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Comparative Study of RC Framed Structure and Tubular Structures

Dattaprasad Patil[1], Prachi Sohoni[2]

[1]M.Tech Structural Engineering, Walchand College of Engineering, Sangli, Maharashtra, India

[2]Assistant Professor, Applied Mechanics Department, Walchand College of Engineering, Sangli, Maharashtra, India

ABSTRACT

In developing countries like India some cities are overcrowded with population and count is increasing annually at the rate of 1.2% as per year 2016 data, therefore the demand for high rise buildings is increased. As height of building increases, lateral loads such as wind and earthquake must be considered along with gravity loads. As compared to vertical loading, lateral load effect on a building increases exponentially with increase in its height. Engineers have developed several new framing schemes for tall buildings in order to minimize the effect of lateral loads. Present work aims to study and compare seismic response of structures subjected to non-linear dynamic analysis. For this study framed structure, framed tube structure and tube-in-tube structure are considered. Results are compared in terms of structural parameters like maximum lateral displacement, maximum storey drift, base shear, and shear lag. ETABS 2016, the structural software for building analysis and design is used for analysis.

Keywords: Framed structure, Framed tube structure, Tube-in-tube structure, Non-linear dynamic analysis, ETABS.

I. INTRODUCTION

Construction of high rise buildings is result of increased population. Due to industrialisation large population migrates towards cities. In metro cities of India there is space limit for horizontal growth so solution is vertical development. In structures built at the beginning of 20th century, structural members were assumed to carry primarily the gravity loads. Now a days due to advancements in structural designs/systems and high-strength materials, building weight is greatly reduced and slenderness has increased, which has demanded 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.

Seismic zone plays significant role in the earthquake resistant design of structures. As the seismic intensity changes, the zone factor changes from low to very severe. Another important aspect in the design of earthquake resistant structures is soil type, as the soil type changes the whole behaviour and design of the structure changes. So we have to design the structure very uniquely to resist the lateral forces that can withstand for the maximum time. It focuses on the safety of the structure which in turn ensures no harm to the society. More the height of building, more it is necessary to identify the proper structural system that can be used for the lateral resistance of high rise buildings. Currently, there are many structural systems such as rigid frame, braced frame and shear-wall frame, frame-tube, braced-tube, bundled-tube, and outrigger systems that can be used to improve the lateral resistance in tall buildings.

II. TYPES OF STRUCTURAL SYSTEMS

From the structural engineer's point of view, the determination of the structural form of a high rise building would involve selection and arrangement of the major structural elements to resist the various combinations of gravity and horizontal loading more efficiently. The taller and more slender a building, the more important it is to choose an appropriate structural form. Following is the classification suitable for reinforced concrete buildings, steel buildings and composite buildings.

- Rigid frame system
- Braced frame and shear-wall frame system
- Frame-tube system
- Braced-tube system
- Tube-in-tube system
- Bundled-tube system
- Outrigger system

A. Rigid Frame System

This system consists of columns and beams joined by moment resistant connections. Lateral stiffness of a rigid frame depends on the bending stiffness of the columns and beams. This is ideally suitable for reinforced concrete buildings because of the inherent rigidity of reinforced concrete joints. It can also be used for steel frame buildings, but moment-resistant connections in steel tend to be costly. While rigid frame is economical up to height of about 25 to 30 stories, above that height flexibility of the frame will be relatively high and it will require large members, in order to control the drift and displacements.

B. Framed Tube System

Framed tube system consists of closely spaced columns joined by deep beams at periphery and acts as tube, so that the whole building works as a huge vertical cantilever to resist overturning moments. The lateral load is resisted by this tube around the perimeter of the building and the gravity load is shared between the tube and interior columns or walls. Besides its structural efficiency, framed-tube buildings leave interior floor plan free of heavy columns, enhancing net usable floor area. Depending on the height and dimensions of the building, exterior column spacing should be kept between 2 m to 4 m center to center.

