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COMPARATIVE STUDY OF DIFFERENT LATERAL LOAD RESISTING SYSTEMS IN HIGH-RISE BUILDINGS USING ETABS

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ABSTRACT

Due to an increase in the population these days, there is a necessity for multi-storied buildings. They can be changed into high-rise buildings in order to attain more floor space but occupy less land space. Earlier structures were mostly designed for gravity and vertical loads, however, now-a-days, lateral loads have gained more importance especially in high-rise structures. Thus, tall structures have become quite challenging for the engineers in terms of resisting loads. The effect of lateral load increases with increase in height of the structure. As a result, certain modern construction methods and structural systems are to be introduced to enhance the structural safety of tall structures.

In the following paper, seismic analysis of a G+30 story building, situated in Zone III, is carried out by using Response Spectrum Analysis. The modeling and analysis is done by using ETABS Software. The comparison of obtained results is made based on Maximum Story Displacement, Story Drift, Story Stiffness and Applied Story Forces. Based on results generated, Tube-in-Tube Structure came out to be the most effective Lateral Load Resisting System as compared to other systems considered because of its least Story Displacement, least Story Drift, least Story Shear and maximum Story Stiffness.

Keywords*- ETABS, *High-Rise building, lateral loads, Response Spectrum Analysis, seismic analysis.

1. INTRODUCTION

A building is defined as a high-rise building when it is considerably higher than the surrounding buildings or if the proportion of the building is slender enough to give the appearance of a tall building. The construction of high-rise buildings started at the end of the 19th century in Chicago. As per IS 16700:2017, a tall building is defined as a building with height more than 50 m and less than 250 m, whereas a building with height of more than 250 m is termed as a super tall building [12].

Tall buildings can be used as a residential building, office building, or other functions including hotel, retail or with multiple purposes combined.

1.1 Background

- In the previous days, the structures were mostly designed for vertical and gravity loads.
- However, now-a-days, lateral loads have attained more importance primarily in high-rise structures.
- Thus, tall structures have become quite challenging for the engineers in terms of resisting loads and the effect of lateral load tends to increase with increase in height of the structure.
- Therefore, certain structural systems and modern construction methods are to be introduced to enhance the structural safety of high-rise buildings.
- Some of the structural systems used to resist the effect of lateral loads on a structure include:
- Rigid frame structures
- Braced frame structures
- Shear wall frame structures
- Tubular structures etc.

1.2 Types of Lateral Load Resisting Systems:

Rigid frame System (Moment Resisting Frame System):

- A moment resisting frame is a special type of frame that consists of a combination of beams and columns and this arrangement is able to resist lateral and overturning forces because of the bending moment and shear strength that is inherent in its members and the connecting joints.

Braced frame System:

- It is a structural system commonly used to withstand strong wind and earthquake loads. This system consists of a series of trusses made up of steel members and the diagonal members of these trusses withstand lateral loads in the form of axial tension and compression.

Shear Wall Framed System:

- It is a structural system that consists of a RCC Frame braced with Concrete Shear Wall. The primary reason for this bracing is to obstruct the effects of lateral loads acting on a structure due to wind, earthquake etc.

Tubular Structures:

- A tube is a structural system that is used to resist lateral loads like wind, seismic etc. in high-rise buildings and it behaves as a hollow cylinder, cantilevered perpendicular to the ground.

Some of the Tubular Systems commonly used now-a-days are:

1. *Tube-in-Tube*: This system is also known as “hull and core” and it is made up of a core tube inside the structure for as well as the usual exterior tube system.
2. *Bundled Tube*: This system consists of several tubes tied together to resist lateral forces and such buildings have interior columns along the perimeters of the tubes.
3. *Tubed Mega Frame*: This system consists of closely spaced perimeter columns interconnected by deep beams. In this arrangement, exterior tube carries all the lateral loads while gravity loads are carried between the tube and interior walls/columns, if they exist.
4. *Braced Tube*: This system is also known as “Trussed Tube” or “Exterior Diagonal-Tube System”.In case of RCC buildings – diagonals are constructed by filling the window openings by RC shear walls-diagonal

IJARSE
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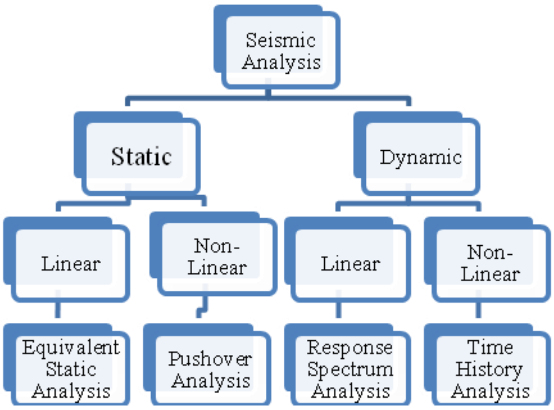
bracing whereas for steel buildings, steel diagonals or trusses are used.

