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Seismic analysis of reinforced concrete tubular structures with lateral load resisting systems in high rise buildings

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Abstract

The development of efficient structural systems, the need for vertical expansion due to urban land constraints, and the fast-expanding population all had a role in the proliferation of high-rise buildings throughout the world. In addition to gravity pressures, lateral loads like earthquake and wind loads must be taken into account while building high-rise structures. To properly handle the effects of lateral loads, structural engineers were asked to design lateral load resisting systems with adequate tubular structural shapes. A strong structural system for resisting lateral loads is more important for structural efficiency and safety. Extended three-dimensional analysis of building systems (ETABS) software was used to develop and analyse the research models under the load combinations prescribed in IS: 1893 (Part 1)-2016. The response spectrum analysis method was used to record the seismic reactions. Results for story displacement, storey shear, and story drift are compared along both lateral directions. A comparison is also made between the model's base shear and mass participation factor results. Two types of reinforced concrete tubular constructions, framed tube and tube in tube structures, with various lateral load resisting systems, were thoroughly compared. A comparison was made between the seismic behaviour of several types of reinforced concrete tube structures. Tube in tube constructions with bracing models performed better than frame tube constructions. X braced framed tube structures and tube in tube structures with V bracing outperformed all other structural models that were tested.

Keywords

Tubular system, Framed tube, Bundled tube, High rise building, Lateral loads, Bracings, Shear wall, Seismic response.

1.Introduction

In recent years, there has been a noticeable increase in demand for high-rise building development with increased slenderness and decreased building weight [1]. Due to population growth, there has been more construction, fast industrialization, and the concomitant lack of land, particularly in urban areas. The consequences of lateral stresses deteriorate with increasing structural height. Building high-rise structures requires taking into account lateral loads in addition to the gravity force, such as earthquake and wind loads [2].

High rise buildings have implemented a variety of lateral load resisting techniques to improve performance against all these loads [3]. As the building rises in height, the right structural system for resisting lateral loads becomes increasingly crucial [4]. Extremely high strains and deflections are caused by lateral forces. Structures must therefore be able to withstand vertical forces and rigid enough to withstand horizontal loads [5].

Similar to a hollow cylinder, the tubular system in structural engineering cantilevers perpendicular to the ground. In tall buildings, the tubular system is widely

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employed and regarded as a better lateral load resisting method [6].

In the 1960s, Engineer Fazlur Rahman Khan initially developed this system and classified building structural systems according to their heights [7].

To increase structural safety, contemporary construction techniques and structural technology will be applied. When lateral load resisting components are chosen and arranged in a beneficial location within the building, then they are effective [8−10]. Tubular buildings are a relatively novel structural concept in high-rise construction [11]. The outer perimeter of columns is meant to resist lateral effects in a framed tube and tube in tube constructions, whereas the inner columns and floors are assumed to take gravity loads [12]. By effectively coupling these structural forms, the lateral stiffness of the outer mega frame and the inside core tube is greatly balanced [13].

Seismic design's primary goal is to withstand lateral stresses during an earthquake and possibly reduce the loss of life and acceptable structural damage but collapse should be prevented [14].

The following are shortcomings of existing seismic analysis:

Because high-rise buildings are susceptible to lateral forces, they should be designed with sufficient lateral stiffness, strength, and ductility. Such provisions call for lateral load resisting elements. Therefore, a specific lateral load resisting system configured appropriately for tubular construction is crucial to the performance of high-rise buildings. To limit the tolerable damage in terms of excessive displacements, drifts, etc. in comparison to the conventional framed construction, the appropriate system for tubular buildings must be identified or suggested.

This paper aims to investigate the seismic performance of various tubular buildings viz., framed tube and tube in tube building configurations adopting several kinds of bracing systems viz., X bracing, V bracing and inverted V bracing by providing shear wall at the central core and at the corners and sides. Tubular building models were developed using extended three dimensional analysis of building systems software (ETABS). To capture the dynamic responses, response spectrum analysis is adopted in the study.

Over the past few decades, a number of structural shapes have been created to guarantee the stability of the structure under lateral forces. To protect structures from the impacts of lateral loads, many structural systems are used. The kind of system available and the right selection of high-rise constructions have a significant impact on the structure's behaviour.

Investigating the seismic behaviour of high-rise tubular structure buildings using diverse load resisting systems is the primary goal of this study. This could be useful for quantifying the appropriate lateral load system needed for the safe and stable performance of high-rise structures under lateral loads.

The structure of the article is as follows. Section 2 provides a thorough review of the current study topic. Summary of the literature review is also discussed here. Problem description and methodology adopted in the study are presented in section 3. Also, Section 3 lists the common building layouts that were taken into consideration for this study. The outcomes are presented in section 4. Discussion of the findings and analytical work done in the current study as a whole reported in section 5 and section 5.1 presents the study's shortcomings, and sections 6 discuss concluding remarks and future research.

2.Literature review

In its simplest tubular form, as part of the building's external perimeter, the construction is made up by closely large spandrel beams that link separated columns.

Tubular structures can be further categorized into following categories:

a) Framed Tube structures: The adherence is offered with a rigid frame that forms a tube surrounding the structure's outside [15, 16]. The building's perimeter is made up of columns with small spacing joined by deep spandrel beams in this design. The system is a natural development of the moment resistant frame, in which beam and column firmness is considerably boosted by narrowing the span and deepening the members.
b) Tube-in-Tube structures: is made up of a superficial-framed tube and an inside tube. In high-rise buildings, the outer and inner tubes work together to resist gravity and lateral loading. However, because of its much higher structural depth, the outer tube frequently takes centre stage. These types of building are also known as Hull

(exterior) and Core (cerebral) constructions [15, 16].

c) Braced Tube structures: Cross bracing the frame with bracing over multiple storeys can improve the tubular system even more. The braces in a tubular transfer the axial force from the very strained columns to the least, thus eliminating load stress disparities in the columns [15, 16].

d) Bundled Tube structures: It can be thought of as a collection of independent tubes that come together to form a multiple-cell tube. The method allows for the biggest floor area and the greatest height. The capacity to modify the cells vertically can generate a powerful vocabulary for a range of dynamic designs, giving architects a lot of leeway when designing tall buildings [15, 16].

Staged construction and one step investigation for reinforced concrete (RC) tall structure with several systems that endure lateral loads was carried out to satisfy both service and ultimate state design [17]. A 16-story structure with plain frame, tube in tube construction with tubes in the middle and core, coupled with the tube mega frame, was subjected to wind and seismic loads using ETABS to conduct a comparative analysis [18]. The seismic parameters were recorded using the comparable static force approach and response spectrum analysis. When compared to the other frame types considered in the analysis, the tube in the tube structure with central tubes was found to be a highly effective structural system.

Seismic response and natural frequency of various tube systems induced structural systems were analysed to assess best appropriate structural arrangements for tall buildings [19].

Utilizing ETABS software, a dynamic analysis of an 88-story high tubular steel structure is performed for a variety of geometric configurations, including a traditional frame and square, rectangle, triangular, and hexagon form [20]. Time history analysis, the equivalent static force method, and wind load analysis were used to forecast the dynamic behaviour of high-rise tubulars based on section patterns. Seismic zone II and Terrain Category 4 were taken into account when creating the study models. The research shows that when exposed to lateral loads in high-rise structures, tubular constructions can outperform conventional beam column moment resistant frame steel systems. In comparison to other structural systems, hexagonal tube architectures have been found to function better.

X bracings and varying column spacing were used in a comparison research of the behaviour of tube-in-tube structures [21]. The seismic responses were computed using the time history method and the equivalent static force approach. Studies reveal that it is significantly sturdy in terms of lateral loads when compared to a conventional structure in terms of efficiency. According to the study, tube-in-tube systems possess a strong resistance to horizontal loads. However, because of shear lag, the corner parts receive greater axial loads when they come into contact with parallel loads, like wind loads.

A range of structural models with 30, 40, 50, and 60 storeys, with shear wall, and framed tube, was used to study the effects of lateral load on high-rise structures [22]. The study indicated that shear wall systems were particularly good at resisting lateral loads up to 30 stories, but that framed tube systems were superior at resisting lateral stresses above 30 stories.

Using structural analysis programme (SAP 2000) software, multiple shapes of tube in tube construction (square and rectangular) were analysed with varied inner core positions in a fifty-story steel moment resisting frame building [23]. The results show that a square-shaped system with a central core is the optimum system for withstanding the characteristics under consideration.

A 25-story, tubular, frame building located in various seismic zones was subjected to seismic study [24]. Various slab types, including membranes, are used to mimic tubular structures with rigid diaphragms. The results indicate that because moment resisting frames have a larger interior floor area, less core bracing, and weaker columns, they are less effective at minimising displacements than framed tube frameworks. In terms of the efficient use of materials, it was also recommended that a tubular structure is more economical.

Nonlinear behaviour of twenty storey bundled tube structure was investigated for far and near field aftershocks to capture the seismic response [25]. A 60-story skyscraper constructed with a variety of lateral load-bearing tubes and situated in zones II and V was the focus of a seismic investigation [26]. In tube structures, moment resisting frames can be found in triangular, rectangle, square, and hexagonal configurations.

A spectrum examination of a response and equivalent static force approach were used to record the seismic properties. Additionally, it was found that tube in tube construction is superior to other structural kinds in terms of lowering storey displacements.

In order to examine the impact of shear walls at the middle and exterior of 40 storey structure in India's earthquake zone V, ETABS software was utilised [27]. The seismic reactions were recorded using the response spectrum method. The study discovered that shear walls significantly outperform structural systems without them in their ability to withstand earthquake-induced lateral forces. It was mentioned that the shear wall positioning is crucial for minimising the effects of displacements and drifts. The ideal seismic analysis was predicted using a life cost study of steel framed tube buildings in various configurations [28].

In a study, the shear lag behaviour of braced tube, pure tube structural systems, and various X-diagonal bracing types were compared [29]. Structural analysis and design project (STAAD Pro) software was used to do dynamic analysis on the models. The efficiency of each method is used to estimate shear lag, construction was evaluated adopting a linear analysis. The results show that adding diagonal braced components to strengthen framed buildings enhances structural stiffness, decrease storey drift, and remove shear lag in tubular frameworks under lateral loads. Six RC framed tube models with loaded 40 and 60 storeys were used to evaluate the impact of plan geometry on the shear lag under seismic loads [30]. Various plan shapes were investigated for this inquiry to be able to capture the shear lag output of tube frames for each form. According to the research, framed tube buildings' geometry and form significantly affect the shear lag effect.

