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Study of Lateral Structural Systems in Tall Buildings

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Abstract

Lateral load effects on high rise buildings are quite significant and increase rapidly with increase in height. In high rise structures , the building of the structure is greatly influenced by the type of lateral system provided and the selection of appropriate lateral structural system plays an important role in the response of the structure . The selection is dependent on many aspects such as structural building of the system ,economic, feasibility and availability of materials.

Few of the lateral structural systems are shear wall system, Framed tube system, Tube in tube system, Bundled tube system. The lateral structural systems give the structure the stiffness, which would considerably decrease the lateral displacements. In the present work a Plain frame system, a Shear wall system and framed tube system are considered for 30,40,50,60 storey structures. The analysis has been carried out using software STAAD Pro-2005. The roof displacements, internal forces (Support Reaction, Bending Moments and Shear Forces) of members and joint displacements are studied and compared. It is seen that the Shear wall system is very much effective in resisting lateral loads for the structures up to 30 stories and for structures beyond 30 stories the Framed tube system is very much effective than Shear wall system in resisting lateral loads.

INTRODUCTION

In the ancient tall structures, which can be considered as prototypes of resent day high-rise buildings, were protective or symbolic in nature and were infrequently used. Tall buildings were primarily solid, serving more as monuments than as space enclosures. Throughout history, people had to make use of the available building materials. The Pyramid of Cheops, for example, was built by piling huge masonry and timber, used in construction through the early centuries had their limitation. The spans which timber and stone could bridge, either as beams, lintels or arches, were limited. Wood was nor strong enough for large structures nor did it possess fire-resisting characteristics. Brick and stone masonry, in spite of their excellent strength and fire resistance, suffered from the drawback of weight. The mass of masonry required to carry the weight of a structure elements, ie, columns, walls, and braces, was inordinately large when compared to gross floor area. This percentage was at a maximum value for the pyramids.

In 1885, an American engineer named William LeBaron Jenny became the creator of the modern skyscraper when he realized that an office building could be constructed using totally different materials. He chose structural steel and incorporated it into a revolutionary system that was to make possible the soaring office towers that mow symbolize the modern metropolis.

Two technological developments, the elevator and modern metal frame construction, removed the prevailing limitations on the height of the buildings, and the race for tallness was on. In 1913, the Woolworth building was the first to reach 60stories, soaring up 732 ft (242 m) in lower Manhattan.

This Gothic cathedral style building is still in vigorous use after 70 years of service and the installation of conditioning and automatic elevators.

The demand for tall buildings increased because large corporations recognized the advertising and publicity advantages of connecting their names with imposing high-rise office buildings even though their operations required a relatively small percentage of floor space.

The collapse of the financial market during the depression put an end to speculative high rises, and only in the late 1940s in the wake of world war2 did a new era of high rise building set in addition to the stimulus of new resources provided by technology was the spur of necessity, with the population doubling in almost every generation and production growing at an even faster pace, developers could scarcely keep up with the demand for space.

Many are spectacle buildings – giant architectural logos that draw enorwous public attention and increased revenues to the companies that build them. These grand new buildings are emerging as good investments, serving not only as advertising symbols and marketing tools but also as sources of above marker rents for excess office space.

Skyscrapers

The history of concrete high-rise truly belongs to the realm of the twentieth century. E. L. Ransome’s system of casting square, twisted, steel bars with concrete as a frame with slabs and concrete exterior walls was used in the Ingalls Building (Fig 1.3.1) in Cincinnati, Ohio, the first 15-story concrete "skyscraper" built in 1903 by A. Go Elzner. Initial speculation by the news media and many skeptics in the construction profession predicted that once shoring was removed, the building would crack and able under its own weight or through shrinkage during curing. One news reporter stayed awake all night waiting for the event in order to be the first to provide news coverage of such a catastrophe. Fortunately, they were proven wrong for the building remained standing. When first designed, tremendous city fires around the world had destroyed numerous steel tall buildings. The steel literally became ribbons when subjected to high heat, which concerned many at the time. Concrete was proving itself to be an excellent fire-resistant material through its use in factories and providing sustenance during fires in those facilities. A. O. Elzner, in a 1904 article, mentioned the additional benefits of concrete over steel: concrete "'is considerably cheaper. Steel requires a great amount of capital and equipment and money to operate a steel plant. Long hauls and heavy freight bills are also involved". In addition, the schedule for completion was tight and concrete construction could begin well in advance of delivery of steel to the site. Elzner further wrote about the building:

> "The structure is a concrete box of 8" walls, with concrete floors and roof, concrete beams, concrete columns, concrete stairs-no steel. It consists merely of bare embedded in concrete, with the ends interlaced, making actually a complete concrete monolith of the entire building, covered on the exterior with a veneer from four to six inches thick of white marble for the lower three stories, glazed gray brick for the next eleven, and glazed white terra cotta for the top story and cornice There are no shrinkage cracks and the building (has sustained) the highest winds, there is not even a perceptible tremor, and that too with concrete walls only eight inches thick in un broken slabs sixteen feet square, a portion of which on the second floor carries a bank vault weighing nearly a hundred tons."

