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DYNAMIC ANALYSIS OF TALL TUBULAR STEEL STRUCTURES FOR SQUARE GEOMETRIC CONFIGURATION

BASAVANAGOUDA A PATIL
Assistant Professor
Department of Civil Engineering, Jain Institute of Technology, Davanagere India

BASAVANAGOUDA A PATIL

ABSTRACT

In structural engineering, the structural frames are the load resisting systems. The analysis and design of structures particularly tall structures needs appropriate analysis methods, precise design concepts along with preliminary designs aided with optimization, in order to resist the gravity as well as lateral load, so that structure remains safe thought its life span. In extremely tall buildings stiffness plays a very important role in controlling the global displacements. Hence new structural systems are developed by combining the previous structural systems in order to resist effectively the lateral loads due to earthquake and wind and to limit global displacements, drifts and accelerations under control. The tube structural concept had become more popular structural systems particularly for high rise steel structures. The basic structural form consists of vertical columns positioned about 1 to 2m center to center, which are connected by deep spandrels. The key Concepts to form a frame which will behave like a uniformly mesh or grid like system. Tube structure will resist the later forces by rigid moment resisting peripheral columns and girders which form a tube. The dead load all and live loads are transferred though columns near the core of the tube structure and also from vertical load bearing structural elements. Tube structures, particularly framed tube structures will have closely spaced exterior columns, and spandrel beams that constitute a rigid lateral Resisting frame tube structures

Introduction

In structural engineering, The structural frames are the load resisting systems. The analysis and design of structures particularly tall structures needs appropriate analysis methods, precise design concepts along with preliminary designs aided with optimisation, in order to resist the gravity as well as lateral load, so that structure remains safe thought its life span. The most important criteria in structural engineering is strength, serviceability and stability of the structures, where strength is taken care by limits of serviceability, stresses, is satisfied by lateral drift limit and finally stability is taken care by factor of safety against P- Delta and buckling effects. Most importantly the comforts for human are satisfied by accelerations of the structures due to dynamic loads. The main goal of a structural engineer is to satisfy all these criteria and finally to develop a suitable

Role and significance of structural systems: There is very high demand for tall structural systems because of scarcity in land in highly developed urban areas, increase in demand for business and residential space, technological advancements, innovation in structural systems concept of city skyline and human aspiration to build higher. In extremely tall buildings stiffness plays a very important role in controlling the global displacements. Hence new structural systems are developed by combining the previous structural systems in order to resist effectively the

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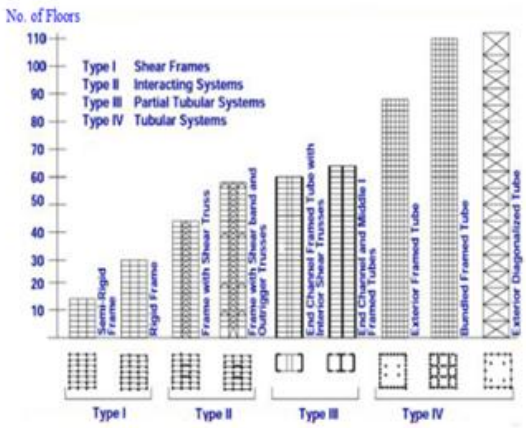
lateral loads due to earthquake and wind and to limit global displacements, drifts and accelerations under control. In structural system loads can be transfers through internally connected structural members or members. In this fast growing generation there is a need for tall, specifically super tall structures, where its height may go in the range of 300m to 500m. In order to achieve structural safety as whole and structural integrity between the components of the super high rise structure, various structural systems are developed.

Classification of structural systems

Structural Systems are classified broadly into 4 types as follows.

