SEISMIC ANALYSIS OF DIFFERENT LATERAL LOAD RESISTING SYSTEMS IN HIGH-RISE BUILDINGS BY EQUIVALENT STATIC METHOD USING ETABS

Pragya Patel[1], Anjali Rai[2], Vinayak Mishra[3]

[1]*M.Tech. Student, Structural Engineering, Institute of Engineering and Technology, Lucknow, Uttar Pradesh, India*

[2]*Assistant Professor, Department of Civil Engineering, Institute of Engineering and Technology, Lucknow, Uttar Pradesh, India*

[3]*Assistant Professor, Department of Civil Engineering, Institute of Engineering and Technology, Lucknow, Uttar Pradesh, India*

ABSTRACT

Due to the developing structural systems and construction technology, there has been an increase in the growth of high-rise buildings. In modern tall buildings, apart from gravity and vertical loads, lateral effects generated by earthquake or wind are also to be taken into account. These lateral loads are resisted by different Lateral Load resisting systems such as Conventional Moment Resisting Frame System, Shear Wall Framed System, Tubed Mega Frame System, Tube-in-Tube System, Outrigger Systems etc.

The following paper performs a comparative seismic analysis of various lateral load resisting systems on a G+30 story building situated in Zone III to find out which system is most beneficial. The modeling and analysis are carried out on ETABS 2018 software. The comparison of different lateral load resisting systems is done by using Equivalent Static Method of Analysis on the basis of various parameters such as Maximum Storey Displacement, Maximum Storey Drift, Applied Storey Forces, Story Stiffness and Base Shear. Based on the 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, Equivalent Method of Analysis, High-Rise building, lateral loads, seismic analysis.

1. INTRODUCTION

A building is defined as ahigh-rise building if the proportion of the building is slender enough to give the appearance of a tall building or when it is considerably higher than the surrounding buildings. 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 for various purposes such as a residential building, office building, or other functions including hotel, retail or with multiple purposes combined.

1.1 Background

- In the earlier days, the structures were mostly designed for vertical and gravity loads.
- However, in the recent scenario, lateral loads are given more importance especially in tall structures.
- Thus, high-rise structures have now-a-days become quite challenging for the engineers in terms of resisting loads and the effect of lateral load such as earthquake, wind etc. tends to increase with increase in height of the structure.
- As a result of which, certain structural systems and modern construction methods are to be introduced to strengthen the structural safety of tall 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 overturning and lateral forces because of the shear strength and bending moment 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:

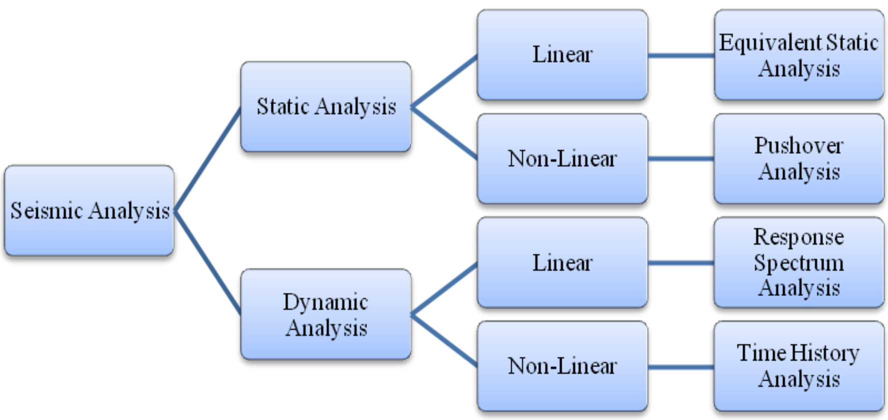
1. *Tube-in-Tube*: This system is also known as "hull and core" and it is made up of a core tube inside the structure for as well as the usual exterior tube system.
2. *Bundled Tube*: This system consists of several tubes tied together to resist lateral forces and such buildings have interior columns 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 bracing whereas for steel buildings, steel diagonals or trusses are used.

2. OBJECTIVE

The objectives of the following study are:

- To perform seismic analysis of a G+30 story building with four different lateral load resisting systems using ETABS 2018 software.
- To analyse the four models using Equivalent Static Method and compare the generated results in terms of Story Displacement, Story Drift, Story Shear and Story Stiffness. To review the advantages and disadvantages of these lateral load resisting systems under different criteria using the obtained results.
- To identify the most efficient and most beneficial lateral load resisting system among the models considered for a particular load condition.