Lateral Load Design Philosophy

In contrast to vertical load, lateral load effects on buildings are quite variable and Increase rapidity with increases in height. For example, under wind load the overturning moment at the base of the building varies in proportion to the square of the height of the building, and lateral deflection varies as the fourth power of the height of the building, other things being equal. The strength requirement is the dominant factor in the design of low height structures. However, as the height increases, the rigidity and stability requirements become more important, and they are often the dominant factors in the design. There are basically two ways to satisfy these requirements in a structure. The first is to increase the size of the members beyond and above the strength requirements. However, this approach has its own limits, beyond which it becomes either impractical or uneconomical to increase the sizes. The second and more elegant approach is to change the form of the structure into something more rigid and stable to confine the deformation and increase stability.

It is significant that there are no reports of completed tall building having collapsed because of wind load. Analytically, it can be shown that a tall building under the action of wind will reach a state of collapse by the so called p-delta effect, in which the eccentricity of the gravity load increases to such a magnitude that it brings about the collapse of the columns as result of axial loads. Therefore, an important stability criterion is to assure that predicted wind loads will be below the load corresponding to the stability limit. The second consideration is to limit the lateral deflection to a level that will ensure that architectural finishes and partitions are not damaged. Although less severe than the collapse of the main structure, the floor to floor deflection normally referred to as the inter story drift never the less has to be limited because of the cost of the replacing the windows and the hazard to pedestrians of falling glass.

Slender high rise buildings should be designed to resist the dynamic effects of Vortex shedding by adjusting the stiffness and the other properties of structure such that frequency of the vortex shedding does not equal the natural frequency of the structure. Lateral deflections of the building should be considered from the stand points of Serviceability and comfort. The peak acceleration at the top floors of the building resulting from the frequent wind storms should be limited to minimize possible perceptions of motions by the occupants.

In earthquake resistant designs it is necessary to prevent outright collapse of the Buildings under severe earthquakes while limiting the nonstructural damage to a minimum during frequent earth tremors. The building should be designed to have a reserve of ductility to undergo large deformations during severe seismic activity.

Structural Systems For Tall Buildings

A structure must be designed to carry gravity, wind, equipment and snow; resist high or low temperatures and vibrations; protect against explosions, and absorb noises. Adding to this the human factor means considering rentable spaces, owner needs, Aesthetics, cost, safety, and comfort. Although one set is not mutually exclusive of the other, careful planning and consideration are essential in an attempt to satisty and integrate both.

Considering structure alone, there are two main categories for high-rise buildings –structures that resist gravity and lateral loads and those that carry primarily gravity loads. Since skyscrapers have the largest needs for resisting high magnitudes of wind, the lateral load resisting system becomes the most important.

In structural steel design, there are two major governing factors

1) Stress in the member
2) Stiffness of the member to control the overall deflection of the building.

In tall structural steel structures, the design of the steel members participating in the lateral load resisting system is governed by stiffiness design and not by stress design. As such, steel members are not required to be connected to its full capacity, and this creates weak points at the connection when subject to impact. In concrete structures, in most cases, every reinforcing bar is spliced and interlocked, which provides more rigid connections.

Subsystems and Components

The subsystems or components of the tall building structural systems are essentially the following.

- Floor systems
- Vertical Load Resisting Systems
- Lateral Load Resisting Systems
- Connections
- Energy Dissipation Systems and Damping

Floor Systems

The floor system carries the gravity loads during and after construction. It should be able to accommodate the heating, ventilating and air conditioning systems, and have built in fire resistance properties these could be classified as two-way systems, one-way systems and beam and slab systems. Two-way systems include flat plate supported by columns, flat slabs supported by columns with capitals or drop panels. Large shears and moments will be carried by the latter. Slabs of constant thickness are also used. Slabs with waffles are also used. Two-way joist are also used. One way systems include following slabs of constant thickness, with spans of 3m to 8m. Closely spaced joists could also be used. Beam and slab systems use beams spaced 1m to 4m. Lattice floor joists and girders are useful to have ductwork inside of them. Floors of small joists are also used, in addition to integral floor slabs which house piping. The IBM Mutual benefits Life building. In Kansas City, MO illustrates the one way and two way joist systems. It also has shear walls for lateral resistance.

Concrete Floor Systems

In concrete floor systems, slabs of uniform thickness are often used with spans of 3 to 8m. One way or two way systems are used. Concrete joists or ribs are used in one Way or two way systems, called pan joists are also used. One shell Plaza, in Houston, TX Uses this. Beam and slab system is used with beams spaced at 3m to 8m. Beam depths of L/15 to L/20 are used.

Steel Floor Systems

In steel floor systems, we use reinforced concrete slab on steel beams. Thickness of slabs is in the range of L/30 to L/15 of the span. Pre-Cast Concrete slabs are also used with some shear connectors, grouted. Spans vary from 1.2m to 9m. Concrete slabs on metal decking are often used, with shear connection. For steel beams, wide flange shapes are used. Welded plate girders, latticed girders and virendeel girders are also used, which house ducts. Castellated beams and stud girders, which allow mechanical ductwork to be placed between short stubs, welded on top of these girders. The stub lengths are 1.5m to 2m long. Stub girders are of composite construction.

Lateral Load Resisting Systems

When reinforced concrete was first introduced as a building material, there wereLimitations on the heights that those buildings could reach. Structural engineers have gradually learned more about the properties of concrete and the structural systems. Fazlur Khan revolutionized the design of tall buildings in both steel and concrete when he proposed his well-known system charts for tall buildings. The concrete systems that are suitable for different ranges of number of stories shown in Fig 1. Shear walls, first used in 1940, may be described as vertical, cantilevered beams, which resist lateral wind and seismic loads acting on a building transmitted to them by the floor diaphragms.