The behaviour of tubes in tube systems subjected to lateral loads and various interior tube placements was investigated using the SAP 2000 programme [31]. Seismic factors, including storey displacement and storey drift were compared using diverse analyses. The outcomes show that time history analysis, contrary to analogous static analysis and response spectrum analysis, more accurately predicts structural reaction. The most common structural forms for high-rise buildings were investigated by researchers [32]. The benefits of structural systems were examined, as well as a practical method for boosting the rigidity and adherence of frame systems by including a variety of structural shapes. ETABS software was used to compare a 20-storey conventional framed structure and a diagrid structure that had been subjected to earthquake load [33]. Development of models adheres to the design principles of IS: 456-2000. According to the research, diagrid systems were proven to be more effective than conventional frame structures at reducing storey drifts and shears. The 150 m tall rectangular plan bundled tube and framed tube buildings' seismic performance was examined using the Response spectrum technique [34]. Construction sites were thought to be in zones IV and V. The modal combinations were created employing a complete quadratic combination approach (CQC method). The seismic characteristics are modelled using IS: 1893-2016. According to the study, bundled tube structures are more resilient to earthquakes than framed tube and conventional frame buildings in both zones.

The performance of a tubed mega frame system with various building configurations subjected to lateral stresses and a 40-story skyscraper with a tube in tube construction were compared [35]. Seismic properties tubulars were contrasted with various geometries. There is evidence that tube in tube constructions, as opposed to tubed mega frames, provides a stronger structural foundation for tall buildings because they have less storey displacement, storey drift, and storey shear.

Employing ETABS, a parametric assessment of the dynamic performance of a 40-story moment-resisting skyscraper and a tube in Tube building was conducted [36]. The supposed location of the structural models is Zone IV. The construction models were examined using a continuum technique. The seismic study's conclusions indicate that moment-resistant frame designs are less effective at withstanding seismic loads than normal tube-in-tube models with smaller storey drifts and storey displacements.

In India's various seismic zones, it was examined how 26-story RC-framed tube buildings with stiff diaphragms responded to earthquakes [37]. Using response spectrum analysis, the seismic responses of diverse structural systems were compared. The study found that the study models' seismic reactions were better withstood by framed tube structures than by conventional framed buildings. More lateral strains have been proven to be carried by tubular constructions than by conventionally constructed buildings. The fragile beam and sturdy column paradigm are used to undertake the seismic research of a 33-story tall building with tubular structures in seismic zone IV [38]. For seismic analysis, an analogous static force technique was used. Modelling and analysis are done with STAAD Pro software. It has been demonstrated that frame-type tube structures and tube-in-tube designs are more efficient at reducing storey displacement and drift than conventional moment-resistant frames.

For evaluating a 40-story skyscraper's dynamic reaction to blast loading, a straightforward technique was put forth [39]. Framed tube, outrigger-belt truss positioned at various building heights, and a shear core were used to represent the structure. In this study, there were attempts to replicate a tall building as an idealised beam with a single degree of freedom (SDOF) adopting an energy principle. The proposed method was shown to be reasonably suitable for capturing the actions of tall buildings whilst blast loading when compared to the finite element method.
Dynamic analysis of a tall tubular building of eight diverse configurations consists of twenty-five floors with central core was carried out [40]. The analyses were performed utilising ETABS software adopting response spectrum analysis and several seismic parameters were determined. From the study discovered that, the central core exhibited improved performance with added stiffness to the structural systems in reducing the displacement significantly, which in turn reduced the period of oscillation of structure. Also, outrigger system found to be the one of the efficient lateral resisting system.

Seismic performance of the braced tube structure with internal tube at various positions was investigated using ETABS software [41]. The equivalent static force method was adopted to determine the seismic parameters. From the study results, it was evident that, tube structures are performed better against lateral loads in reducing the displacements. Seismic performance of tall steel structures with diagrid structures was assessed. Time history and pushover analyses were taken up to capture the various seismic parameters [42]. Study results showed that the higher energy dissipation of diagrid structures with better seismic performance because of improved stability of structures due to diagrid. This may be the reason for reduced lateral displacements with high energy absorption. Seismic analysis of variety of tubular structures of various floors with diverse beam – end connections was carried out [43]. The different reinforcement ratio was adopted for inner core tube. Seismic fragility curves and damage evaluation indices were developed with the help of probabilistic seismic demand models. For this nonlinear dynamic analysis was made use of. Study results demonstrate the usefulness of fragility curves and ductility with drift ratio.

Seismic performance of the super tall building made with concrete encased tubes and middle steel tube with rigid and hinged connections was investigated [44]. A shaking table test was carried out to assess the performance of sixty-eight storey building. The large rotating ability was observed in hinged connection and with bolted joints, lateral stiffness found to be less. This may be the reason for larger periods in general core tube structures.

Comparative investigation of dynamic performance of various tubular tall buildings was carried out using ETABS software [45]. For the study purpose, the structures are presumed to be located in the diverse seismic locality with different soil strata. Study results showed that, framed tube and tube in tube structures performed far superior to the regular framed structure as far as various seismic parameters investigated in the study.

Performance of diagrid structure against lateral stiffness for the evaluation of seismic damage was investigated for tall buildings [46]. Fragility curves were derived using a performance-based approach, taking into account code specified limiting value as for as seismic damage is concerned. For the study, there was no denying that the diagrids showed improved efficiency with large lateral stiffness and reduced lateral displacement.

According to the literature review, in order to control the structural response against lateral loading in high-rise structures, fill-ins, effective structural forms, and additional dampness can be used to raise the building weight, stiffness, and density of the structural system (tuned mass dampers).The seismic performance of ten-story RC tubular structural forms like framed tube in tube structures with various lateral load resisting systems like shear wall at core and corners, V, inverted V, and X bracings was compared in this study under the influence of lateral loads as well as gravitational loads.

3.Materials and Methods

For the analysis, RC tubular structures such as a framed tube and tube in tube structures with various lateral systems like a shear wall at core, corners, and three distinct bracings are used. RC structures of ten stories, each having a 3 m floor height, an open ground floor, and brick infill walls in top storey are used in the study. There are 11 bays in the X direction and 4 bays in the Y direction, with a c/c distance of 4 m in both directions. The structures are located in Mangalore, Zone III. The slab is 150 mm thick, while the given shear wall is 200 mm thick. The seismic effects were collected using the response spectrum analysis strategy, which was one of several approaches available. The building's layout and loads to be considered are as follows: *Table 1* shows the geometrical properties of tubular structures used herein. *Figure 1* displays the complete procedure for the methodology adopted in the current research to analyze seismic performance of tubular structures under investigation using the response spectrum method.

Figure 2 displays the plan configuration of framed tubular structure with shear wall at its center and *Figure 3* displays its 3D view.

Table 1 Sectional properties of tubular structures considered

Description	Building configuration for	
	Framed tube structure	**Tube in tube structure**
Column size	800 mm × 800 mm	500 mm × 500 mm (Exterior and Interior Columns)
Exterior peripheral beam	230 mm × 600 mm	230 mm × 600 mm (Exterior and Interior Peripheral beam)
Interior main beam	230mm × 900 mm	230 mm × 600 mm
Interior secondary beam	230mm × 450 mm	230 mm × 450 mm

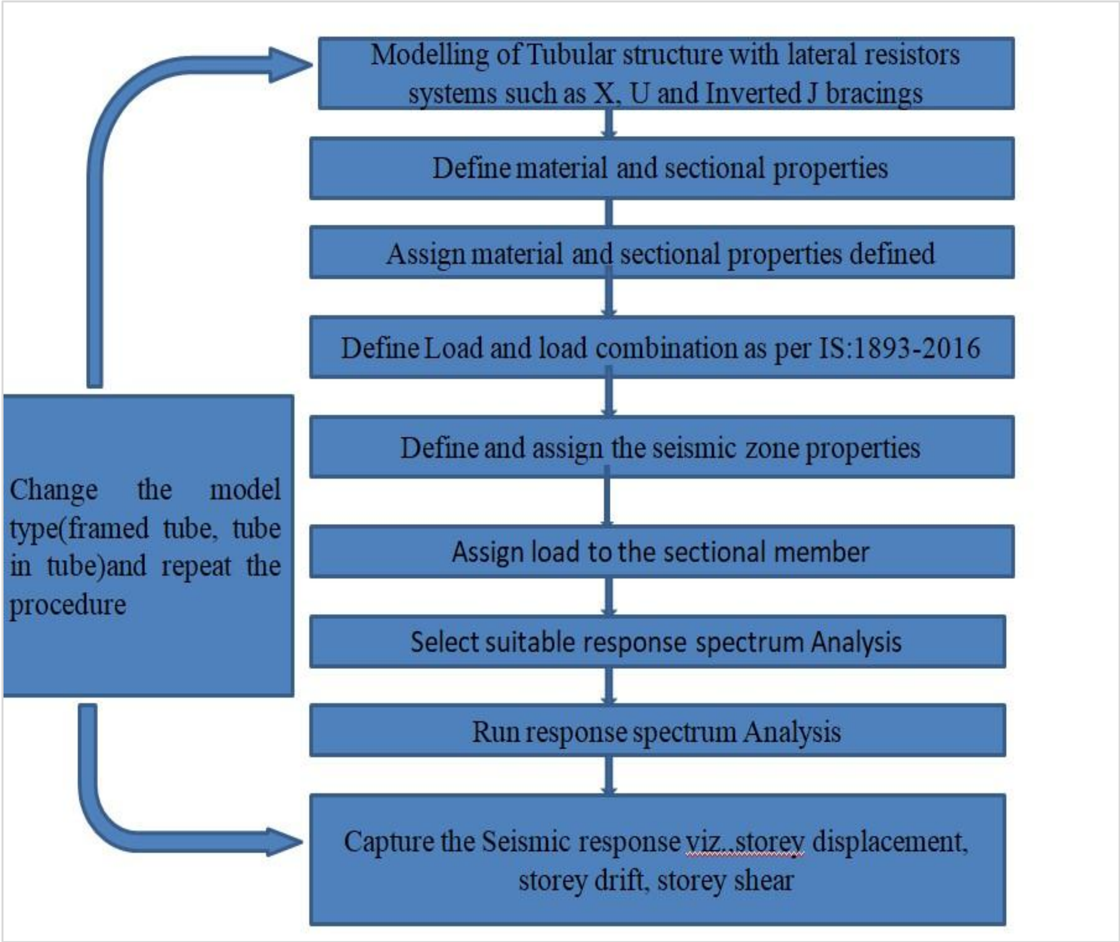

Figure 1 Flow chart/ Block diagram of the methodology adopted in the in the current research