- ➢ Type 1 – Shear Frames
- ○ Rigid and Semi rigid frames
- ➢ Type 2 – Interacting frames
- ○ Frames with shear truss
- ○ Frames with shear band and outrigger truss
- ➢ Type 3 – Partial Tubular frames
- ○ End channel framed tube with interior shear truss
- ○ End channel and middle I framed tubes
- ➢ Type 4 – Tubular Systems
- ○ Exterior framed tube
- ○ Bundle framed tube



Different forms of Structural system for different heights

Tubular Structures

The tube structural concept had become more popular structural systems particularly for high rise steel structures. The basic structural form consists of vertical columns positioned about 1 to 2 m centre to centre, which are connected by deep spandrels. The key concept is to form a frame which will behave like a uniformly mesh or grid like system. Tube structure will resist the later forces by rigid moment resisting peripheral columns and girders which form a tube. The dead load and live loads are transferred though columns near the core of the tube structure and also from all other vertical load bearing structural elements. Tube structures, particularly framed tube structures will have closely spaced exterior columns, and spandrel beams that constitute a rigid lateral resisting frame tube structure.

The framed tube structural system will behave as web and flange system, where the outer frames which orient along the direction of lateral load will work like web of and frames perpendicular to the direction of later load behaves as flanges. In this structural form, vertical elements of middle portion of flange will subjected to less stress than the columns at the extreme locations (corner). And flange frames will subjected to shear lag.

Objectives:

1. To understand the behaviour of the tall tubular steel structures for geometric configuration of square shape in plan, in comparison with the steel beam column rigid frame system.
2. Earth quake Analysis is carried out using equivalent static method using IS 1893- 2002 and dynamic time history analysis using ETABS. Also wind analysis is done to understand the behaviour under the wind loads.
3. Efficiency of tall tubular steel structures with respect the base shear, story and peak Displacement, drift and acceleration are found out for all geometric configurations.
4. The effect of geometric configurations on behaviour of tall tubular steel structures are summarised using the obtained results, by concluding the optimum geometric Configuration for tall tubular steel structures.

Methodology

Following methodology is adopted to analyse tall tubular structure

1. Tall steel structure is considered for the study having 88 numbers of floors of 3.6 m height, total height of 316.8 m.

2. The regular steel frame resisting moment of square plan with central core opening is considered as base or reference model.
3. With reference to base model, all the tube structures of different configuration having square, rectangular, triangle and hexagonal geometric configuration are modelled using ETABS.
4. In order to get consistent results, the floor area is kept constant for all geometric configurations.
5. To understand the behaviour under lateral loads, earth quake and wind loads are applied as per IS 1893 2002 and IS 1875 part 3 respectively.
6. Based on the results and responses from earth quake and wind loads applied, conclusions are made.

LATERAL LOAD ANALYSIS OF TALL STRUCTURES: The design criteria for tall buildings are stability, serviceability, strength and comfort for human. But the factors control the slender buildings and design of tall buildings all the times are human comfort serviceability and serviceability against lateral loads. This work will make an effort to analyze tall building's structural systems, particularly frame tube structures of different geometric configurations. For seismic analysis equivalent static method and time history used as dynamic and for wind analysis has also carried out by using standard package ETABS. To check the variation of models for different parameters like storey displacement, storey drift, and storey shear, mode shape with respect to time period are presented for load cases.

The effect of earth quake forces on building structures is to displace the each floor mutually to create inter story drifts. Due to axis deformations in the structure flexural mode will develop and girder or diagonal bracings deformation shear mode will exists. Lateral stiffness of the structure is due to the shear mode displacements in case of buildings with lesser height. In tall or high rise structures, axial forces will tend to accumulate which causes flexural component of displacement to be predominant in nature.

Design Lateral Force due to earth quake as per IS 1893 (Part I):2002: Most of the civil engineering structures will suffer more during earthquake than disasters due to wind forces, since earthquake forces are very complex in nature and we cannot expect earthquake to occur repeatedly many times during short span of years. During earthquake, soil layers below sub structures will encounter different kinds of vibrations in three dimensional directions, where shock waves propagates are of P-wave, longitudinal wave and S-wave. For the structural analysis purpose, only vibrations or movements along horizontal direction is considered, since this movement will affect the superstructure and dangerous hazard to civil structures. The vertical component of the earthquake is taken care by the structural components itself, since in general all the civil engineering structures, including load bearing structures are designed to carry gravity loads which is also a vertical component force of the structure. The seismic co-efficient method or equivalent static method is used to analyse buildings with lesser to medium in height. And tall structures are analysed using dynamic analysis only.