2. OBJECTIVE

The objectives of the following study are:

- To carry out seismic analysis of a high-rise building with four different lateral load resisting systems using ETABS software.
- To compare the four models in terms of Story Displacement, Story Drift, Story Shear and Story Stiffness. To analyse the advantages and disadvantages of different lateral load resisting systems under different criteria using the obtained results.
- To identify the most efficient and most effective lateral load resisting system among the models considered for any given load condition.

3. METHODOLOGY



The method of analysis incorporated for following work is Response Spectrum Method of Analysis which is a Linear Dynamic Analysis Method. In this approach multiple mode shapes of the building are taken into account. For each mode, from the design spectrum, a response is read, based on the modal frequency and therefore the modal mass. They are then combined to supply an estimate of the entire response of the structure using modal combination methods.

Structural Modelling

- For the following study, a Reinforced Concrete building is considered, having a height of 90 m. The building consists of 30 stories, each floors being 3 m in height.
- For the reference base model, a regular Reinforced Concrete moment resisting frame model is considered.
- Tube-in-Tube, Tubed Mega Frame and Shear Wall Framed structures are modelled by using ETABS Software and seismic analysis of all the models is carried out using Response Spectrum Method of Analysis.
- The floor height is kept constant for all models in order to get consistent results.
- To understand the behaviour under lateral loads, the loads applied are as per IS 1893: 2016.
- Based on the results and responses from applied gravity and lateral loads, conclusions will be drawn based on various parameters such as mode shapes, base shear, story drift, story displacement, story shear and story

IJARSE
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stiffness.

- Various design parameters of the building and seismic data considered for analysis are:

Table 1 Design Parameters of the building and Material Properties

Parameter	**Value**
Number of Stories	G+30
Height of each Storey	3m
Plan Area of the building	$1600m^2$
Length of the building	40m
Width of the building	40m
Thickness of slab	150 mm
Thickness of wall	230 mm
Size of Beams	350 mm * 600 mm
Size of Columns (0-10th Floor)	1000 mm * 1000 mm
Size of Columns (11th-20th Floor)	800 mm * 800 mm
Size of Columns (21st-30th Floor)	600 mm * 600 mm
Grade of Steel	Fe500
Grade of Concrete	M30
Density of Brick	20 KN/m^3 [10]
Density of Concrete	25 KN/m^3 [10]

Table 2 Loads Considered for Design

LOAD	**CALCULATIONS**
Dead Load of parapet wall on Terrace beams	0.25 × 20 × 1 = 5KN/m
Dead Load of walls on other floor beams	(3-0.6) × 0.25 × 20 = 12KN/m
Floor Finish on Terrace	1.5 KN/m^2
Floor Finish on other floors	1 KN/m^2
Live Load on Terrace	1.5 KN/m^2 [11]
Live Load on other floors	4 KN/m^2 [11]
Seismic Parameters as per IS 1893: 2016 [9]	**Value**
Seismic Zone	III
Zone Factor	0.16
Damping Ratio	5% (Clause 7.2.4 of IS 1893:2016)
Importance Factor	1.0 (Table No.8 of IS 1893:2016)
Response Reduction Factor	5.0 (Table No. 9 of IS 1893:2016)