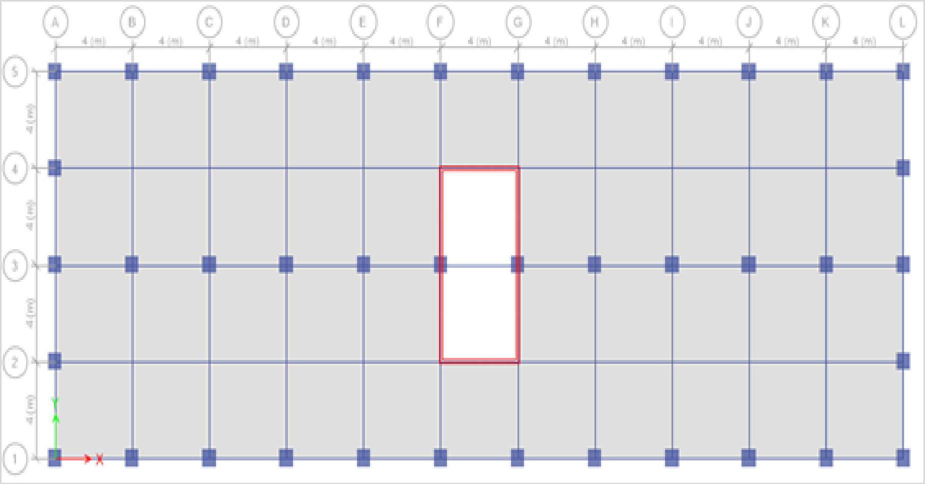

Figure 2 Plan of framed tube structure with core shear wall

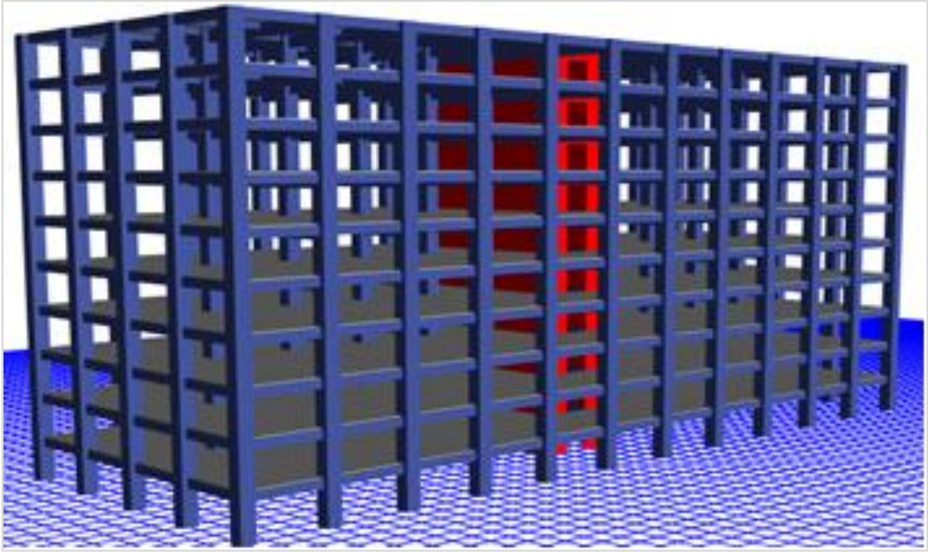

Figure 3 3D View of structural skeleton of framed tube structure with core shear wall

Along with the above arrangement, the performance of a framed tube construction with 200 mm thick shear walls on the sides and corners, X, V, and inverted V bracings in the building's periphery is also investigated.

Figure 4 shows the plan configuration of framed tube structure with Shear wall at core, corners and side and *Figure 5* displays 3D view of framed tube building with X bracing.

Figure 6 and *Figure 7* shows 3D view of framed tube structures with V bracing and inverted V bracing respectively.

Figure 8 shows the planned configuration of tube encased with shear wall at its centre and *Figure 9* displays its 3D view.

Along with the above configuration the performance of the framed tube structure with Shear wall at the sides and corner of 200 mm thickness, X bracings, V bracings and inverted V bracings in the periphery of the building is also studied.

Figure 10 shows the planned configuration of tube encased Shear wall at core, corners and side.