Reinforced concrete's ability to dampen vibration and provide mass to a building Makes it a good choice of materials. These elements are a variety of shapes such as Circular, curvilinear, oval, box-like, triangular or rectilinear. Many times, a shear wall exists as a core-wall holding internal services like elevators, janitor's closets, stair wells and storage areas. Sometimes they serve external functions as a diagonal bracing system. When carefully planned, these walls may be used as partitions in a structure serving as both gravity- and a lateral-load bearing system. Concrete's quality of sound absorption makes it suitable for use in hotels and apartment buildings to reduce the transfer of noises from unit to unit.

Few of the Lateral Load Resisting Structural Systems are

- Frame Action of Column and Slab Systems
- Braced Frame
- Shear Wall
- Shear Truss-Outrigger Braced Systems
- Framed shear Wall
- Framed Tube System
- Tube in Tube System
- Bundled Tubes
- Truss Tubes with out interior Columns

Frame Action of Column and Slab Systems

Concrete floors in tall buildings often consist of a two-way floor system such as a Flat plate, flat slab, or a waffle system.

In a flat plate system the floor consists of a concrete slab of uniform thickness which frames directly in to columns. Two way flat slabs make use of either capitals in columns or drop panels in slab or both, requiring less than a flat plate because extra concrete is provided only at columns where the shears and moments are the greatest. The waffle system is obtained using rows of joists at right angles to each other; the joists are commonly formed by square domes. The domes are omitted around the columns to increase the moment and shear capacity of the slab. Any of the three systems can be used to function as an integral part of the wind-resisting systems for buildings in the 10 to 20 storey range. The concept of an "effective width" is usually used in the analysis of such buildings subjected to lateral forces.

Braced Frame

Braced frames have single diagonal x-braces and k-braces. Lattice and knee bracing are also used. Concrete braced frames are often not used, since shear walls superior for construction and lateral resistance. Lattice bracing is used in pre-cast panel construction. Steel braced frames are used in interior cores, so connections could easily made with wall panels. Composite braced frames may have steel bracings in concrete bracings in steel frames. Concrete encasement of columns and composite floor beams has also been used.

Shear Walls

Shear walls are planes elements made up of reinforced concrete the walls having Length and thickness providing lateral stiffness. The Shear and overall flexural deformations are design constraints, along with the stress levels, axial and bending. Concrete shear walls may be cast in place or pre-cast. Pre- cast panel walls are also used with in a concrete or steel frame to provide lateral resistance. The ductile shear walls used in earthquake resistant design have to be detailed carefully. Coupling beams should have diagonal reinforcement to develop shear resistance. Steel shear walls are also used sometimes, by connecting them to frame work by welding or high strength bolts. Masonry shear walls are also used, with solid walls and grouted cavity masonry to carry shears and moments, with reinforcement encased.

Shear Wall-Frame Interaction

This is the most popular system for resisting lateral loads. This system has beenused for buildings as low as 10 stories to as high as 50 storey or even taller buildings. With the advent of haunch girders, the applicability of the system could be extended to buildings in the 70-80 storey range.

The interaction of frame and shear walls has been understood for quite some time, the classical mode of the interaction between a prismatic shear wall and a moment frame is that the frame basically deflects in a so called shear mode while the shear wall predominantly responds by bending as a cantilever. Compatibility of horizontal deflection introduces interaction between the two systems which tends to impose a reverse curvature in the deflection pattern of the system. The combines' structural action, therefore, depends on the relative rigidities of different elements used in the makeup of the lateral-load-resisting system.

The distribution of total wind shear to the individual shear walls and frames as given by the simple interaction diagram is valid only if one of the following two conditions is satisfied.

1. Each shear wall and frame must have constant stiffness properties throughout height of the building.
2. If stiffness properties vary over the height, the relative stiffness of each wall and frame must remain unchanged throughout the height of the building.

Coupled Shear Walls

When two or more shear walls are interconnected by a system of beams or slabs,

It is well known that the total stiffness of the system exceeds the summation of the individual wall stiffiness. This is because the connecting slab or beam restrains the cantilever action of each wall by forcing the system to work as composite section. Where shear walls are compatible with other functional requirements and are of sufficient length, such walls can economically resist lateral forces up to 30 to 40 stories. However, planar shear walls are efficient lateral load carriers only in their plane. Therefore, it is necessary to provide walls in two orthogonal directions. Walls around elevators, stairs and utility shafts offer an excellent means of resisting both lateral and gravity loads without requiring undue comprises in the leas ability of buildings. Closed or partially closed shear walls are efficient in resisting torsion, bending moments and shear forces in all directions, especially when sufficient strength and stiffness are provided around door and other penetrations through these core walls.

Framed Tube System

The introduction of the tubular system for resisting lateral loads has brought about a revolution in the design of high rise buildings. All recent high-rise buildings in excess of 50 to 60 stories employ the tubular concept in one form or another. Khan is generally credited with its invention in the 1960s. It is defined by Khan as

"A three dimensional space structure composed of three four, or possibly more frames, braced frames, or shear walls, joined at or near their edgesto form a vertical tube-like structural system capable of resisting lateralforces in any direction by cantilevering from the foundation."