3. METHODOLOGY



The method of analysis incorporated for following work is Equivalent Static Method of Analysis which is a Linear Static Analysis Method. It is a simplified approach in which the effect of dynamic loading of an expected earthquake is substituted by a static force distributed laterally on a structure for design purposes.

Structural Modelling

- For the following research work, a G+30 Story Reinforced Concrete building is considered. The height of each floor is 3m and therefore the total height of the building is 90 m. For reference base model, a regular Reinforced Concrete Moment Resisting Frame 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 Equivalent Static Method of Analysis.
- For all models, the floor height is kept constant in order to get consistent results.
- In order to understand the behaviour of the building under lateral loads, the loads applied are as per provisions mentioned in IS 1893: 2016.
- Based on the results and responses from applied lateral and gravity loads, conclusions will be drawn based on various parameters such as Story Displacement, Story Drift, Story Stiffness, Applied Story Shear and Base Shear.
- Various design parameters of the building and material properties 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 (0-10^{th} Floor)	1000 mm * 1000 mm
Size of Columns (11^{th}-20^{th} Floor)	800 mm * 800 mm
Size of Columns (21^{st}-30^{th} 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]

ijates
ISSN 2348 - 7550

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)

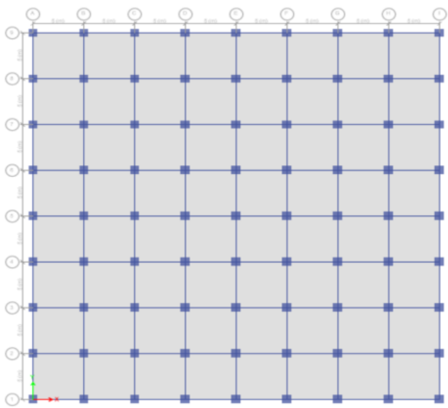


Fig. 1 Plan of CMRF

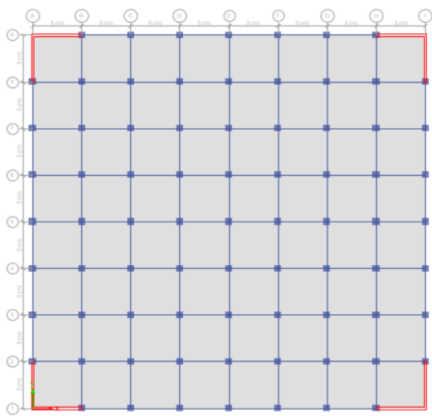


Fig. 2 Plan of SWF

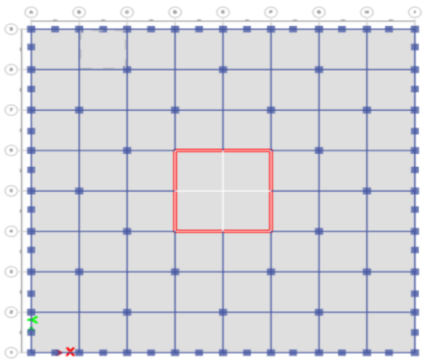


Fig. 3 Plan of TMF

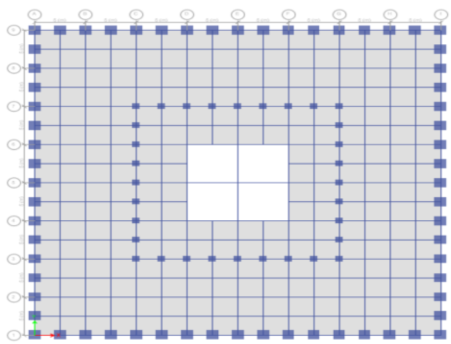


Fig. 4 Plan of TTS

4. ANALYSIS

The method of analysis used for the following research work is Equivalent Static Method of Analysis. The 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*: Story Displacement is defined as the total displacement of any particular story with respect to the ground.
- *Story Drift*: Story Drift is defined as the relative displacement between the floors above and/or below the story considered.
- *Story Stiffness*: It is generally defined as the ratio of story shear to story drift.
- *Story Shear*: It is defined as the sum of design lateral forces at all levels above the story considered.
- *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 Equivalent Static Method of Analysis on ETABS.