C. Tube-in-Tube System

Tube-in-tube structure is advancement in framed tube structure and consists of an inner tube in addition to an outer frame tube. The inner tube which may consists of braced frames or shear wall enclosing service core or closely spaced columns connected by beams, similar to outer tube. Outer and inner tubes are interconnected through floors and acts jointly in resisting both gravity and lateral loading. The outer framed tube and the inner core interact horizontally as the shear and flexural components of a wall-frame structure, with the benefit of increased lateral stiffness.

III. NON-LINEAR TIME HISTORY ANALYSIS

The non-linear dynamic analysis consists of the non-linearity of the structure. It is a very complex model to analyze the effect of dynamic loading and it can be used for any number of degrees of freedom. In non-linear dynamic analysis, force is considered as time dependent. So, the governing equation is now also function of time apart from function of dimensions. Other assumption in this analysis is that the material is non-linearly elastic. This can be addressed by changing the strain-displacement equation and adding higher order terms in the equation. This method consists of performing a time-history analysis in the non-linear domain. The seismic action is directly applied, by means of accelerogram, at the base of the structure.

IV. MODLING OF BUILDING

For this study 30 storied framed structure, framed tube structure and tube-in-tube structure are considered with plan dimension 24m x 24m. The structures are considered to be located in zone IV and designed according to IS 456:2000. The structures are considered to be fixed at the base. The structures are modeled using software ETABS 2016. Models are studied for comparing maximum lateral displacement, maximum story drift, base shear and shear lag.

The data used for modelling of buildings is given in Table I and Table II

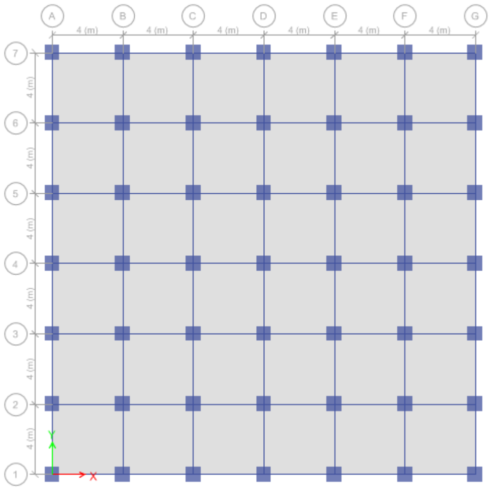

Figure 1: Plan of Framed Structure

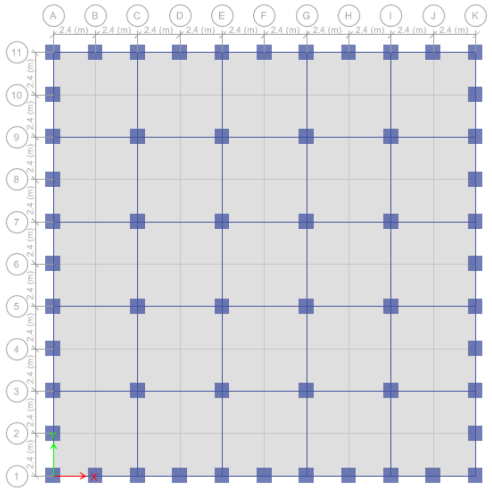

Figure 2: Plan of Framed Tube Structure

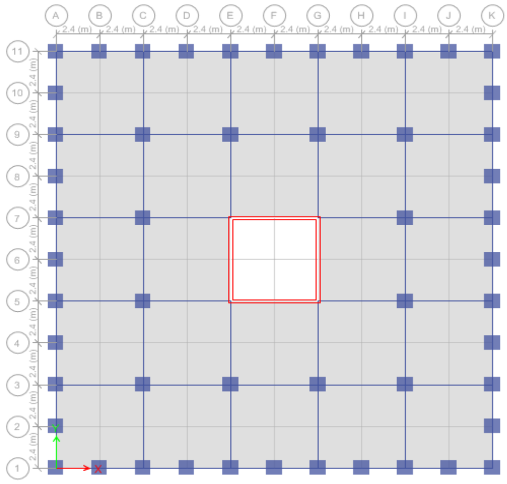

Figure 3: Plan of Tube-in-tube Structure

TABLE I

COMMON DETAILS OF BUILDINGS

No. of storey	30
Each storey height	3 m
Thickness of slab	125 mm
Grade of concrete	M 40
Grade of steel	Fe 500
Importance factor	1.5
Response reduction factor	5
Soil type	Medium
Seismic zone	IV