The tubular structure operates as an inherently stiffened three-dimensional framework where the entire building works to resist overturning moments. Tubes can encompass shear walls, columns and beams attempting to make them act as one unit. The main feature of a tube is closely spaced exterior columns connected by deep spandrels that form a spatial skeleton and are advantageous for resisting lateral loads in a three-dimensional structural space. Window openings usually cover about 50% of exterior wall surface. Larger openings such as retail store and garage entries are accommodated by large transfer girders, albeit disrupting the tubular behavior of the structure locally at that location. The tubular concept is both structurally and architecturally applicable to concrete buildings as is evident from the DeWitt-Chestnut Apartment building(Fig;3.4.2) in Chicago completed in 1965, the first known building engineered as a tube by khan.

Several configurations of tubes exist: framed, braced, solid core-wall tubes, tube-in-tube and bundled tubes. The framed or boxed tube is the one most likely associated with the initial definition given above. The DeWitt-Chestnut Apartment building in Chicago is a framed tube. A braced tube is three dimensionally braced or a trussed system. Its unique feature is that members have axial but little or no flexural deformation. The Onterie Center in Chicago is an example of such a system in concrete.

Because the entire lateral load is resisted by the perimeter frame, the interior floor plan is kept relatively free of core bracing and large columns, thus increasing the net leasable area for the building. The tube system can be constructed of reinforced concrete, structural steel, or a combination of the two, termed composite construction, in various degrees. The tube has become the workhorse of high-rise construction system because it minimizes the structural premium for lateral strength and stiffness, simultaneously accommodating recent trends in architectural forms

Tube-in-Tube system

Tube-in-tube is a system with framed tube, an external and internal shear wall core, which act together in resisting the lateral resisting loads. The development of the Tube-in-Tube concept for tall buildings was an important step. The exterior and interior columns of the structure are placed so closely together that they not only appear to solid, but they act as a solid surface as well. The entire building acts as a huge hollow tube with a smaller tube in the middle of it. The lateral loads are shared between the inner and outer tubes.

The tube-in-tube system of the Petronas Twin Towers consists of a shear wall core and a perimeter tube linked together by outriggers at the mid-height mechanical level.

The perimeter tube, about 46 meters in diameter, is composed of 16 columns linked together by a concrete ring beam. The size of the core measures 22.60 meters by 22.60 meters at the lower floors, and 22.60 meters by 19.22 meters at the upper floors. The concrete core and the perimeter tube are linked together by a series of cast-in-place concrete outrigger wall beams located at Level 38 and 39 mechanical floors. Both the core and the perimeter tube participate in the resistance of lateral load.

In the World Trade Center, the perimeter tube structure, in addition to taking some of the gravity loads, was also the key singular element in the resistance of all Lateral loads, by the framing action between the tube columns and the spandrel beams. The decision to use high strength concrete was strictly a function of construction logistics. Concrete structure, because of its mass, has latent dampening effect and thus provides superior occupant comfort to the top levels. To achieve the same Effect with steel construction, either a 80-tonne tuned mass damper will have to be Installed which would add significant cost to the project, or alternatively, heavy Sections with built-up plates up to 200mm thick will need to be used which would Require pre-heating and welding procedure.

Bundled tube system

It is the natural extension of the "Tube- in-Tube" system. The Stiffness and Strength of these very tall buildings is generated by all of the "tubes" of the building being "bound" together to act as one big bundle. This is similar to the cellular structure of bamboo or trees. A distinct advantage of the modular or bundled tube concept is that the individual tubes can be assembled in any configuration and terminated at any level without loss of structural integrity. This feature enables the architect to create setbacks with a variety of shapes and sizes.

The structural principle behind the modular concept is that the interior rows andcolumns and spandrels act as internal webs of huge cantilever beam in resisting shear forces, thus minimizing the shear lag effect.

Structural system in world trade center

The twin Towers were the tallest buildings in the world when they were completed in 1972. The design, created by architect Minoru Yamasaki, was innovative in several ways, including its elevator system, and its structural system. These innovations would be widely adopted in later skyscrapers.

Elevator System

A conventional elevator system would have taken up half the space of the lower floors. A novel system employing express and local elevators was developed by Otis Elevators. The express elevators took people to "sky lobbies" on the 44th and 78th floors, Where they could board local elevators. This system halved the number of elevator shafts.

Structural System

World Trade Towers I& Il used the so-called tube within a tube architecture, in which closely-spaced external columns form the building's perimeter walls, and a dense bundle of columns forms its core. Tall buildings have to resist primarily two kinds of forces: lateral loading (horizontal force) due mainly to the wind, and gravity loading (downward force) due to the building's weight. The tube within a tube design uses a specially reinforced perimeter wall to resist all lateral loading and some of the gravity loading, and a heavily reinforced central core to resist the bulk of the gravity loading. The floors and hat truss completed the structure, spanning the ring of space between the perimeter wall and the core, and transmitting lateral forces between those structures. The tube within tube architecture was relatively new at the time the Twin Towers were built, but has since been widely employed in the design of new skyscrapers. In fact most of the world's tallest buildings use it, including:

- The Sears Tower (1450 ft)
- The World Trade Center Towers(1350ft)
- The Standard Oil of Indiana Building (1125 t)
- The John Hancock Center(1105 ft)

The Structural System of the Twin Towers

Each tower was supported by a structural core extending from its bedrock foundation to its roof. The cores were rectangular pillars with numerous large columns and girders, measuring 87 feet by 133 feet. The core structures housed the elevators, stairs, and other services. The cores had their own flooring systems, which were structurally independent of the floor diaphragms that spanned the space between the cores and the walls.