Table 3 Result for Conventional Moment Resisting Frame

Maximum Story Displacement	44.306
Maximum Story Drift	0.000751
Maximum Story Stiffness	7189594
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 Equivalent Static Method of Analysis on ETABS.

Table 4 Result for Shear Wall Framed System

Maximum Story Displacement	42.362
Maximum Story Drift	0.000613
Maximum Story Stiffness	11670772
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 Equivalent Static Method of Analysis on ETABS.

Table 5 Result for Tubed Mega Frame System

Maximum Story Displacement	31.539
Maximum Story Drift	0.000468
Maximum Story Stiffness	13715059
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 Equivalent Static Method of Analysis on ETABS.

Table 6 Result for Tube-In-Tube System

Maximum Story Displacement	30.558
Maximum Story Drift	0.000419
Maximum Story Stiffness	19509307.33
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
Equivalent Static Method of Analysis (EQx)	44.306	42.362	31.539	30.558
Equivalent Static Method of Analysis (EQy)	44.306	42.362	31.539	30.558

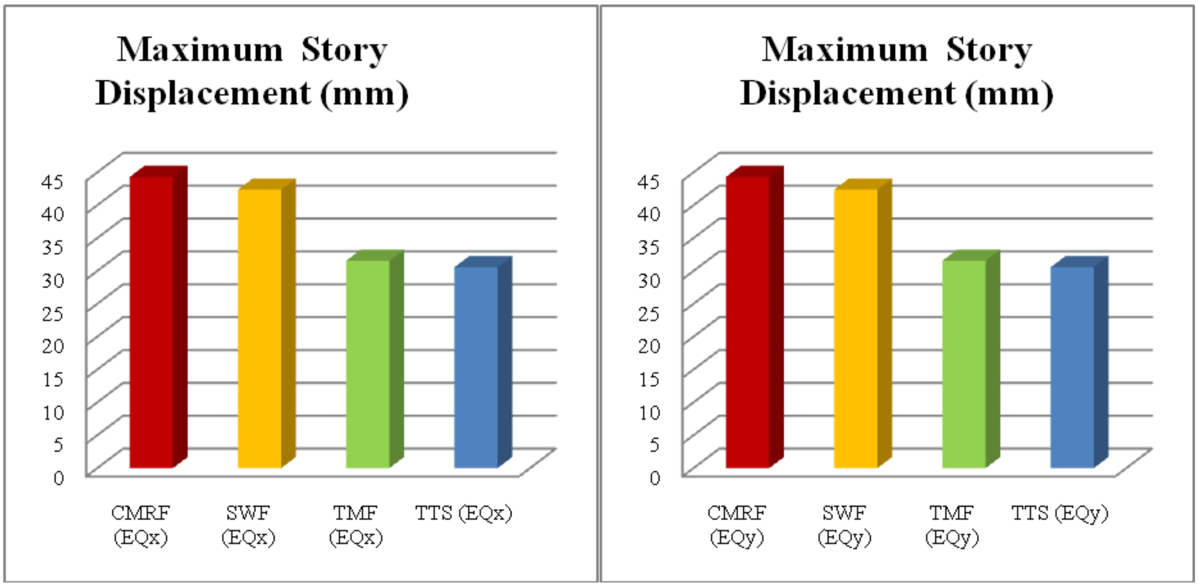


Fig. 5 Comparison of Maximum Story Displacement

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

Table 8 maximum Story Drift

	CMRF	SWF	TMF	TTS
Equivalent Static Method of Analysis (EQx)	0.000751	0.000613	0.000468	0.000419
Equivalent Static Method of Analysis (EQy)	0.000751	0.000613	0.000468	0.000419