The determination of earthquake force based on the code IS 1893(Part I):2002. Mainly two types of design procedures,

- Equivalent static analysis
- Dynamic analysis

Equivalent Static load analysis of building

Design seismic Base shear as per IS 1893 (Part I):2002

First step is find out design base shear, the design base shear of any building along principle direction is given below$V_b=(A_h)xW$

WhereA_h= seismic design co-efficient of the structure in horizontal direction.

W= weight of the seismic building.

Horizontal co-efficient of the structure is given by

$A_h = \frac{ZISa}{2Rg}$

In this equation

Z = Zone factor depends on the region in which the structure is constructed.

I = Importance factors.

R= reduction factor. It explains the structure is brittle or ductile.

$\frac{Sa}{g}$ = it is the average response acceleration co-efficient; it is varying for different type of soil.

T= Approximate fundamental natural period vibration.

T_a= 0.085 x ($h^{0.75}$) for steel frame building

In these equations 'h' is total building height in meters, lateral force at each floor depends on

- Mass of the floor
- Stiffness distribution of the structure
- Displacement of nodes at each mode shape

Base shear Distribution along the height building height is given by

$Q = V_B \frac{Wihi}{\sum_{i=1}^{n} Wihi2}$

Dynamic Time History Analysis: Time-history analysis provides for linear or nonlinear evaluation of dynamic structural response under loading which may vary according to the specified time function. Dynamic equilibrium equations, are solved using either modal or direct-integration methods. Initial conditions may be set by continuing the structural state from the end of the previous analysis. In the present study time history data of ELCENTRO is considered as per the following specifications.

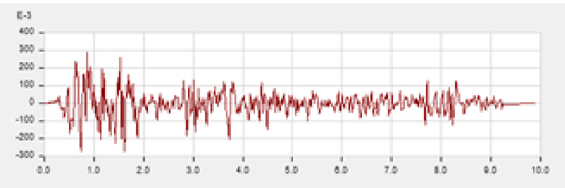
point :- "El Centro (Array #9)"

Direction:- Horizontal, 180°

acceleration:- g= 9.81 m/s2 (acceleration of gravity)

Time instants:- 4,000

Time sampling:- Δt = 0.01 s (f= 100 Hz)



Time History Input – El-Centro

Wind Analysis: Wind is one of nature's force which will exist continuously and affect particularly tall/high rise structures. Most of the iconic steel structures like Eiffel Tower and other steel structures are designed to resist wind loads of high intensity. Wind always cerates suction or negative force on leeward side and positive force along wind ward directions. Suction can be encountered even on the side walls or roof which depends on the geometric configuration of the structure. Pressure will be uniformly varying across the surface though out the height of the building. Since wind direction is unpredictable, and can be a load on the structure in any of the direction, structural design engineer should take care of these conditions. And most importantly the intensity of wind pressure which acts on the surface of the structure is directly proportional to speed of the wind.

Provisions of IS 1875:1987 for wind loads is considered as follows: Exposure from Extents of Diaphragms are considered for the following inputs.

Wind Speed: V_b = 33 m/s

Terrain Category = 4

Structure Class = C

Risk Co-efficient = 1

Topography factor = 1

Summary: Consideration of lateral forces both wind and earthquake for high rise steel structural behaviour study is necessary and responses of tall structures. The above lateral load inputs are given in the present study and responses such as lateral displacement, story drifts, base shear, and member forces are presented. Also peak acceleration and peak displacements are extracted for dynamic time history inputs and conclusions are made based on the results obtained.