The core structures, like the perimeter wall structures, were 100 percent steel-framed. Reports on the number of core columns vary from 44 to 47. The exact an arrangement of the columns is not know due to the secrecy of detailed engineering drawings of the towers. It is clear from photographs, such as the one on the right, that the core columns were abundantly cross-braced.

In addition, the outside of each tower was covered by a frame of 14-inch-wide steel columns; the centers of the steel columns were 40 inches apart. These exterior walls bore most of the weight of the building. The interior core of the buildings was a hollow steel shaft, in which elevators and stairwells were grouped.

Columns

The core columns were steel box-columns that were continuous for their entire height, going from their bedrock anchors in the sub-basements to near the towers tops, where they transitioned to H-beams. Apparently the box columns, more than 304.8m (1000 feet) long, were built as the towers rose by welding together sections several stories tall. The sections were fabricated by mills in Japan that were uniquely equipped to produce the large pieces. Some of the core columns apparently had outside dimensions of 914.4mm (36 inches) by 406.4mm (16 inches). Others had larger dimensions, measuring1320mm (52 inches) by 558.8mm (22 inches). The core columns were oriented so that their longer dimensions were Perpendicular to the core structures.

The top illustration indicates what may have been typical dimensions and thickness of the smaller core columns, about half-way up the tower. The outermost rows of core columns were apparently considerably larger, measuring 1371.6mm (54 inches) wide.

Like the perimeter columns and like steel columns in all tall buildings the thickness of the steel in the core columns tapered from bottom to top. Near the bottoms of towers the steel was four inches thick, whereas near the tops it may have been as little as the 1/4th inch thick. The top figure in the illustration to the right is a cross-section of one of the smaller core columns from about half-way up a tower, where the steel was about two inches thick. The bottom figure shows the base of one of the larger core columns, where the steel was five inches thick. The bases of the columns also had slabs of steel running through their centers, making them almost solid.

The Perimeter Walls

The towers perimeter walls comprised dense grids of vertical steel columns and horizontal spandrel plates. These, along with the core structures, supported the towers. It is controversial whether the perimeter columns were expected to bear much of the towers weight, in addition to their role in stiffening the structures against lateral loads. Regardless, it is clear that the core structures were designed to support several times the weight of each tower by themselves.

As the diagram and photograph illustrate, the perimeter wall structures were assembled from pre-fabricated units consisting of 3 column sections and 3 spandrel plate sections Welded together. Adjacent units were bolted together: column sections were bolted to adjacent columns above and below, and spandrel plate sections were mated with adjacent sections on either side with numerous bolts.

There were 59 perimeter columns on each face of the towers, and one column on each corner level, making a total of 240 perimeter columns in each tower.

The Floors

The floors of the Twin Towers completed the structural system whose main elements were the core structure and the perimeter walls. The floor diaphragms were annular structures that spanned the distance between the core structures and the perimeter walls, providing large expanses of uninterrupted floor space. The cores had their own flooring systems, which were structurally independent of the surrounding floor diaphragms.

The 10 cm thick concrete slabs were apparently a light weight form of concretetypically used in high-rises. Its density and exact composition remain unknown, but such lightweight concrete is typically 60% as dense as concrete used in roads and sidewalks. The floors were the only major part of these mostly steel buildings that contained concrete.

The Hat truss

The fourth primary structural subsystem in each tower was the hat truss latticeof large diagonal I-beams that connected the perimeter walls to the core structure between the 107th floor and roof. This structure was also known as the outrigger truss system.

The hat truss structure strengthened the core structure, unified the core and perimeter structures, and helped to support the large antenna mounted atop the North tower. The hat truss, which contained both horizontal and sloping I-beams, connected core columns to each other, and connected the core to the perimeter walls. Most the beams connected core columns to each other, while a set of sixteen horizontal and sloping beams spanned the distance the core and perimeter walls. Eight of these, the outrigger trusses, connected the corners of the core to the perimeter walls, while another eight connected the centers of the core's periphery to the perimeter walls.

Analysis of lateral structural systems

The structural systems are very much essential for the tall buildings, to resist the gravity and lateral loads. Selection of an appropriate Structural system for the structure is very essential and vital. Knowledge of behavior each structural system, rapid preliminary design methods, approximate analysis and optimization techniques are necessary to achieve this balance in design. In order to compare systems, different columns spacing, member sizes, truss and other subsystem dimensions such as outriggers, and diagonal truss system should be carefully examined.

Statement of the Problem

In the present work building with 10, 20,30 and 40 storey are considered, whichhave got the similar floor plan dimensions (96m x76m). Different structural system such as shear wall and framed tube system had been used to the buildings with different heights (viz. 10, 20, 30, 40 storied) and the various internal forces(Reactions, Bending moment, Shear force, Axial force) of the members, joint displacements and storey drifts in all cases had studied and compared. The comparison is also done between the structures with internal cores and without internal cores.