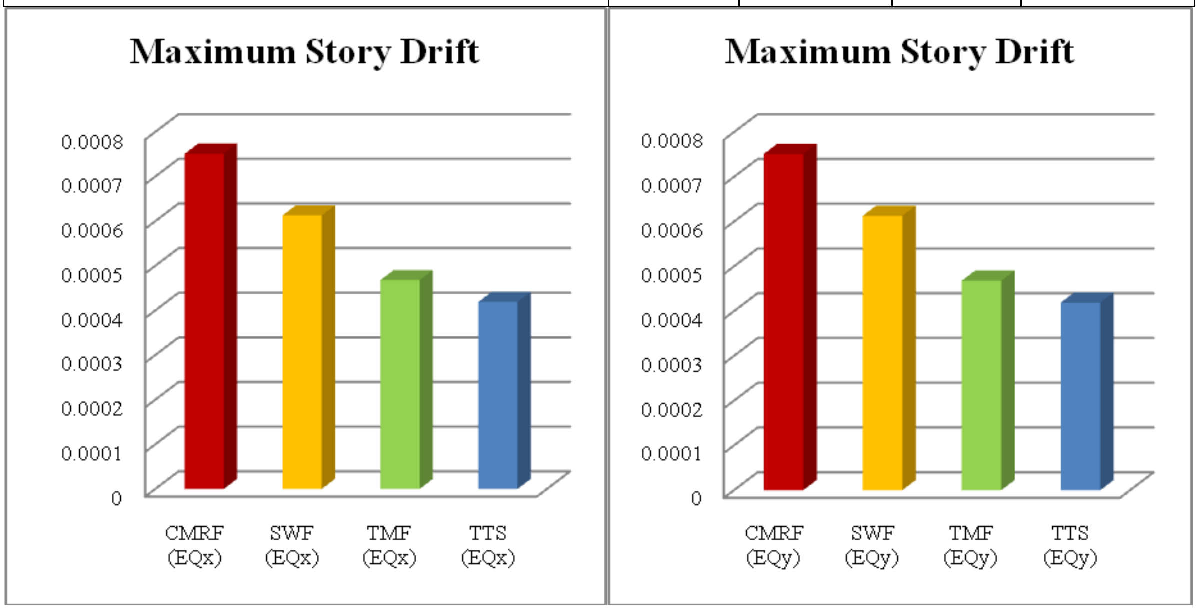


Figure 6 Comparison of Maximum Story Drift

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

International Journal of Advanced Technology in Engineering and Science
Vol. No. 09, Issue No. 08, August 2021
www.ijates.com
ijates
ISSN 2348 - 7550

Table 9 Maximum Story Stiffness

	CMRF	SWF	TMF	TTS
Equivalent Static Method of Analysis (EQx)	7189594	11670772	13715059	19509307.33
Equivalent Static Method of Analysis (EQy)	7189594	11670772	13715059	19509307.33