STRUCTURAL MODELING AND LOADING: Structural modeling of steel framed tube structure is done using ETAB 2015 for 4 geometrical configurations i.e., square, rectangle, triangle and hexagon shape frame tube structures, including a regular moment resisting steel frame section. All buildings in general having 88 number of stories. To obtain the consistent results, over all area of floor diaphragm which will take lateral loads and transmits to beams are is taken constant for all geometric configurations. A central core is permitted for lighting, ventilation and service criteria for all buildings.

Building Modelling and Loading Data

Building Data

Type of Structure - Steel Moment Resisting Framed tube

Plan Configurations - Square, Rectangular

Number of Stories - G+87 (88 Storied)

Height of each floor - 3.6 m

Height of building - 316.8 m

Floor Area - 3550 m^2

Building type- Office Building

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Material Properties

Grade of Structural Steel - 345 Grade

Grade of concrete- M30 (Deck Slab)

Material Property Design Data

Section Properties

Column Sections - Built up (ISWB 600)

Beam Sections - ISMB 600

Deck Section - 200 mm thick

Gravity and Lateral load consideration

(a) Gravity load:

Live load - 4 Kn/m^2

Floors finish - 1.5 Kn/m^2

External Glazing - 2.0 Kn/m

(b) Earth quake inputs as per IS 1893 (Part I):2002

Location of Building- In Moderate intensity (Z-II)

Soil type - Type II

Importance factors - 1.0

Response reduction factors - 5.0

Fundamental Natural Period - 6.382 seconds

Load Combinations Table 1 shows the list of design load combinations considered during the analysis as per 1893(Part I):2002.

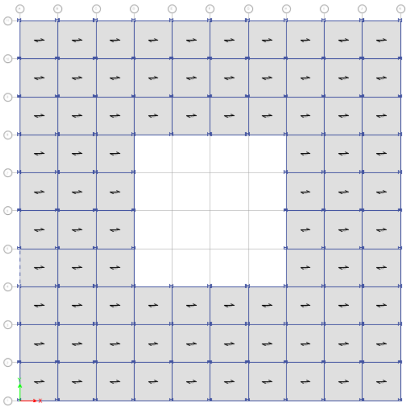
Table 1: Design Load combinations

	Design Load Combinations
Gravity analysis	1.5 (Dead Load + Live Load)
Equivalent Static Analysis	1.2 (Dead Load + Live Load + EQX)
	1.2 (Dead Load + Live Load - EQX)
	1.2 (Dead Load + Live Load + EQY)
	1.2 (Dead Load + Live Load - EQY)
	1.5 (Dead Load + EQX)
	1.5 (Dead Load - EQX)
	1.5 (Dead Load + EQY)
	1.5 (Dead Load - EQY)
	0.9 (Dead Load + EQX)
	0.9 (Dead Load - EQX)
	0.9 (Dead Load + EQY)
	0.9 (Dead Load - EQY)
Load Combination (Wind)	**Load Factors**
Wind Analysis	1.2 (Dead Load + Live Load + WINDX)
	1.2 (Dead Load + Live Load - WINDX)
	1.2 (Dead Load + Live Load + WINDY)
	1.2 (Dead Load + Live Load - WINDY)
	1.5 (Dead Load + WINDX)
	1.5 (Dead Load - WINDX)
	1.5 (Dead Load + WINDY)
	1.5 (Dead Load - WINDY)
	0.9 (Dead Load + WINDX)
	0.9 (Dead Load - WINDX)
	0.9 (Dead Load + WINDY)
	0.9 Dead Load - WINDY)

Geometric Configurations of Framed Tube Structures

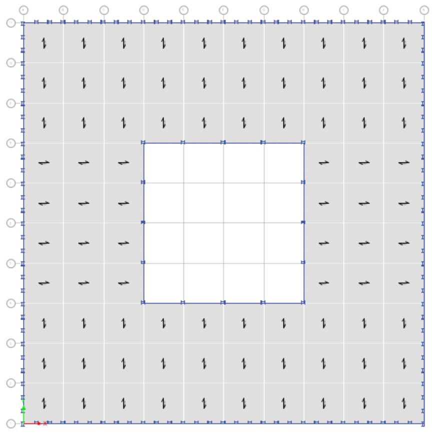
Following geometric configurations are taken for the present study and modelled using ETABS 2015.