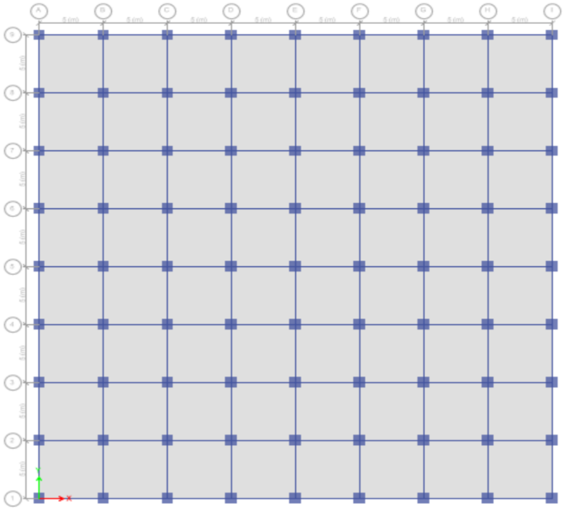

Fig. 1 Plan of CMRF

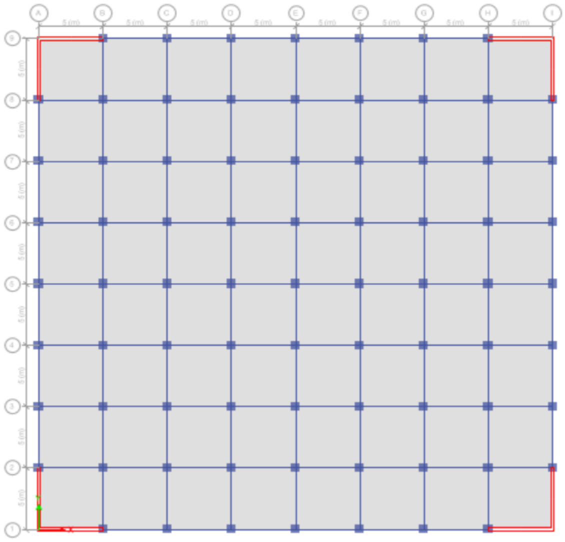

Fig. 2 Plan of SWF

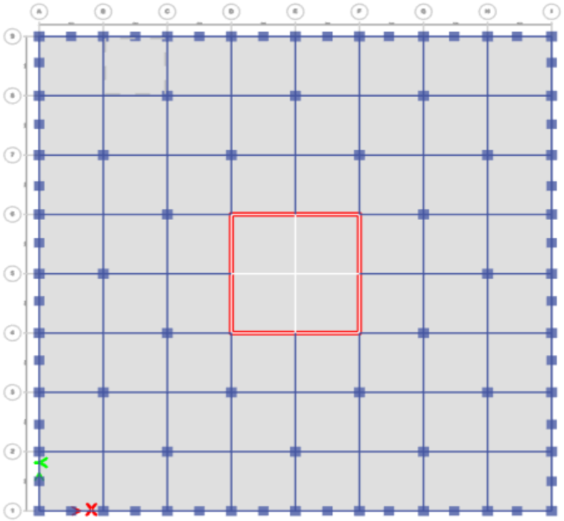

Fig. 3 Plan of TMF

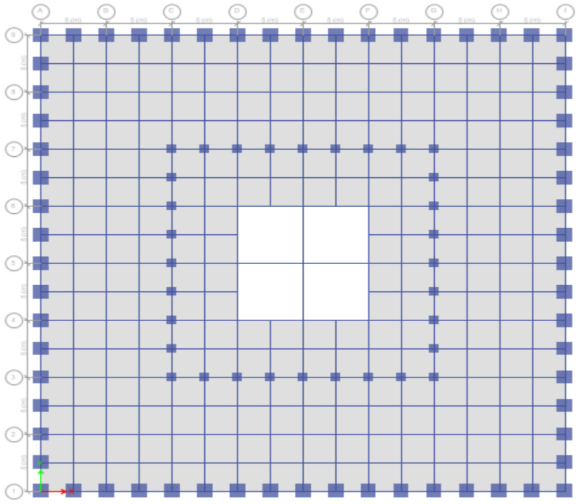

Fig. 4 Plan of TTS

4. ANALYSIS

The method of analysis used for the following research work is Response Spectrum Analysis. The Response Spectrum Analysis of Conventional Moment Resisting Frame (CMRF) (Model 1), Shear Wall Framed System (SWF) (Model 2), Tubed Mega Frame System (TMF) (Model 3) and Tube-In-Tube System (TTS) (Model 4) are carried out using ETABS software.

The various parameters considered for analysis in the following study are:

- *Story Displacement*: It is defined as the total displacement of any storey with respect to ground.
- *Story Drift*: It is defined as the relative displacement between the floors above and/or below the storey under consideration.
- *Story Stiffness*: The lateral stiffness of a story is generally defined as the ratio of story shear to story drift.
- *Story Shear*: It is the sum of design lateral forces at all levels above the storey under consideration.