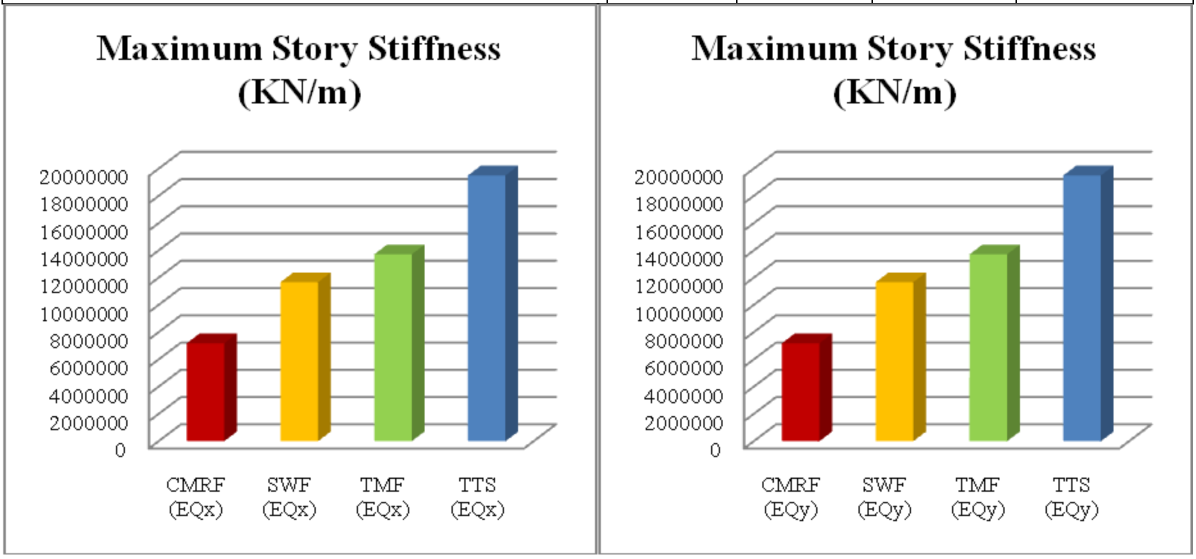


Fig. 7 Comparison of Maximum Story Stiffness

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

Table 10 Maximum Story Shear

	CMRF	SWF	TMF	TTS
Equivalent Static Method of Analysis (EQx)	516.8377	498.0166	301.6333	279.4895
Equivalent Static Method of Analysis (EQy)	516.8377	498.0166	301.6333	279.4895

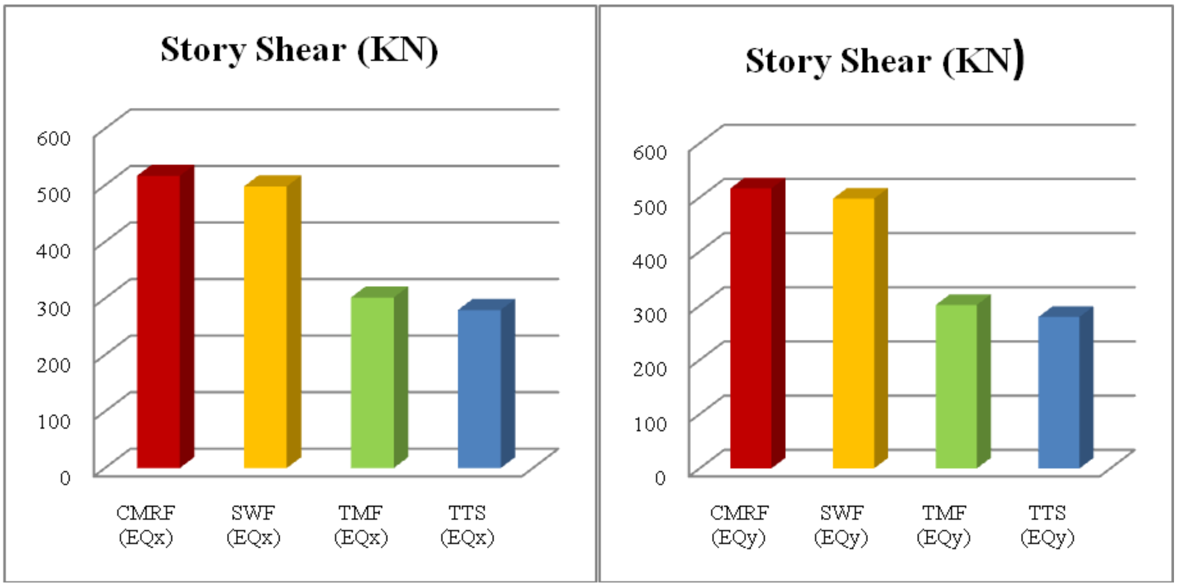


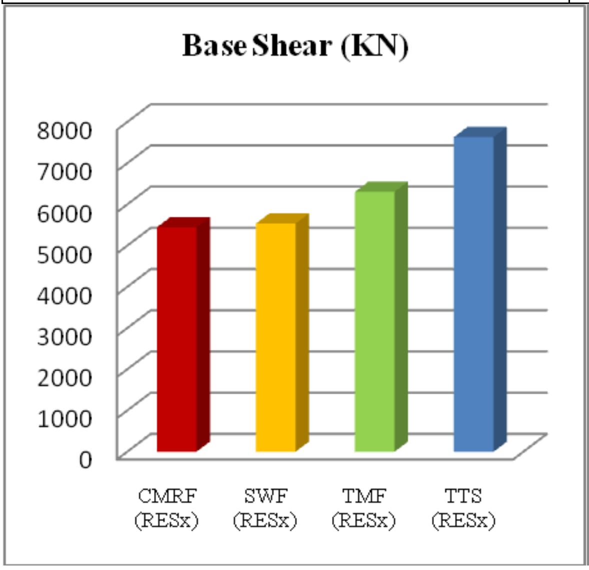
Fig. 8 Comparison of Maximum Story Shear

International Journal of Advanced Technology in Engineering and Science
Vol. No. 09, Issue No. 08, August 2021
www.ijates.com
ijates
ISSN 2348 - 7550