a) **Model 1** : Steel Moment Resisting frame : Square in Plan



Steel Moment Resisting Frame: Square in Plan

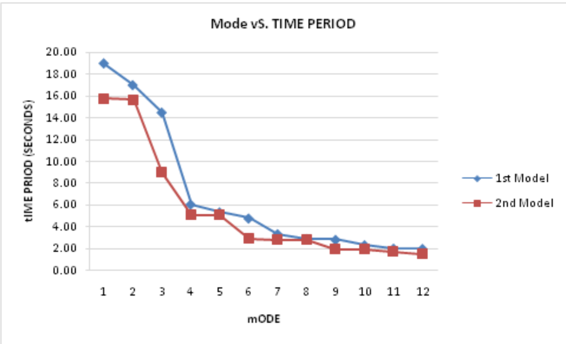
b) **Model 2** : Framed tube structure : Square in Plan



Framed Tube Structure: Square in Plan

ANALYSIS RESULTS AND DISCUSSIONS: This chapter presents important responses obtained by the analysis of different configuration of framed tube structures using ETABS 2015. Modal analysis has been done to understand the behavior under different modes and corresponding time period and frequencies are presented. Also base shear, story displacement, inter story drifts, due to lateral loads have been presented and discussed. Results from time history analysis i.e., peak displacement and peak accelerations are extracted and presented. Based on the results and discussions, conclusions are drawn and presented in the next

Modal Analysis: Modal analysis has been carried out for all geometric configurations and time period and frequencies. Time period is maximum for hexagonal tube structure compared to all other systems, which is 34% higher than that of steel moment resisting frame and 29% compared to all other geometric configurations. Maximum frequency is found in model 2 i.e., for square tube structure which is found to be 0.063 cycles/sec. and the variation of mode and time period and mode and frequency as show in the figure respectively



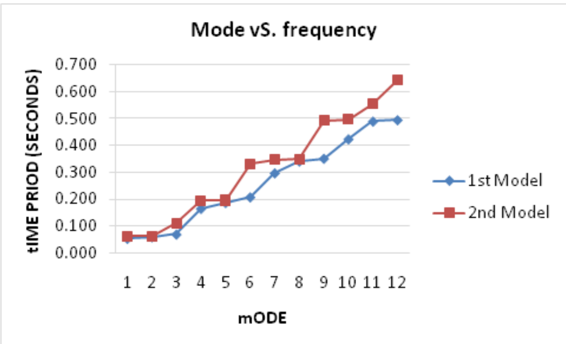
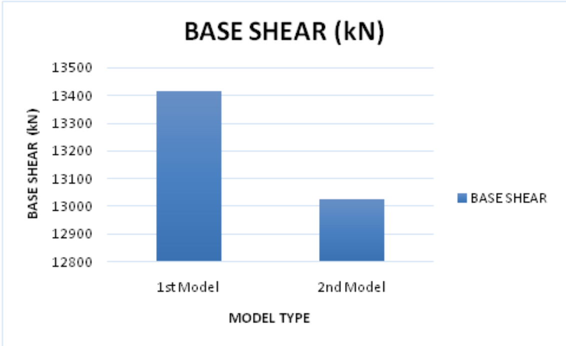


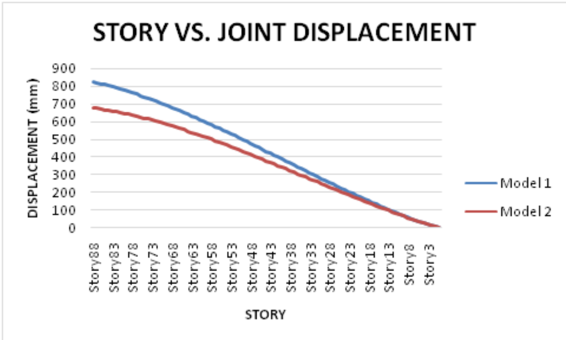
Table 2. Maximum Base Shear

Base Shear (KN)	
1st Model	2nd Model
Moment Resisting Frame	Square Tube
13415	13024