- *Base Shear*: Base Shear is defined as the maximum expected lateral force on the base of the structure due to seismic activity.

5. RESULTS AND DISCUSSION

The table below shows the values of Maximum Story Displacement, Maximum Story Drift, Maximum Story Stiffness, Base Shear and Maximum Story Shear for Conventional Moment Resisting Frame i.e. Model 1 obtained from Response Spectrum Analysis on ETABS.

Table 3 Result for Conventional Moment Resisting Frame

Maximum Story Displacement	31.392
Maximum Story Drift	0.000595
Maximum Story Stiffness	7270094
Base Shear	5446.747
Maximum Story Shear	516.8377

The table below shows the values of Maximum Story Displacement, Maximum Story Drift, Maximum Story Stiffness, Base Shear and Maximum Story Shear for Shear Wall Framed System i.e. Model 2 obtained from Response Spectrum Analysis on ETABS.

Table 4 Result for Shear Wall Framed System

Maximum Story Displacement	28.881
Maximum Story Drift	0.000409
Maximum Story Stiffness	11919865
Base Shear	5535.9258
Maximum Story Shear	498.0166

The table below shows the values of Maximum Story Displacement, Maximum Story Drift, Maximum Story Stiffness, Base Shear and Maximum Story Shear for Tubed Mega Frame System i.e. Model 3 obtained from Response Spectrum Analysis on ETABS.

Table 5 Result for Tubed Mega Frame System

Maximum Story Displacement	23.722
Maximum Story Drift	0.000370
Maximum Story Stiffness	15603405
Base Shear	6306.7108
Maximum Story Shear	301.6333

The table below shows the values of Maximum Story Displacement, Maximum Story Drift, Maximum Story Stiffness, Base Shear and Maximum Story Shear for Tube-In-Tube System i.e. Model 4 obtained from Response Spectrum Analysis on ETABS.

Table 6 Result for Tube-In-Tube System

Maximum Story Displacement	20.883
Maximum Story Drift	0.000027
Maximum Story Stiffness	20803818.16
Base Shear	7636.027
Maximum Story Shear	279.4895

6. COMPARISON OF RESULTS

The table below shows comparative values of Maximum Story Displacement of all the four models.

Table 7 Maximum Story Displacement

	CMRF	SWF	TMF	TTS
Response Spectrum Analysis (RESx)	31.392	28.881	23.722	20.883
Response Spectrum Analysis (RESy)	31.392	28.881	23.722	20.883