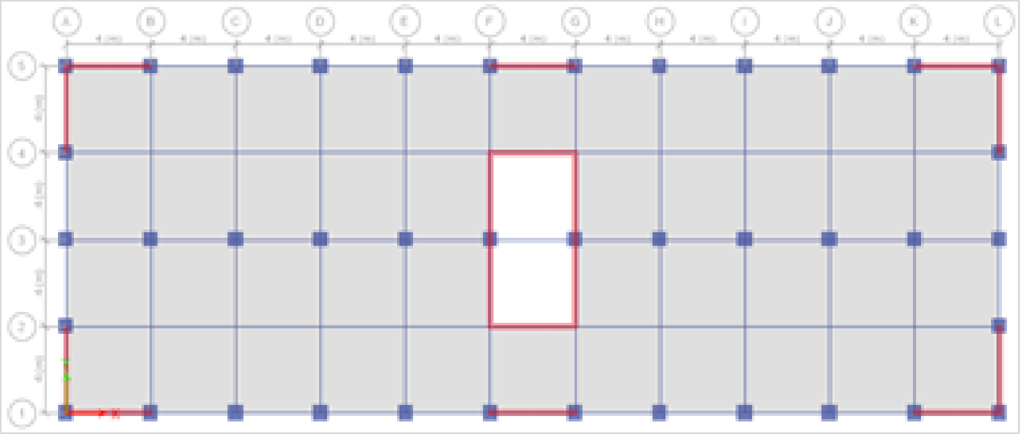

Figure 4 Plan of framed tube structure with shear wall at core, corners and side

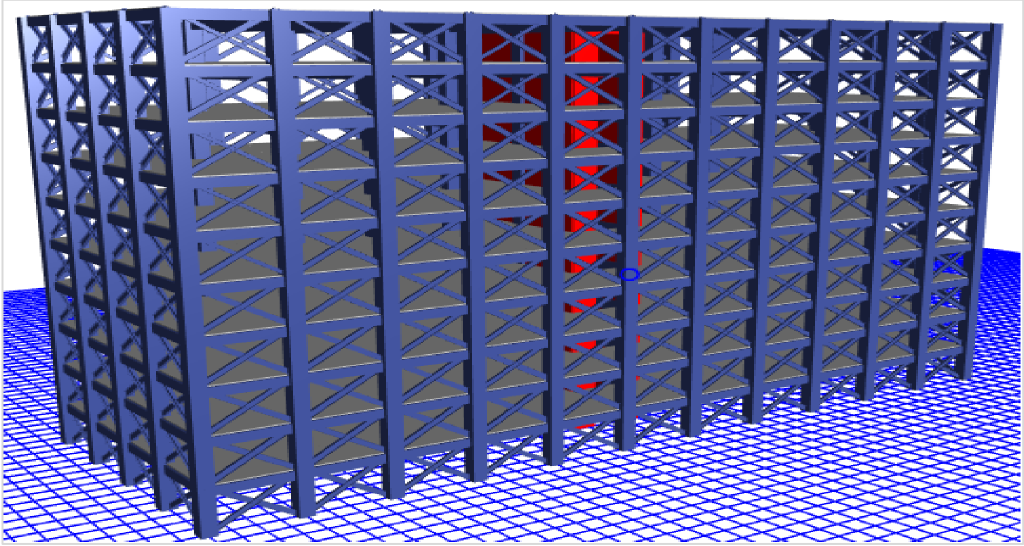

Figure 5 3D View of structural skeleton of framed tube structure with X bracings

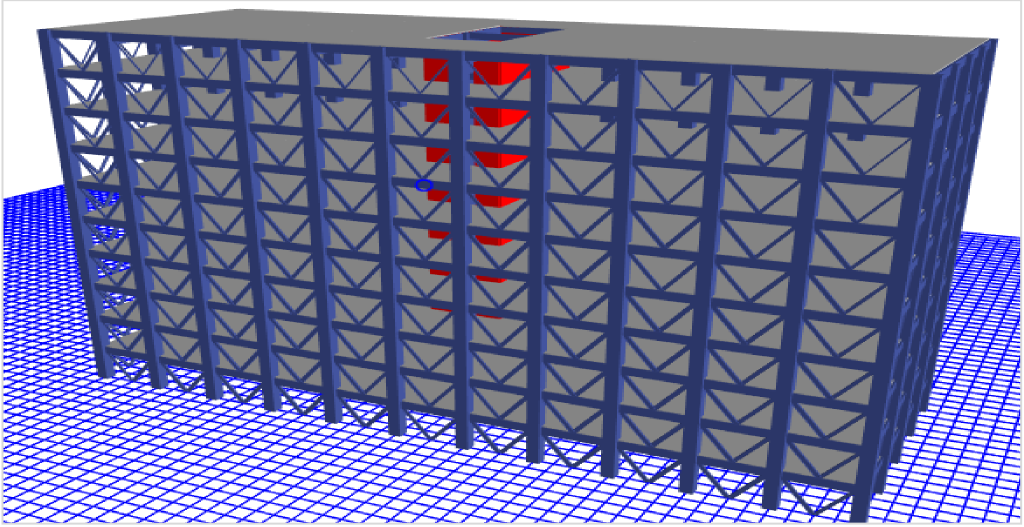

Figure 6 3D View of structural skeleton of framed tube structure with V bracings

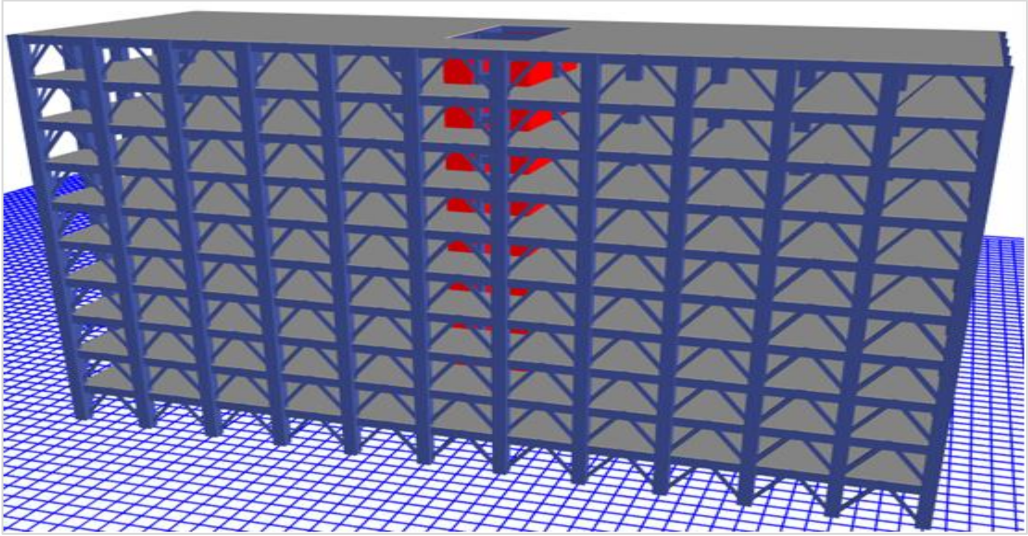

Figure 7 3D View of structural skeleton of framed tube structure with Inverted V bracings

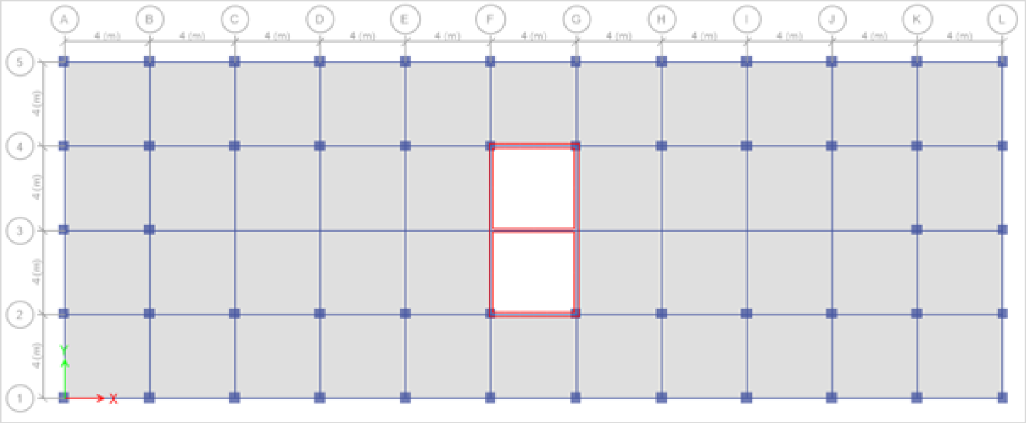

Figure 8 Plan of tube in tube structure with core shear wall

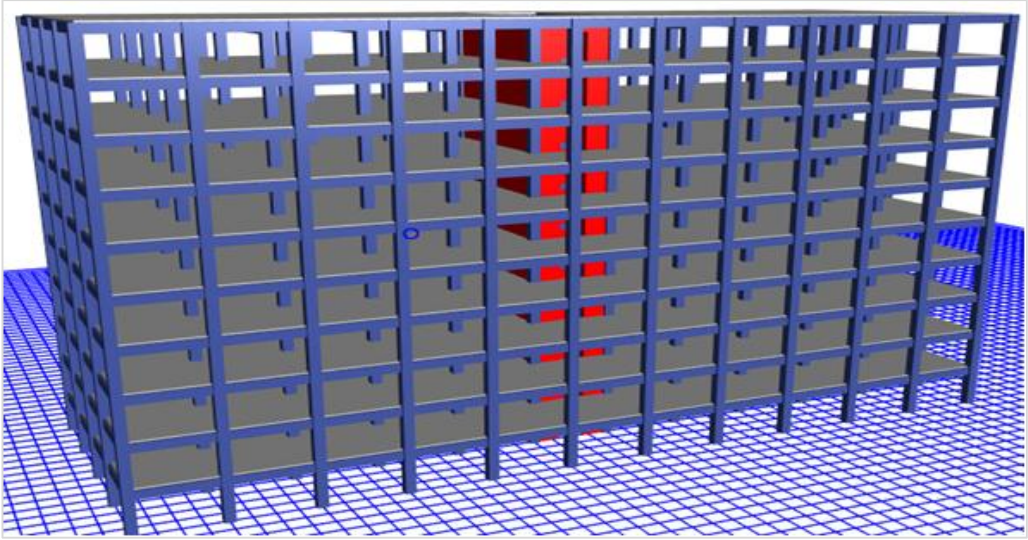

Figure 9 3D views of structural skeleton of tube in tube structure with core shear wall

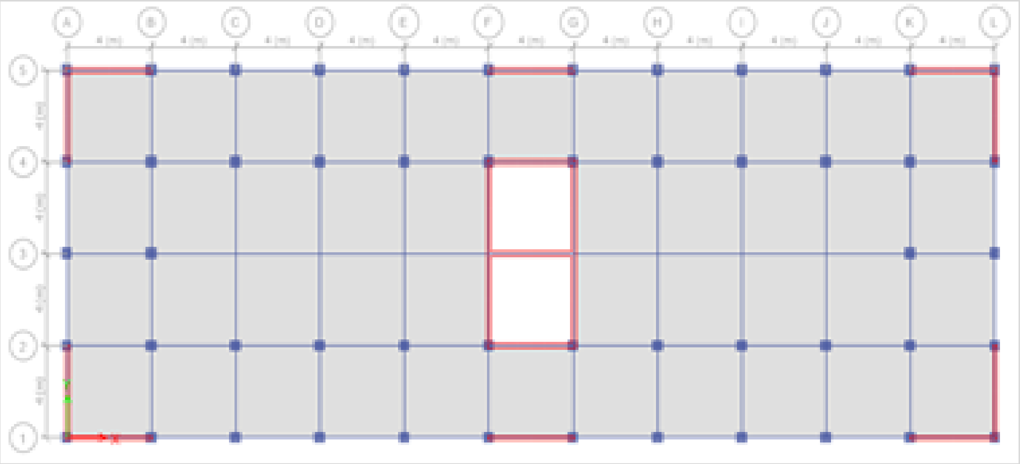

Figure 10 Layout of Tube in tube structure with shear wall at core, corners and side

Loads considered: Loads considered are same for all type of structures modelled.

Gravitational loads were considered as per IS [47−49]. Load combinations have been considered as per [50]. The study models are in accordance with the design aspects of IS: 456-2000 [51]. The values are reported for critical load combination. The seismic parameters considered are:
Location: Mangalore, Karnataka, India
Seismic Zone: III Seismic Zone factor: 0.16.
Importance factor: 1.5. Response reduction factor: 5.

4.Results

ETABS software was used to model and analyze the study models under the load combinations specified. The seismic reactions were captured by response spectrum analysis approach method. The following are the outcomes of the model's investigation.

4.1Storey displacements

In the case of tall constructions, storey displacement against lateral load is an important criterion for stability. The storey displacement regards to its base is known as storey displacement and it should not cross H/500, where H is the structure's whole height. All of the models are in the permissible displacement range.

Figures 11 and *12* show the displacements in X and Y directions for framed tube constructions with various lateral resisting systems. Maximum displacements were found at the higher storeys, with nil at the bottom. The displacement was higher in the highest storey of framed tube structures in the X direction decreased in the order of structure with a core shear wall, at corners, structure with V bracing, and structure with inverted V bracing, followed by structure with X bracing, as shown in *Figure 13.*