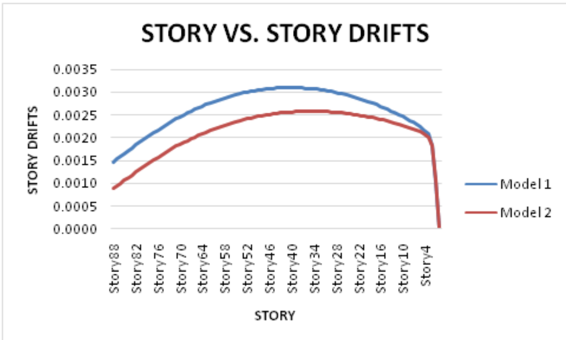


Maximum base shear

Story Displacements:



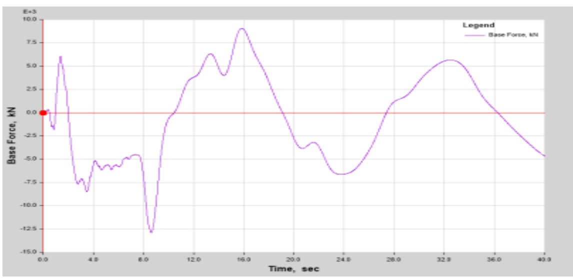
Story Drift ratios:



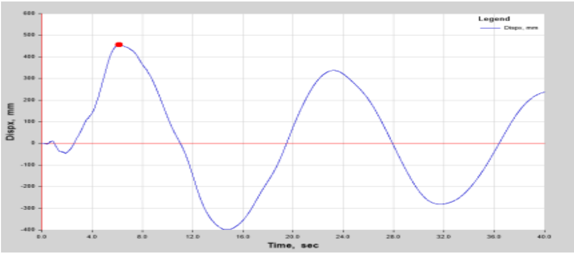
Earth Quake Analysis results: Dynamic Time History : The results of Dynamic analysis by Time history are presented here as like a time history response plots obtained. And all the results are summarized in the Table for discussions.

Dynamic Time History Analysis results for square geometric configurations)

Model 1: Steel moment resisting frame



Base force (kN) for Model 1: Steel moment resisting frame



Peak displacement (mm) for Model 1: Steel moment resisting frame

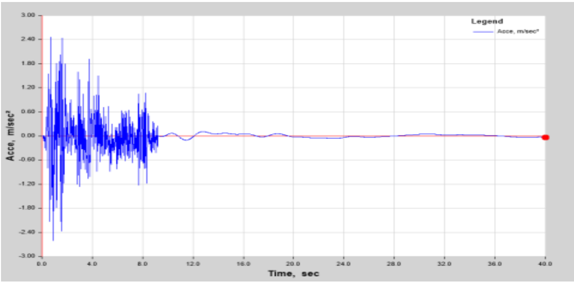
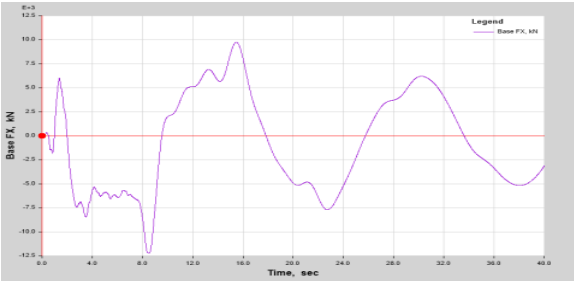
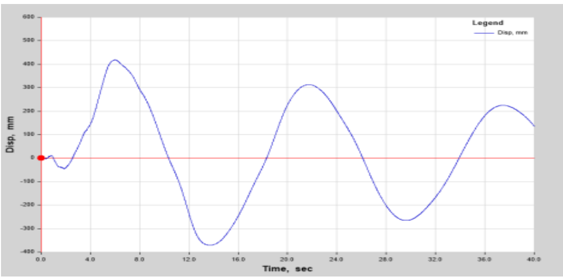