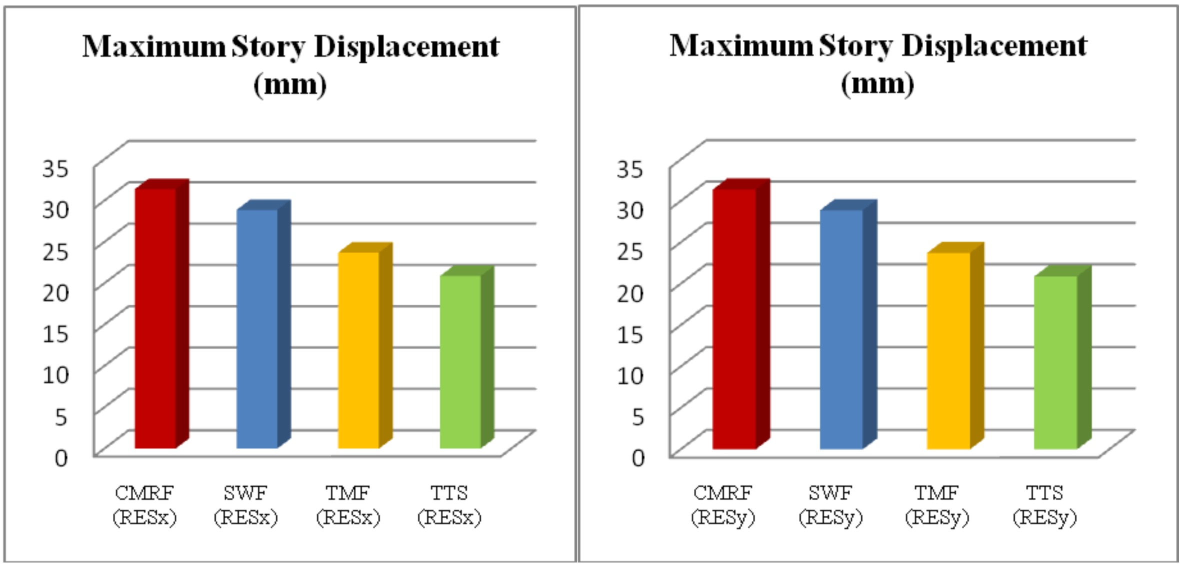

Fig. 5 Comparison of Maximum Story Displacement

The table below shows comparative values of Maximum Story Drift of all the four models.

Table 8 maximum Story Drift

	CMRF	SWF	TMF	TTS
Response Spectrum Analysis (RESx)	0.000595	0.000409	0.000370	0.000027
Response Spectrum Analysis (RESy)	0.000595	0.000409	0.000370	0.000027

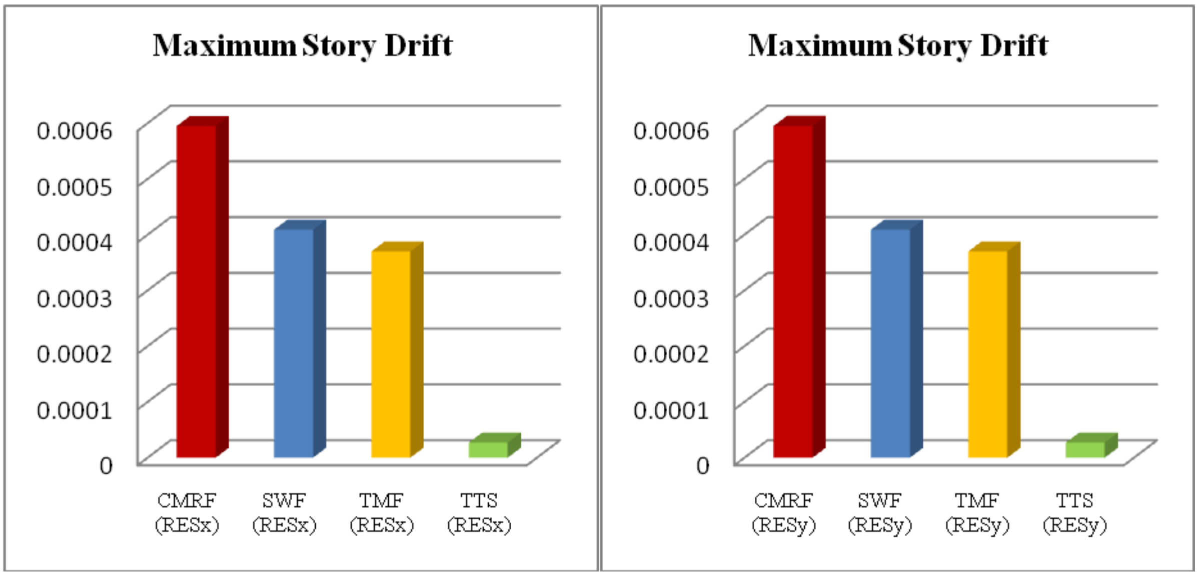

Figure 6 Comparison of Maximum Story Drift

The table below shows comparative values of Maximum Story Stiffness of all the four models.

Table 9 Maximum Story Stiffness

	CMRF	SWF	TMF	TTS
Response Spectrum Analysis (RESx)	7270094	11919865	15603405	20803818.16
Response Spectrum Analysis (RESy)	7270094	11919865	15603405	20803818.16