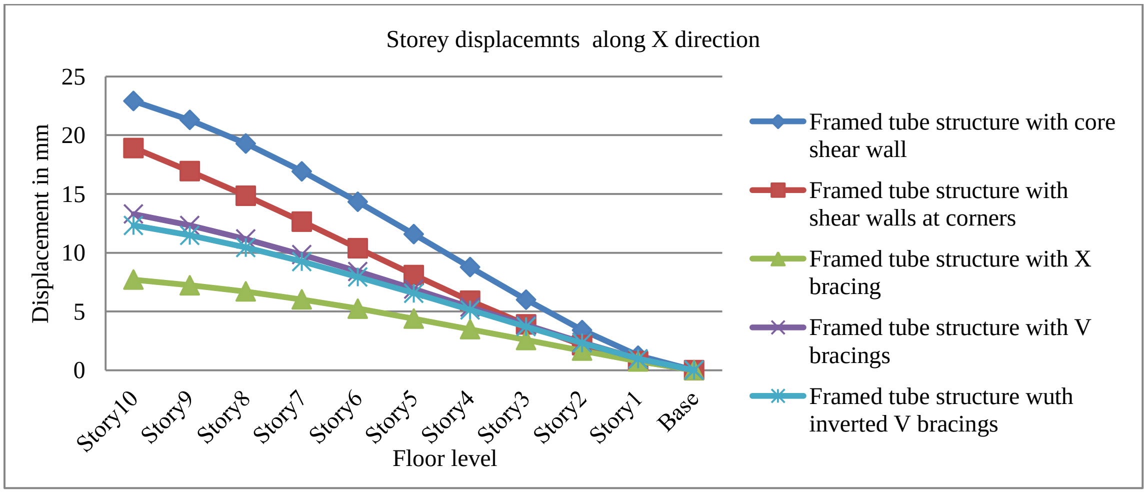

Figure 11 Storey displacements for framed tube structures along X direction

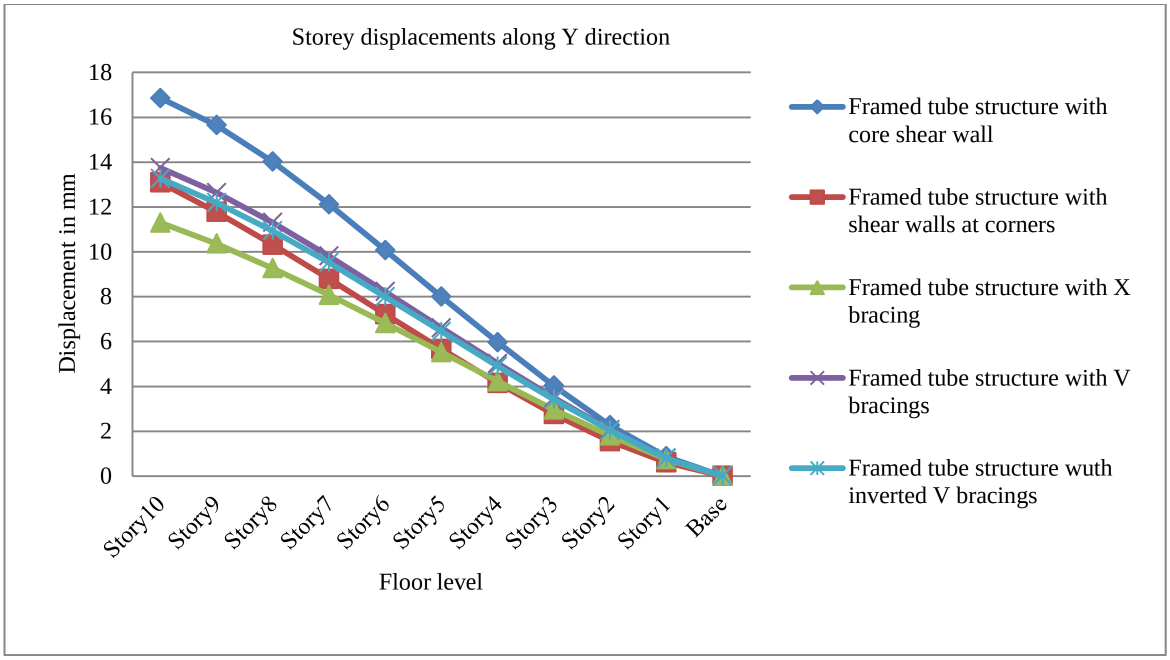

Figure 12 Storey displacements for framed tube structures along Y direction

Figures 13 and *14* shows the storey displacements, as well as the X and Y directions, for the tube in tube construction with various lateral resisting systems. *Figure 15* shows that the higher displacement at highest storey of a tube in tube structure along the X direction decreased in the sequence of core shear wall, shear wall at the corners, X and inverted V bracing, followed by V bracing.

For tube in tube structures, the fluctuation in storey displacement followed a similar trend as in *Figure 16.* When versus other structures, the tube in the tube structure with V bracings in its peripheral showed the least displacement in its top storey, while the core shear wall structure showed the most storey displacement.

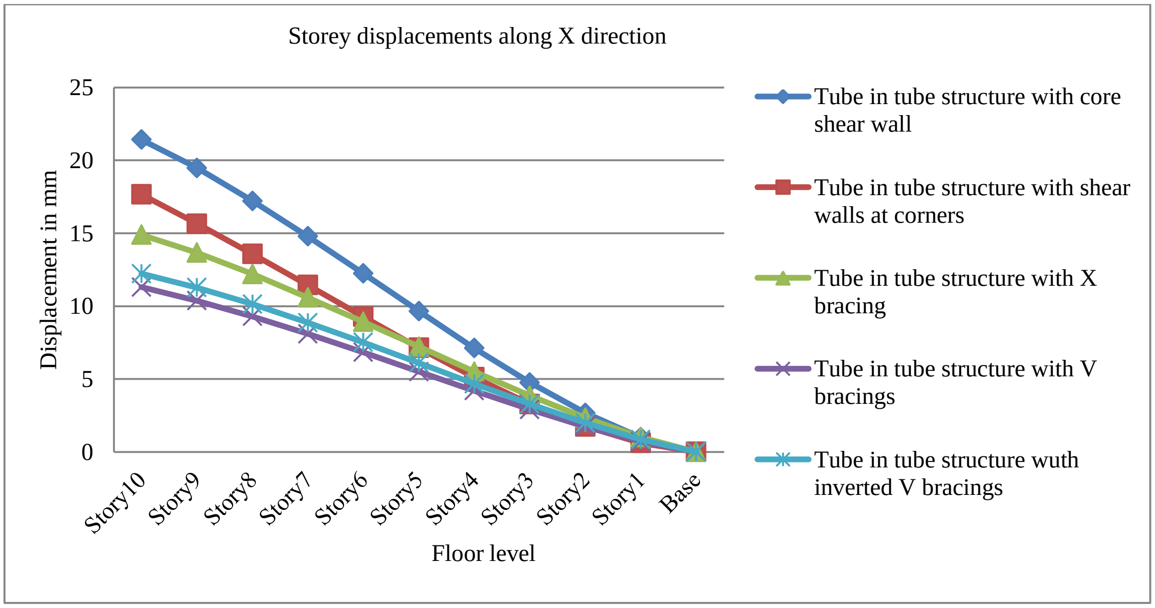

Figure 13 Storey displacements for tube in tube structures along X direction

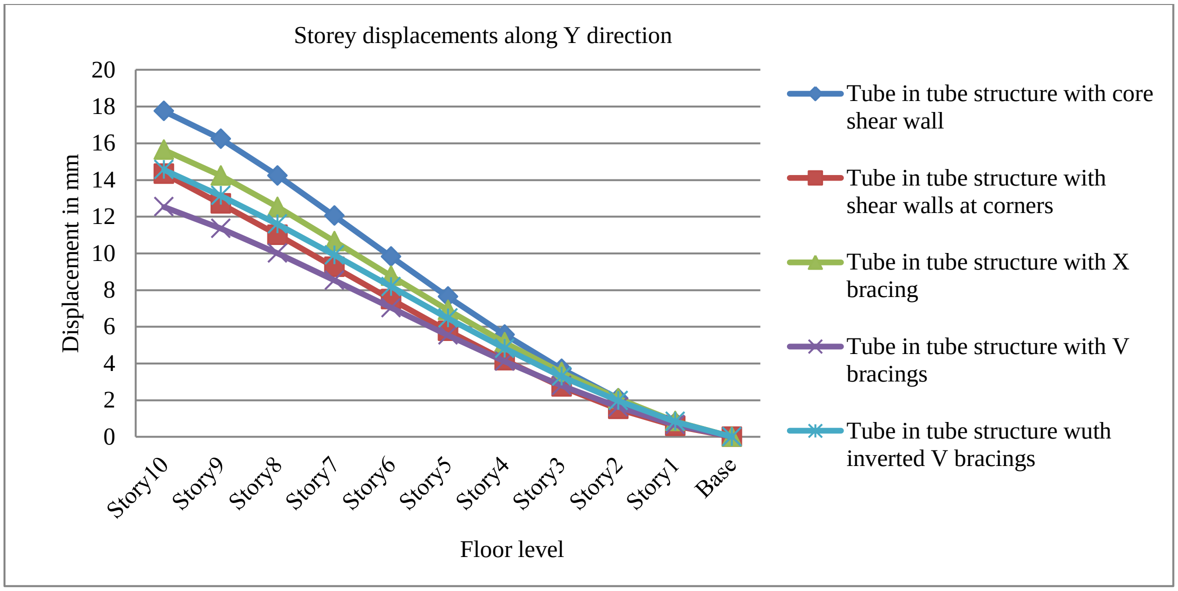

Figure 14 Storey displacements for tube in tube structures along Y direction

4.2The story drifts

It's a floor displacement under consideration in proportion to the storey displacement of the level above or below it. The maximum storey drift due to lateral loads in any storey of a structure must not exceed 0.4% of the overall storey height. *Figures 15* and *16* show the variation of drifts in both directions for framed tube structures with various lateral resisting methods.

The studies revealed that when lateral load resisting devices are used in framed tube constructions, the drifts gradually decrease. In both directions, the structure with X bracings showed the least drift, while the structure with core shear wall solely showed the most drift. (*Figure 15* and *Figure 16*).

Figures 17 and *18* show variations in drifts in both directions for tube in tube construction with various lateral resisting systems. The storey drift was gradually decreased in tube in tube structures as well, when lateral load resisting devices were inserted into the structure in the same way that they were in framed tube structures. However, the structure having V bracings on its edge in both directions showed the least storey drift (*Figure 17* and *Figure 18*).