Figure. 5 Peak acceleration (m/s²) Model 1: Steel moment resisting frame

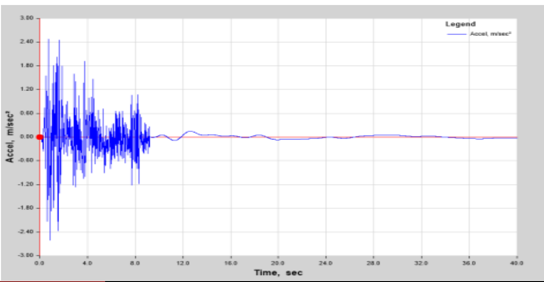
b) Model 2: Framed Tube Structure: Square



Base force (kN) for Model 2: Framed Tube Structure: Square



Peak displacement (mm) for Model 2: Framed Tube Structure: Square

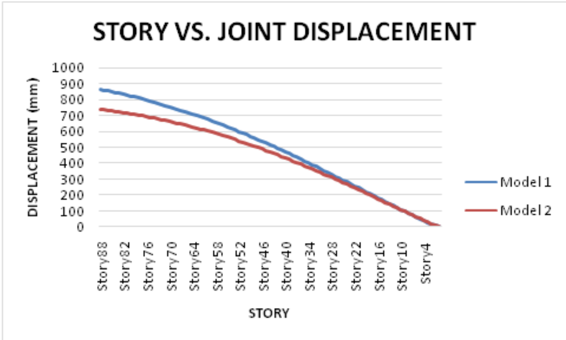


Peak acceleration (m/s^2) Model 2: Framed Tube Structure: Square

Table 3. Time History Response Summary Chart

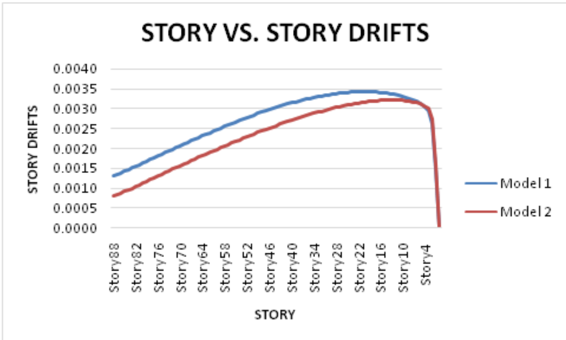
Models	Base Force (kN)	Peak Displacement (mm)	Peak Acceleration (m/s^2)
Model 1	12894	457	2.6
Model 2	12200	418	2.6

Wind Analysis results: Story Displacements:



Story Displacements – Wind Analysis

Story Drift ratios:



Story Displacements – Wind Analysis

CONCLUSIONS AND SCOPE OF FURUTHER STUDY

Conclusions

- Form the results and discussion of modal analysis, it can be concluded that Moment resisting frame structure is having highest time period i.e., 18.96 seconds in first mode of vibration and having less frequency 0.053 cycles per second. Hence this framed tube structure can be considered as stable with point of view of time period and frequency.
- From the lateral load analysis both earthquake and wind analysis, we found maximum displacement and story drifts are

encountered for Moment resisting frame structure.

- Square frame tube structural systems behaviour and responses are similar in case of earthquake and wind load analysis.
- Dynamic time history analysis results are comparatively lower than that of equivalent static analysis. Hence to know the exact behaviour of the high rise structural system, dynamic analysis is preferable.
- Form the overall results and discussion it can be concluded that tube structure is preferable for high rise structures in place of conventional beam column moment resisting frame steel system.

Scope of future work

- Additional structural systems like diagrids, steel plate shear walls can be incorporated to hexagonal frame tube structure to bring down the displacements and story drifts.
- Mega braces can be incorporated for all geometric configurations and study can be extended.
- Analysis can be extended for complex shape tubular structures.
- Tube in tube structures can be analysed for same geometric configurations.

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