TABLE II. OTHER DETAILS OF BUILDINGS

Parameter	Framed Structure (mm)	Framed Tube Structure (mm)	Tube-in-tube Structure (mm)
Thickness of Slab	125	125	125
Inner Beam size	230 x 350	230 x 350	230 x 350
Outer Beam size	230 x 350	230 x 750	230 x 750
Column size (Base-15 storey)	850 x 850	850 x 850	850 x 850
Column size (16-30 storey)	600 x 600	600 x 600	600 x 600
Inner Column spacing	4000	4800	4800
Outer Column spacing	4000	2400	2400
Shear wall Thickness	-	-	200

The loads considered for the modelling of buildings are given in Table III

TABLE III. LOADING DETAILS

Sr. no.	Load type	Value (kN/m^2)
1	Live load	5
2	Floor finish load	1

A. Time history data

Various time histories were applied on the buildings and the response was checked. Among applied ones, time histories which gave maximum response were selected and listed below:

- El Centro
- Gazli USSAR
- Imperial valley
- Santa Monica, California
- Sylmar-country hospital

V. RESULTS AND DISCUSSION

The structures are analyzed using software ETABS 2016 for five different time history data. Results are compared for maximum lateral displacement, maximum story drift, base shear and axial force distribution in column.

A. Results for Lateral Displacement:

Table IV shows displacement of buildings for different time history.

TABLE IV. COMPARISON OF DISPLACEMENT OF BUILDINGS

Time History	Displacement (mm)		
	FS	FTS	TTS
El Centro	180.85	60.23	40.75
Gazli USSR	178.65	57.73	47.81
Imperial Valley	270.77	76.96	58.44
Santa Monica	296.85	56.45	52.5
Sylmar Country	220.36	52.37	47.37

Figure 4 shows the maximum lateral displacement of the buildings for different time history.

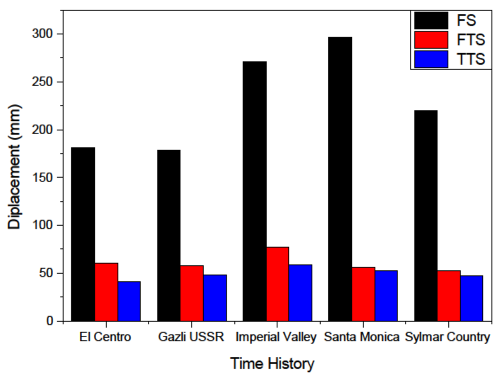

Figure 1: Max. Lateral Displacement of Buildings

From table IV and figure 4 it is observed that FS has large displacements for various time histories. FTS has 67-81 % less displacement compared to FS, TTS has 77-87 % less displacement compared to FS and 7-32 % less displacement compared to FTS for various time histories.

B. Results for Storey Drift:

Table V shows storey drift of buildings for different time history.

TABLE V. COMPARISON OF STOREY DRIFT OF BUILDINGS

Time History	Storey Drift (mm)		
	FS	FTS	TTS
El Centro	9.20	2.69	1.77
Gazli USSR	9.27	3.61	2.59
Imperial Valley	12.23	3.64	2.55
Santa Monica	12.46	3.23	2.09
Sylmar Country	9.53	2.43	2.02