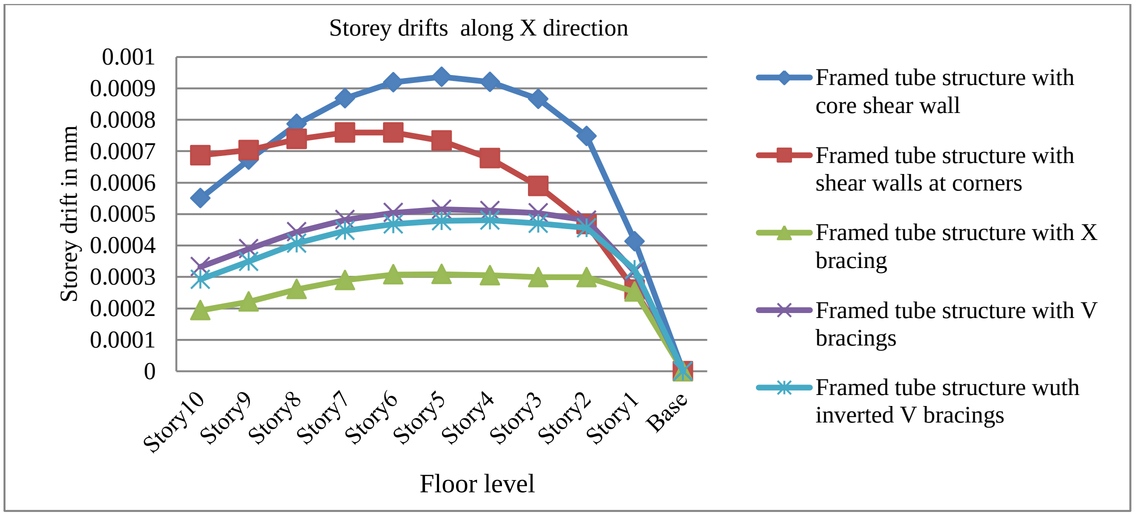

Figure 15 Storey drifts for framed tube structures along X direction

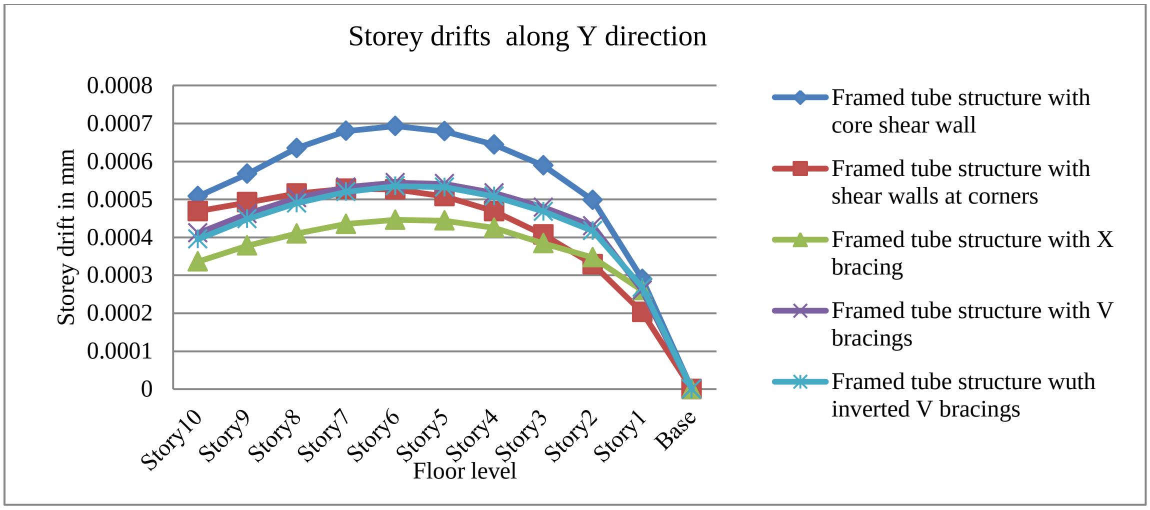

Figure 16 Storey drifts for framed tube structures along the Y direction

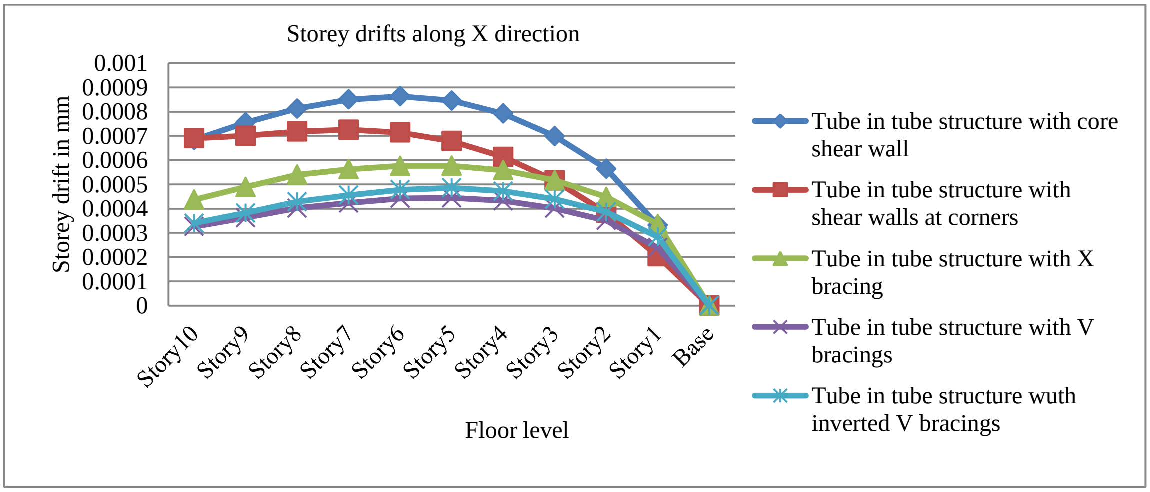

Figure 17 Storey drifts for tube in tube structures along X direction

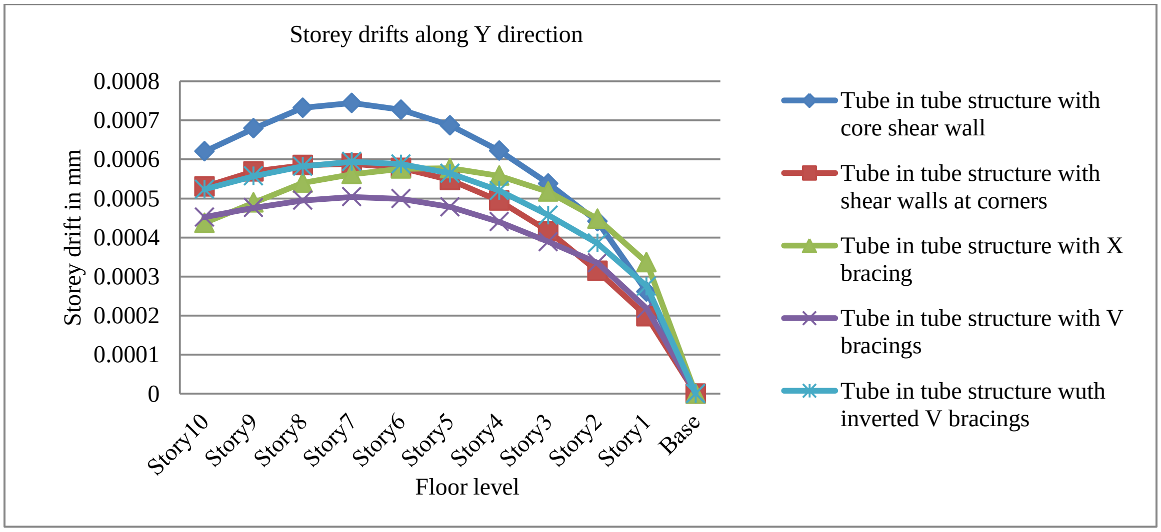

Figure 18 Storey drifts for tube in tube structures along the Y direction

4.3Storey shear

Storey shear is the lateral load that operates on every ground level. Shear values are highest at the base floor scale and lesser at the roof.

Figures 19 and *20* show the change of storey shear throughout the height in both directions for framed tube constructions with varied lateral resisting systems.

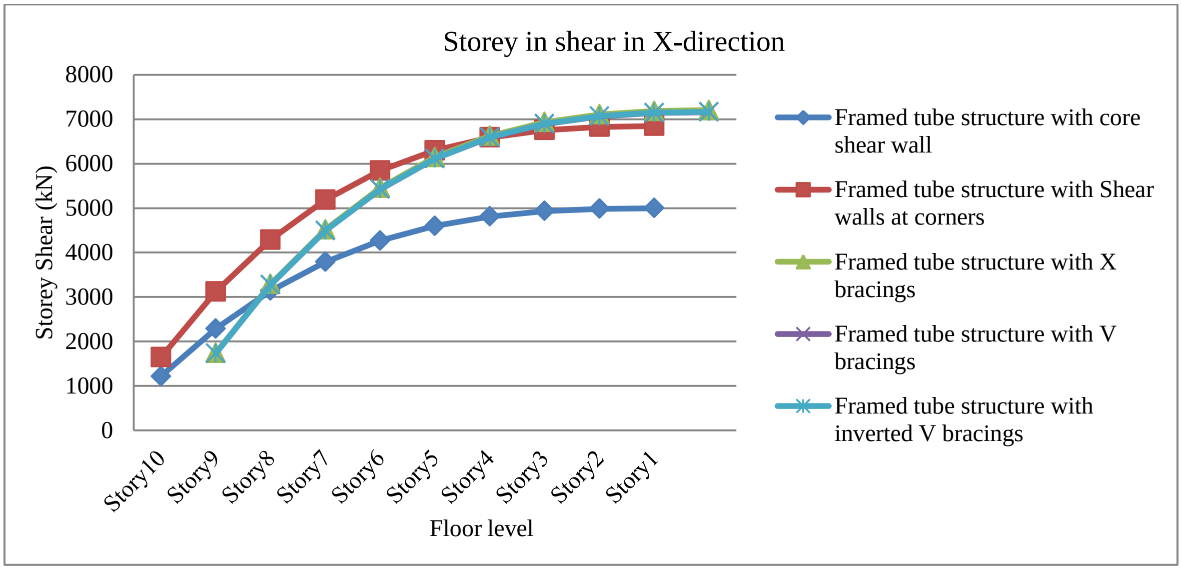

Figure 19 Storey Shear for framed tube structures along X direction

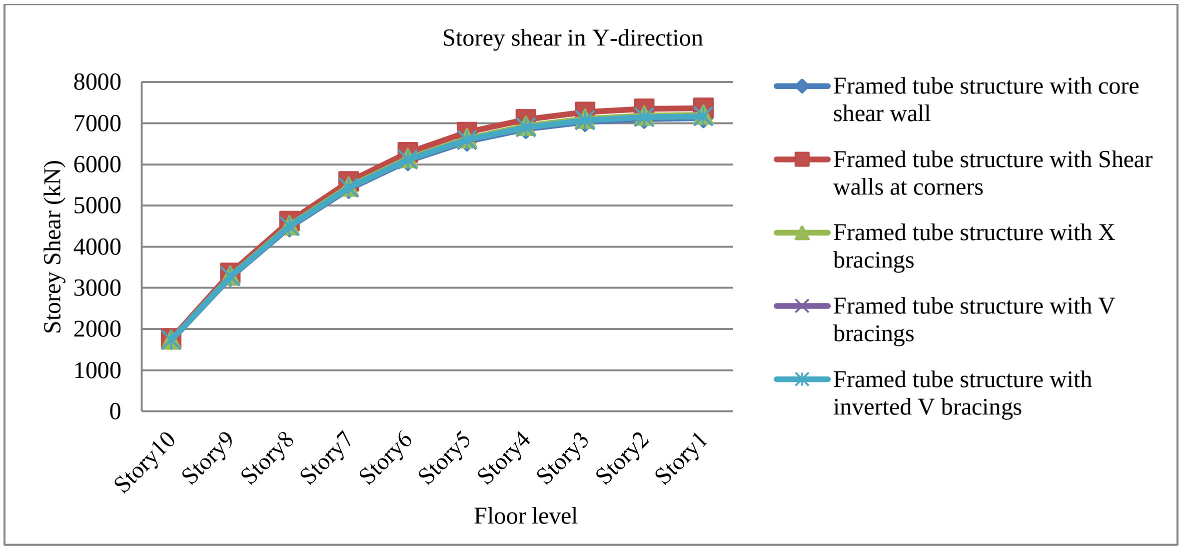

Figure 20 Storey shear for framed tube structures along Y direction

When the structure was examined for storey shear, a parabolic shape of the curve was observed as expected. The variation of storey shear in structures with core walls and structures with shear walls, at corners followed different paths while the variation of storey shear in other structures with bracings showed nearly identical values for shear in each floor in both directions.