Analysis is carried out on structural software Staad-Pro 2005 Software with theParameters assigned below. To account for the in-plane rigidity master-slave concept is adopted for the slabs. Shear Wall is considered as plate. Plate with plane stress is considered to reduce the degrees of freedom at each node and make the analysis much faster.

Details of Structure

Plan Dimension : 48m X 36m

Floor to Floor height : 3m

Heights of structures Considered for the Study

30- Storey Structure - 91.5m

40-Storey Structure - 121.5m

50-Storey Structure - 151.5m

60-Storey Structure - 181.5m

Loads :

Dead Load

Self Weight of the Slab + Self Weight of beams and

column + Floor finish +Wall LoadWall load -6kN/m(Aerocon light weight Blocks are considered)

Live Load

Live Load-4kN/m2 - Considered as a Mercantile Building as Per IS:875 (Part 2)-1987. Live load reduction is considered as per clause 3.2.1 of the code IS 875 (Part 2)- 1987.

Wind Load

Wind Load considered for the Hyderabad region for the terrain category 3 and class B from IS: 875 (Part 3)-1987

Earthquake Load

Earthquake load is considered in the form of Spectrum load for Zone-2, Response reduction factor -4, Importance factor 1.5 Soil Type - medium values taken from IS: 1893 -2002

Cases Considered : Lateral Load Resisting Structural System Considered are

- Beam – Column Frame or Plain Frame
- Shear Frame System
- Framed Tube System

Plain Frame System

The beam-Column frame is considered here, there is no lateral load resisting structural system.

Shear Wall System

The shear wall acquires the 33% of the total plan area.

The Tube System

Columns in the tube system in the outer periphery are 2m centre to centre.

Preliminary Design of the Columns

Maximum axial force for the column is taken from the results of pre-analysis for the design of the column. Minimum radius of gyration is taken for the section and slenderness ratio is known. From the table 5.3 from IS : 800 - 1984, the permissible axial compression stress is known. Hence the load carrying capacity is known.Columns for all he structures is designed in the similar process.

Example

Factored load on column 50109kN

Considering an axial stress of 140N/mm2

Area required for the column - 0.357 m

Providing column of area of 0.36

Slenderness ratio for the column 14.15

From table 5.1 of IS: 800 -: 1984,

permissible axial stress obtained i148N/mm2

>140N/mm2, Hence Safe

Beams Considered:

Steel Girders of I section of the required strength are considered.

Foundation

30- Storey Structure - Elastic mat of 2m thick concrete is considered with Sub-grade

reaction of 25000 kN/m2 throughout the plan.

40- Storey Structure - Elastic mat of 2.5m thick

concrete is considered with Sub-grade

reaction of 25000 kN/m2 throughout the plan.

50- Storey Structure - Elastic mat of 3m thick concrete is considered with Sub-grade

reaction of 25000 kN/m2 throughout the plan.

60- Storey Structure - Elastic mat of 4m thick

concrete is considered with Sub-grade

reaction of 25000 kN/m throughout the plan.

Shear wall Thickness

30- Storey Structure - 250mm thick concrete wall from Om to 46 5m height

200mm thick concrete wall from 46.5m to 91.5m height

40-Storey Structure – 300mm thick concrete wall

from Om to 61.5m height

200mm thick concrete wall from 61.5m to 121 5m height

50-Storey Structure - 300mm thick concrete wall from O m to 61.5m height

250mm thick concrete wall from 61.5m to 106.5m height.

200mm thick concrete wall from 106.5m to 151.5m height

60-Storey Structure - 300mm thick concrete wall from Om to 61. 5m height

250mm thick concrete wall from 61.5m to 12.5m height

200mm thick concrete wall from 121.5m to 181.5m height

Properties of Materials used in Structure

Elastic Modulus of Concrete - 2.Se+007 kN/m2

Density of concrete - 25 kN/m3

Elastic Modulus of Steel - 2.05e+008 kN/m2

Density of Steel - 78.5kN/m3

RESULTS AND DISCUSSIONS

Structures with different structural systems such as Beam-Column Frame system Shear wall structural system and Tube Frame structural system are considered for the 30,40, 50, 60 storey structures as prescribed in chapter 4. Analysis is carried out for the given problem and the results (Displacements, Base Shear and Support Reactions) obtained are presented in this chapter.

Results for the 30 storey structures

The Displacements due to the wind load and due to the Earthquake load for the 30 storey structure have been presented in this chapter. Also the maximum support reactions for the central supports and the outer peripheral supports are presented. Maximum displacement due to wind load is obtained for the dead and wind load combination in all the cases. Maximum displacement due to Earthquake load is obtained for the dead and Earthquake load combination in all the cases.

