in this regard. FTS shows least base shear among all tubular models.
- Tube-in-Tube Structure get maximum reduction in displacement for Seismic loading in zone 2 and zone 5. The Maximum Storey Displacement values are in limit as per code for tubular structures under seismic loading in zone 2 and zone 5.
- Tube-in-Tube Structure get maximum reduction in storey drift for Seismic loading in zone 2 and zone 5. The Maximum Storey Drift values are in limit as per code for tubular structures under seismic loading in zone 2 and zone 5.
- FTS showing maximum storey acceleration than all tubular models under seismic loading in zone 2 and zone 5. BTS having least storey acceleration under seismic loading in zone 2 and zone 5 among tubular models.
- Tube-In-Tube with shear core system in very tall structures are found to be most suitable system for resisting both gravity and lateral loads.

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