Figures 21 and *22* show the variation of storey shear throughout the height in both directions for tube in tube construction with varied lateral resisting systems. When storey shear plots for tube in tube structures were examined, it was discovered that storey shear in constructions with V and inverted V bracings was nearly identical in all floors.

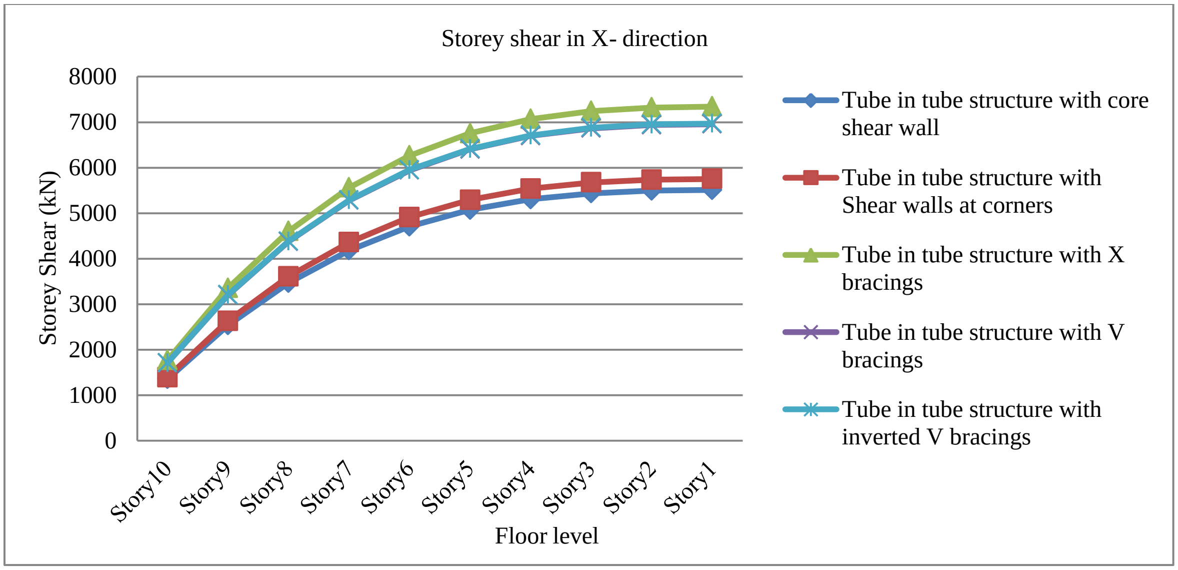

Figure 21 Storey shear for tube in tube structures along X direction

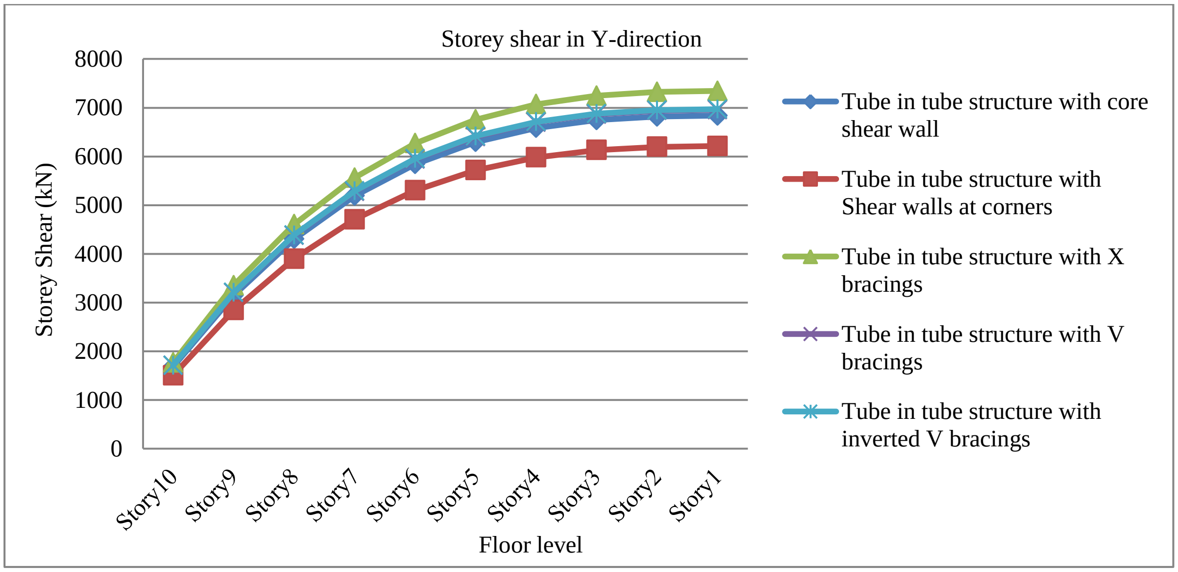

Figure 22 Storey Shear for tube in tube structures along Y direction

4.4 Base shear

Figure 23 shows the variance of base shears for framed tube structures in both directions. The base shear for framed tube structures with bracings on their periphery is about uniform in both directions, according to the results. The lesser were found in structures with core shear walls, whereas the highest base shear values were found in structures with X bracings.

Figure 24 shows the change of base shears for tubes in tube construction in the X and Y directions. Similar variations in base shear were seen in tube constructions with bracings around the perimeter, i.e. The base shear for the tube in tube structures with bracings around the perimeter is equal in both directions. As in framed tube constructions, structures with core shear walls had the least base shear while structures with X bracings had the most.

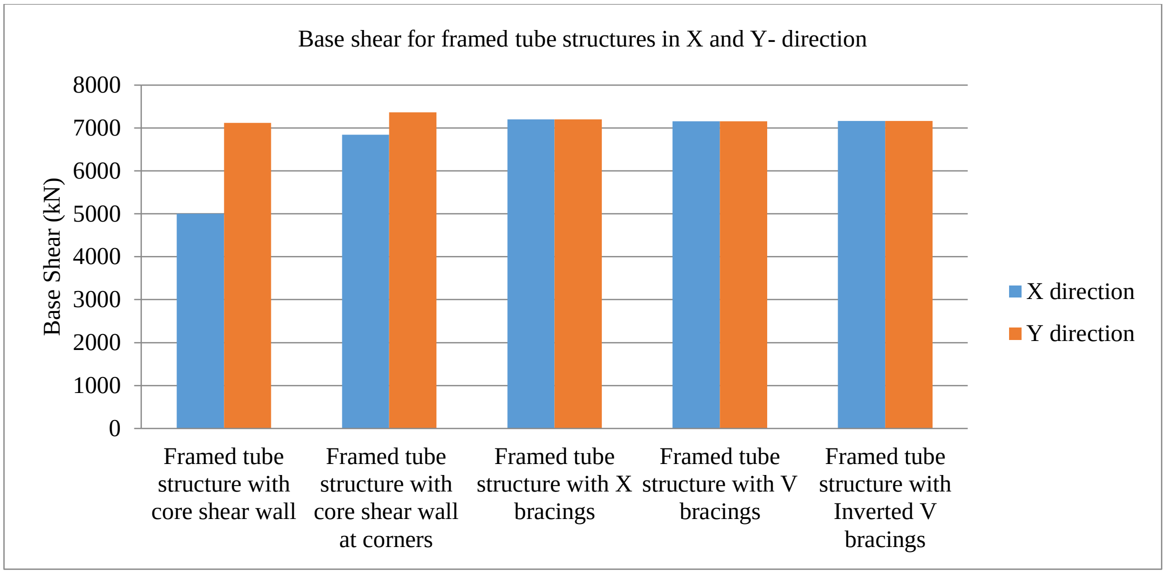

Figure 23 Base shear for framed tube structures

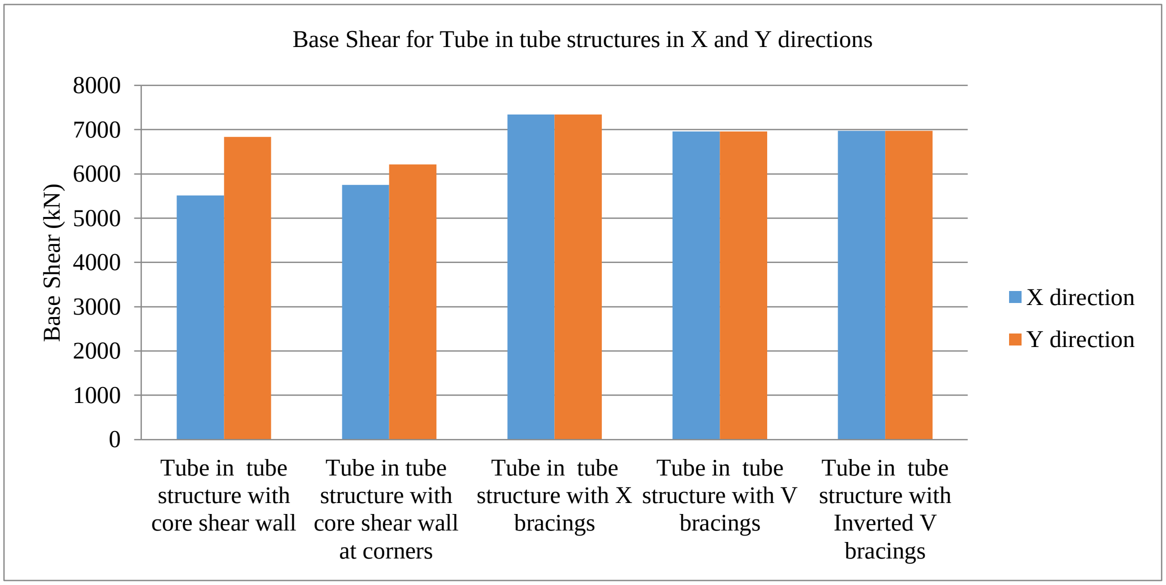

Figure 24 Base Shear for tube in tube structures

4.5 Modal participation factor

Figure 25 shows the fluctuation of the modal participation factor for framed tube constructions in all relevant modes of vibration. During an earthquake, the time period refers to how long it takes for a structure to complete one oscillation. The time period in framed tube structures decreased in the following order: structure with only core shear wall, structure with shear wall at corners and sides, structure with V bracings, structure with inverted V bracings, structure with X bracings, structure with inverted V bracings, structure with X bracings. The structure's stability is shown by a shorter time period during an earthquake.