Table 5.1a. Result obtained for support reactions for the 30 storey structures

	Beam–Column Frame	**Shear wall Frame**	**External Tube Frame**
Maximum Support Reactions in kN	9.59E+04	8.94E+04	7.33E+04
Maximum Support Reactions in kN(outer Periphery)	5.26E+04	40625	10916

Table 5.1b. Lateral displacements due to wind load at different storey heights

Storey number	**Displacement (mm) for Beam – Column Frame**	**Displacement (mm) for Shear Wall Frame**	**Displacement (mm) for External Tube Frame**
5	5	3	2
10	9	6	4
15	13	9	6
20	26	13	14
25	35	16	19
30	40	19	22

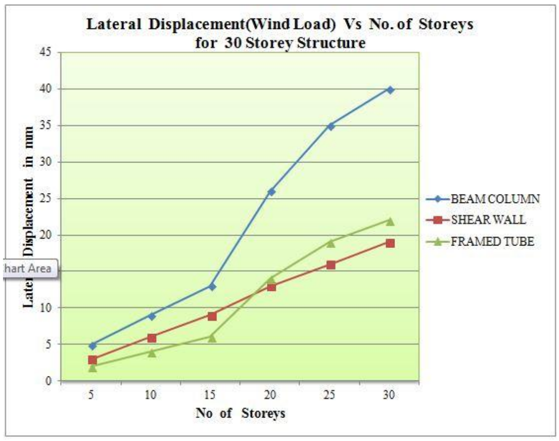

Figure 5.1a. Graph – Lateral displacement due to wind load Vs Number of storey

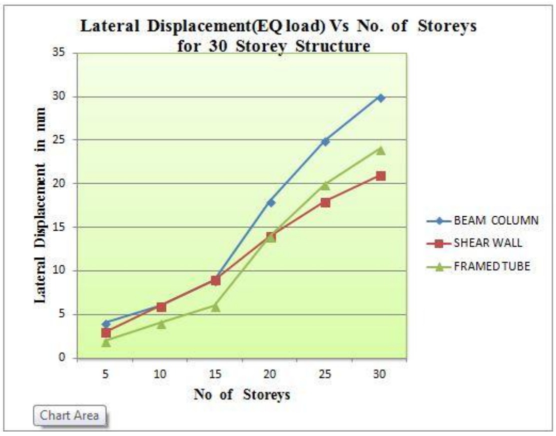

Figure 5.1b. Graph – Lateral Displacement due to earthquake load Vs Number of storey

Results for the 40 storey structures

The Displacements due to the wind load and due to the Earthquake load for the 40 Storey structure have been presented in this chapter. Also the maximum support reaction for the central supports and the outer peripheral supports are presented.

Table 5.2a Results obtained for support reactions for the 40 storey structures

	Beam - Column Frame	**Shear wall Frame**	**External Tube Frame**
Maximum Support Reactions in kN	1.28E+05	1.23E+05	1.24E+05
Maximum Support Reactions in kN(outer periphery)	6.99E+04	54156	16183

Table 5.2b. Lateral displacements due to wind load at different storey heights

Storey Number	**Displacement(mm) for Beam – Column Frame**	**Displacement (mm) for Shear wall Frame**	**Displacement (mm) for External Tube Frame**
5	7	5	3
10	13	9	6
15	20	14	9
20	26	19	11
25	42	25	16
30	55	31	19
35	65	36	22
40	72	41	25

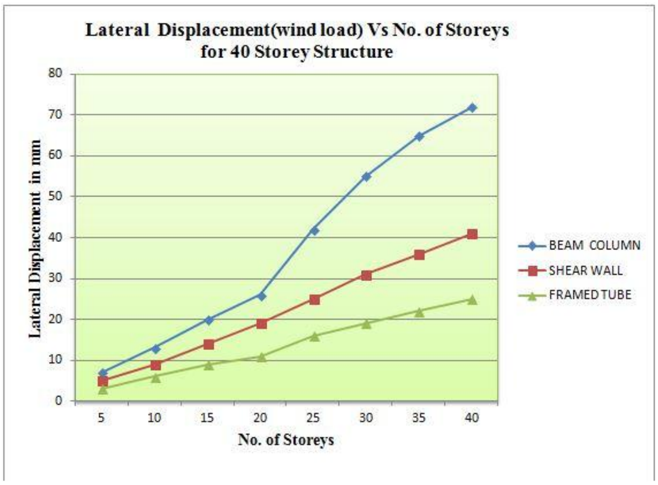

Figure 5.2a. Graph – Lateral Displacement due to wind load Vs Number of storey

Table 5.2c Lateral displacement due to earthquake load at different storey heights

Storey Number	**Displacement (mm) for Beam – Column Frame**	**Displacement (mm) for Shear wall Frame**	**Displacement (mm) for External Tube Frame**
5	4	3	3
10	7	7	6
15	10	10	9
20	13	13	12
25	21	18	17
30	29	22	21
35	35	27	24
40	39	30	28

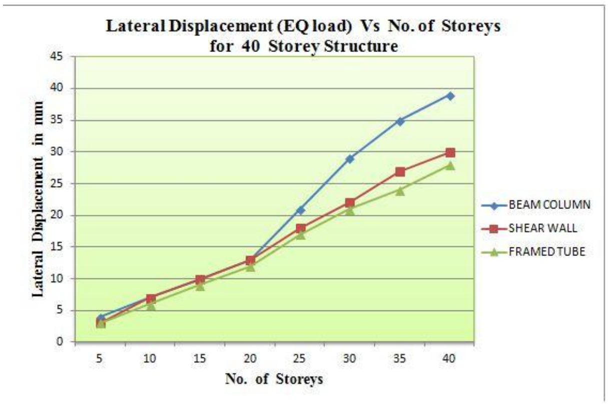

Figure 5.2b. Graph - Lateral displacement due to earthquake load at different storey

Results for the 50 storey structures

The Displacements due to the wind load and due to the Earthquake load for the50 storey structures have been presented in this chapter. Also the maximum support reactions for the central supports and the outer peripheral supports are presented.