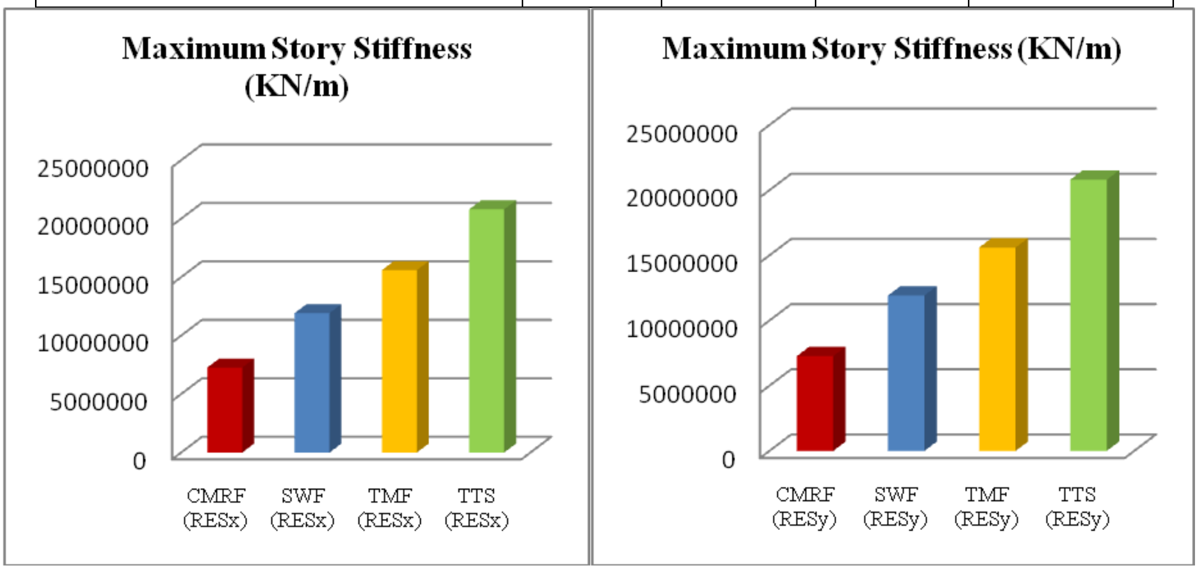

Fig. 7 Comparison of Maximum Story Stiffness

The table below shows comparative values of Maximum Story Shear of all the four models.

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Table 10 Maximum Story Shear

	CMRF	SWF	TMF	TTS
Response Spectrum Analysis (RESx)	516.8377	498.0166	301.6333	279.4895
Response Spectrum Analysis (RESy)	516.8377	498.0166	301.6333	279.4895

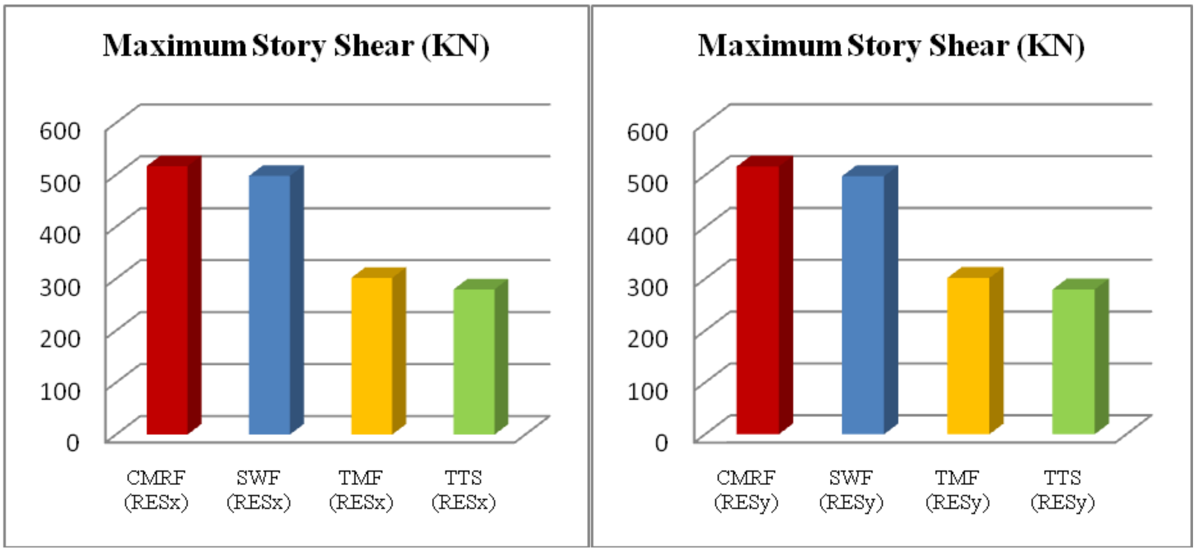

Fig. 8 Comparison of Maximum Story Shear

The table below shows comparative values of Base Shear of all the four models.