Figure 26 shows the fluctuation of the modal participation factor for tube in tube construction in all relevant modes of vibration. The time period for tube in a tube construction dropped when lateral load resisting systems were used with structures that had the shortest time period, as seen in the figure.

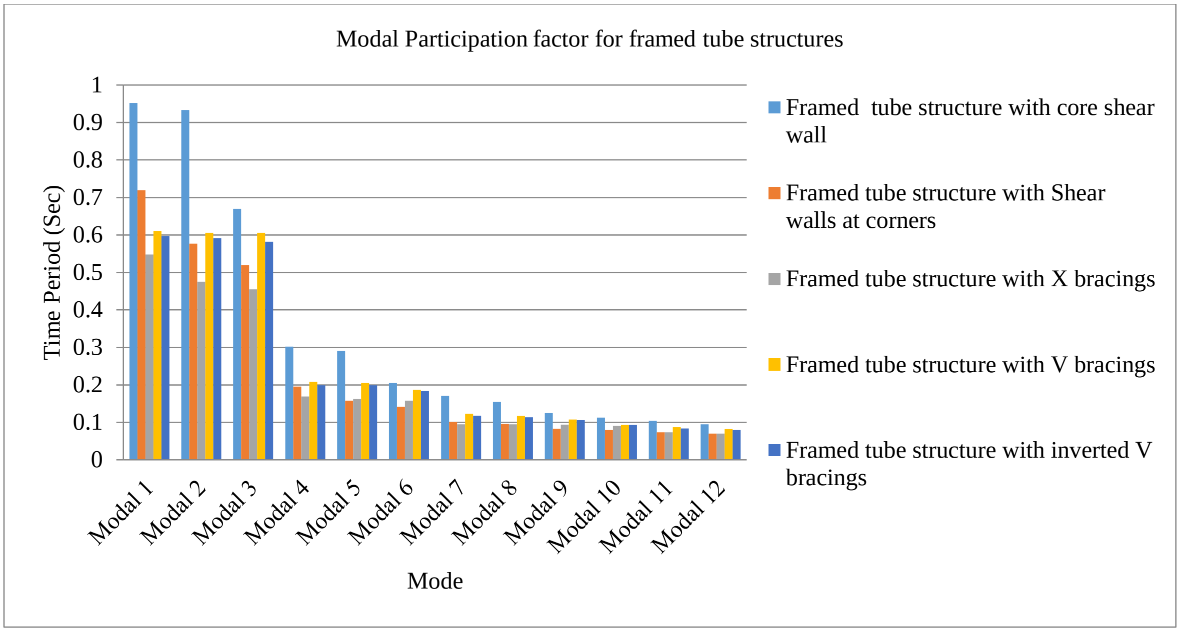

Figure 25 Modal participation factor for framed tube structures

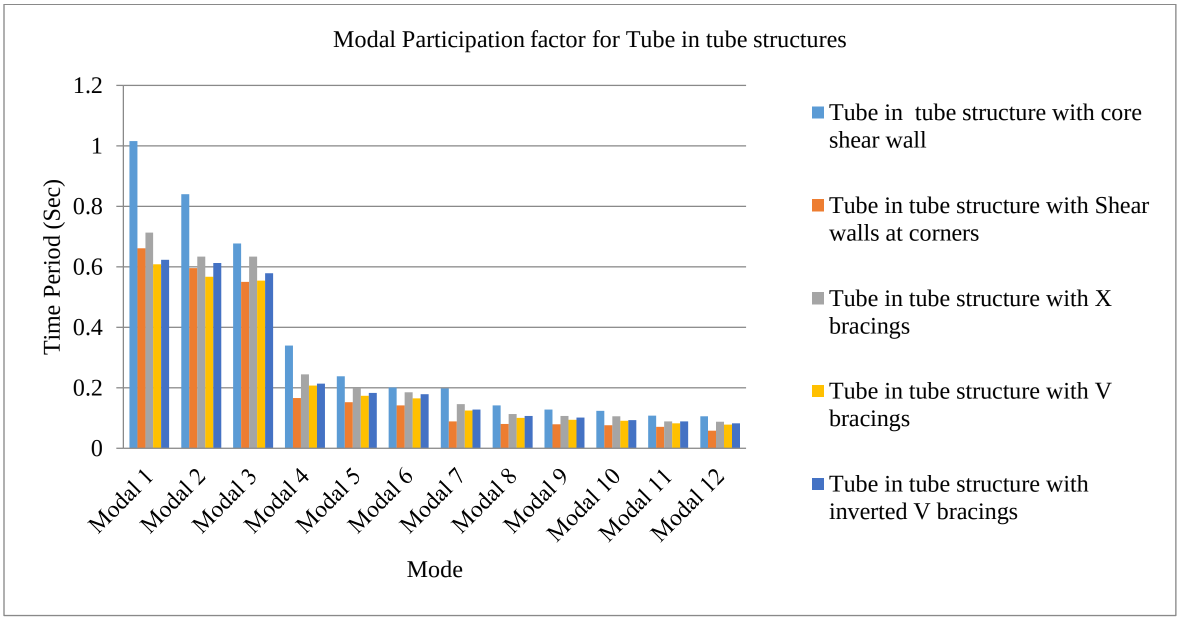

Figure 26 Modal participation factor for tube in tube structures

5.Discussion

1) In framed tube structures, the structure with the most X bracings around its perimeter had the least displacement. The structure with V bracings in its periphery showed reduced displacement in the other. The displacement was found to be 31.80% lower than that of a tube in a tube construction with V bracings in a framed tube structure with X bracings in the X direction and 10% in the Y direction.
2) In a framed tube structure, the structure with the core shear wall had the most drift in both directions, while the structure with X bracings had the least drift (i.e. 67 percent in X and 35.65 percent in Y). In contrast, the structure with the core shear wall had the most drift in both directions, while the structure with V bracings had

the least drift (48.55 percent in X and 32.26 percent in Y reduced).

3) The construction with X bracings had the shortest time period among framed tube structures (i.e. 43.43 percent lesser than framed tube structure with only core shear wall). The structure with V bracings had the shortest time period in tube in tube structures (i.e. 40.15 percent lesser than in other with core shear wall only).
4) First three modes are found to be significant for modal participation factor. Framed tube structures and tube in tube structures with V bracing performed better compared to other model types.
5) The base shear for framed tube structures and tube in tube structures with bracings on their periphery is about equal in both directions. Provision of core shear wall at corners in both tubular structures have lesser base shear values.

5.1Limitations of the study

This study only examined how high-rise tubular buildings with various lateral load resisting systems performed under lateral forces brought on by earthquakes. Future research can be conducted employing wind load as a lateral force. While just two structural arrangements—framed tube and tube in tube—were examined in the study, an analogous exercise might be performed with other configurations like bundled tube and braced tube. Plan abnormalities and vertical irregularities are not taken into consideration; the study is only applicable to symmetrical building plan configurations.

The structural members which are designed as per Indian standards do have heavy sections because of the higher factor of safety induced [52]. The effectiveness of the governing factors of designed sectional members with the lateral load carrying ability was not addressed in this paper.

The sole focus of current investigations is a dynamic performance assessment of tubular buildings using a response spectrum method only. Pushover analysis or nonlinear static analysis is not employed in the present study because, the performance based seismic design is not the scope of the present study.

A complete list of abbreviations is shown in *Appendix I.*

6.Conclusion and future work

The results of the current study are as follows:

1) The base shear grew steadily with a core shear wall, shear wall at the sides and corners, structure with inverted V bracings, structure with V bracings, and structures with X bracings in the progressive sequence of construction. Tube in tube construction with X bracings had a higher base shear than framed tube structure with X bracings.
2) Once bracings were added to the structure in both framed and tube in tube configurations, the base shear was found to be the same in both directions.
3) As a result, when framed tube constructions were subjected to seismic load, structures with X bracings at their peripheral produced the best outcomes. When seismic loads were applied to tube in tube structures with V bracings around the perimeter, the best results were obtained.
4) Tube in tube structural form bracings increase the building's resistance and stiffness, making the system more efficient than framed tube constructions.
5) Tube in tube structural form bracings provides additional resistance and stiffness in the building, making the system more effective than framed tube constructions.

As a result of the aforementioned research, it can be stated that good structural form, as well as appropriate lateral load resisting systems, is critical for high-rise buildings to operate effectively and efficiently in withstanding lateral loads.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author’s contribution statement

Ranjith A: Study conception, investigation, supervision and writing-original draft. **Mahesh Kumar C L:** Preparation of Draft. **Sanjith J:** Scrutiny and interpreting results. **Shwetha K G:** Collection of background information and writing. **Kiran B M:** Review writing and editing.

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Appendix I

S. No.	Abbreviation	Description
1	CQC	Complete Quadratic Combination
2	ETABS	Extended Three Dimensional Analysis of Building Systems
3	RC	Reinforced Concrete
4	SAP	Structural Analysis Programme
5	SDOF	Single Degree of Freedom
6	STAAD Pro	Structural Analysis and Design Project