Figure 5 shows the storey drift of the buildings for various time histories

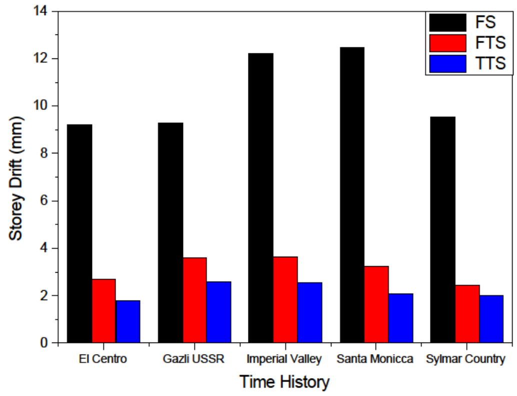

Figure 2: Storey Drift of Buildings

From table V and figure 5 it is observed that FS has large drift for different time histories. FTS has 61-74 % less drift compared to FS, TTS has 72-83 % less drift compared to FS and 17-35 % less drift compared to FTS for various time histories.

C. Results for Base shear:

TABLE VI. COMPARISON OF BASE SHEAR OF BUILDINGS

	FS	FTS	TTS
Base Shear (kN)	4234.18	4459.87	4538.16

Figure 6 shows the base shear variation of buildings

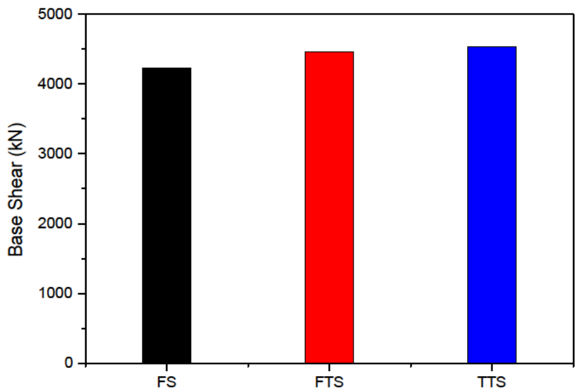

Figure 6: Base Shear variation of Buildings

From table VI and figure 6 it is observed that, TTS has large base shear followed by FTS and then FS. Values of base shear are same for different time histories.

D. Results for Axial Force (Shear Lag):

Though FTS is very good in resisting lateral loads it has considerable degree of shear lag. Shear lag is phenomenon where axial force distribution in periphery columns is uneven.

TABLE VII

COMPARISON OF AXIAL FORCE IN PERIPHERY COLUMNS OF BUILDINGS

Column No.	Axial Force (kN)	
	FTS	TTS
1	112.19	103.95
2	151.29	136.19
3	156.68	143.63
4	165.39	147.70
5	168.84	148.32
6	172.36	149.94
7	168.84	148.32
8	165.39	147.70
9	156.68	143.63
10	151.29	136.19
11	112.19	103.95

Figure 7 shows the axial force variation for periphery columns of buildings.

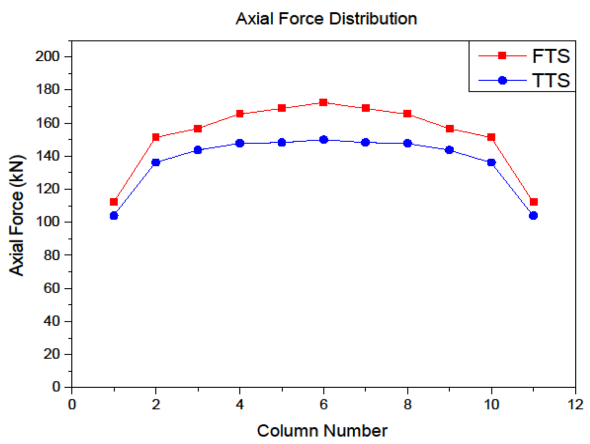

Figure 7: Axial Force variation of periphery columns of Buildings

From table VII and figure 7 it is observed that, FTS has uneven distribution of axial forces, so it is affected by shear lag. TTS has slightly even distribution of axial forces in columns. So shear lag is reduced in TTS due to introduction of inner tube (shear wall).

VI. CONCLUSION

The analysis of 30 storied framed structure, framed tube structure and tube-in-tube structure for five different time history is carried out. Results for lateral displacement, storey drift, base shear and axial force in columns shows that, tube-in-tube structure is best suitable for resisting lateral loads caused due to earthquake, when compared to framed structure and framed tube structure.

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