Table 11 Base Shear

	CMRF	SWF	TMF	TTS
Response Spectrum Analysis (RESx)	5446.747	5535.9258	6306.7108	7636.027
Response Spectrum Analysis (RESy)	5446.747	5535.9258	6306.7108	7636.027

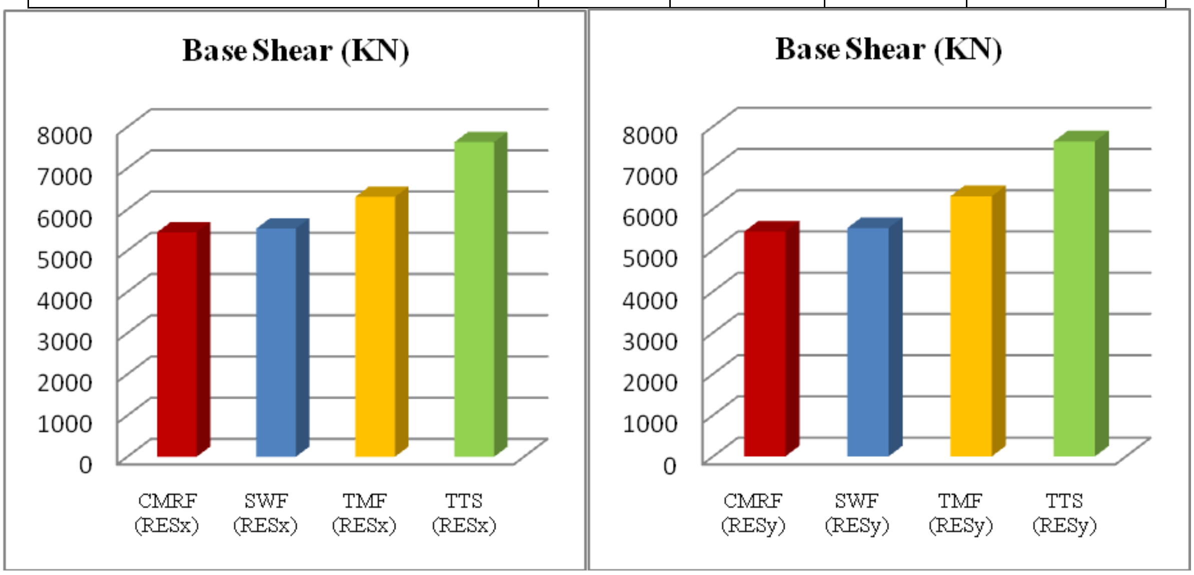

Figure 9 Comparison of Base Shear

7. CONCLUSIONS

The Response Spectrum Method of Analysis was considered for Conventional Moment Resisting Frame, Shear Wall Framed System, Tubed Mega Frame System and Tube-In-Tube System. From analysis results, it is clear that the Tube-In-Tube Structure shows better result than that of Conventional Moment Resisting Frame, Shear Wall Framed System and Tubed Mega Frame System. In Response Spectrum Analysis, Tube-In-Tube Structure shows least values in Maximum Story Displacement, Maximum Story Drift and Story Shear. In conclusion, Tube-In-Tube Structure can be suggested as a better structural system for high-rise buildings as compared to other lateral load resisting systems. From the results obtained in Response Spectrum Analysis, Tube-In-Tube Structure shows 33.48%, 27.69% and 11.97% reduction in Maximum Story Displacement than that of Conventional Moment Resisting Frame, Shear Wall Framed System and Tubed Mega Frame System. Tube-In-Tube Structure shows 95.46%, 93.4% and 92.7% reduction in Story Drift than that of Conventional Moment Resisting Frame, Shear Wall Framed System and Tubed Mega Frame System. In terms of Story Stiffness, Tube-In-Tube Structure shows 65.05%, 42.7% and 25% increment as compared to that of Conventional Moment Resisting Frame, Shear Wall Framed System and Tubed Mega Frame System. From the comparative analysis, Tube-In-Tube Structure shows 45.92%, 43.88% and 7.34% reduction in Story Shear as compared to that of Conventional Moment Resisting Frame, Shear Wall Framed System and Tubed Mega Frame System. Since Tube-in-Tube Structural System shows least values of Maximum Storey Displacement, Maximum Story Shear, Maximum Story Drift and Maximum value of Maximum Story Stiffness, therefore it has proved to be the most effective lateral load resisting system amongst all systems considered.

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