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

Table 11 Base Shear

	CMRF	SWF	TMF	TTS
Equivalent Static Method of Analysis (EQx)	5446.747	5535.9258	6306.7108	7636.027
Equivalent Static Method of Analysis (EQy)	5446.747	5535.9258	6306.7108	7636.027



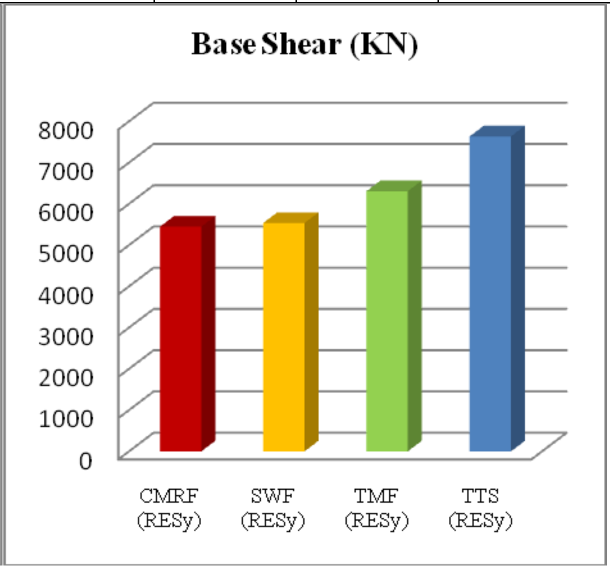


Figure 9 Comparison of Base Shear

7. CONCLUSIONS

The Equivalent Static Method of Analysis was considered for analysis of 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 Equivalent Static Method of 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 Equivalent Static Method of Analysis, Tube-In-Tube Structure shows 31.03%, 27.86% and 3.11% 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 44.21%, 31.65% and 10.47% 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 63.15%, 40.18% and 29.7% 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 other systems considered.

REFERENCES

1. Archana, Reshmi P R, "Comparative Study on Tube in Tube Structures and Tubed Mega Frames", *International Journal of Innovative Research in Science, Engineering and Technology*. (IJIRSET) (2016).
2. Balakrishnan, S. and James, R.M., "Comparative Study on Tube In Tube And Tubed Mega Frames On Different Building Geometry Using ETABS", *International Journal of Applied Engineering Research* (IJAER) (2019).
3. Gunadeep. Ch, "Comparative study of shear wall system and mega framed tube system in high rise buildings", *International Conference on Emerging Trends on Engineering Science, Technology And Management*. (ICRTESTM) (2017).
4. Ibrahim, A.A. and Dr. Ramana Rao, N. V., "A Comparative Study between the Use of Framed Shear Wall System and Framed Tube System in Tall Buildings", *International Journal & Magazine of Engineering, Technology, Management and Research*. (IJMETMR) (2015).
5. Naik, B.H. and Suresh Chandra, B.S., "Comparative Analysis between Tube in Tube Structure and Conventional Moment Resisting Frame", *International Research Journal of Engineering and Technology* (IRJET) (2017).
6. Singh, S., Lata, N., Dr. Nagar, B. and Kumar, R., "Comparative Analysis of RCC Structure and Tube-In-Tube Structure", *International Research Journal of Engineering and Technology* (IRJET) (2019).
7. Wadagule, S. R. and Charantimath, V. R., "Comparative Study of Tube in Tube Structure and Frame Tube Structure", *International Research Journal of Engineering and Technology* (IRJET) (2017).
8. IS 456:2000, *Code of practice for Plain and Reinforced Concrete*, BIS, New Delhi.
9. Bureau of Indian Standards: IS-1893, part 1 (2016): *Criteria for Earthquake Resistant Design of Structures: Part 1 General provisions and Buildings*, New Delhi, India.
10. IS 875 (part 1): 1987 - "*Code of practice for design loads (Other than earthquake) for Buildings and structures - Dead loads* ", Indian Standards, New Delhi.
11. IS 875 (part 2): 1987 - "*Code of practice for design loads (Other than earthquake) for Buildings and structures - Imposed loads* ", Indian Standards, New Delhi.
12. IS 16700:2017, "*Criteria for Structural Safety of Tall Concrete Buildings*".