Table 5.3a. Results obtained for support reactions for the 50 storey structures

	Beam – Column Frame	**Shear wall Frame**	**External Tube Frame**
Maximum Support Reactions in kN	1.63E+05	1.59E+05	1.43E+05
Maximum Support Reactions in kN (outer periphery)	8.68E+04	68260	18230

Table 5.3b. Lateral displacements due to wind load at different storey heights

Storey Number	**Displacement (mm) for Beam – Column Frame**	**Displacement (mm) for Shear wall Frame**	**Displacement (mm) for External Tube Frame**
5	8	7	5
10	16	14	9
15	24	21	13
20	32	28	18
25	49	37	24
30	66	46	31
35	81	56	37
40	100	65	48
45	115	74	58
50	126	82	64

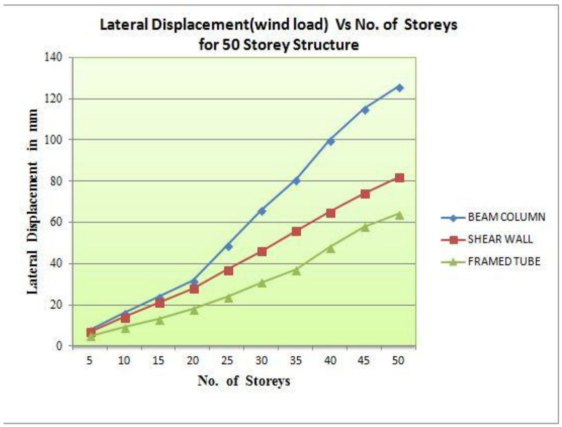

Figure 5.3a Graph – Lateral displacement due to wind load Vs Number of storey

Table 5.3c Lateral displacements due to earthquake load at different storey heights

Storey Number	**Displacement (mm) for Beam Column Frame**	**Displacement (mm) for Shear wall Frame**	**Displacement (mm) for External Tube Frame**
5	3	4	3
10	6	7	5
15	9	10	8
20	12	14	10
25	19	18	14
30	25	23	18
35	31	28	22
40	39	33	30
45	47	38	37
50	52	42	41

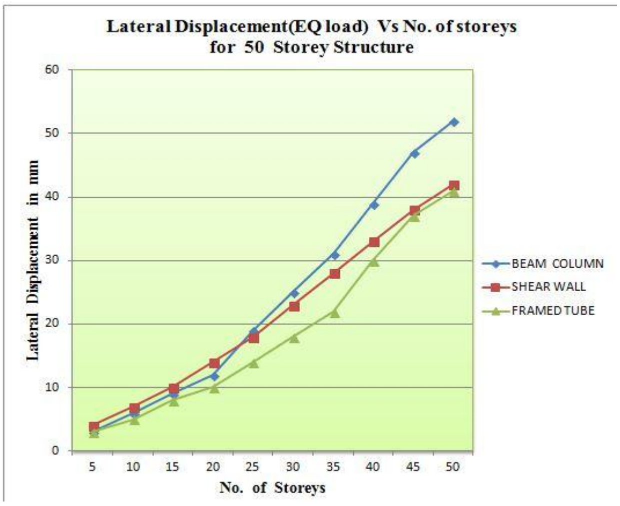

Figure 5.3b. Graph – Lateral displacements due to earthquake load Vs Number of storey

Results for the 60 storey structures

The Displacements due to the wind load and due to the Earthquake load for the 60 storey structure have been presented in this chapter. Also the maximum support

Reactions for the central supports and the outer periphery supports are presented

Table 5.4a. Results obtained for support reactions for the 60 storey structures

	Beam – Column Frame	Shear wall Frame	External Tube Frame
Maximum Support Reactions in kN	1.94E+05	1.90E+05	1.76E+05
Maximum Support Reactions in kN (outer periphery)	1.02E+05	81148	21830

Table 5.4b. Lateral displacements due to wind load at different storey heights

Storey Number	Displacement (mm) for Beam – Column Frame	Displacement (mm) for Shear wall Frame	Displacement (mm) for External Tube Frame
5	10	9	7
10	19	18	13
15	29	28	19
20	40	37	25
25	53	50	33
30	66	64	41
35	88	78	50
40	109	92	59
45	133	107	72
50	153	122	83
55	171	135	93
60	185	149	101

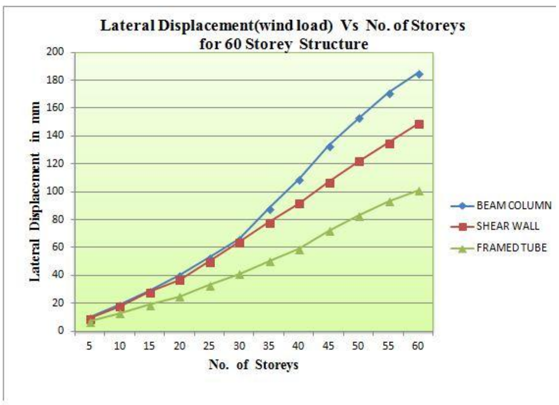

Figure 5.4a. Graph – Lateral displacement due to wind load Vs Number of storey

Table 5.4c. Lateral displacement due to earthquake load at different storey heights

Storey Number	Displacement (mm) for Beam – Column Frame	Displacement (mm) for Shear wall Frame	Displacement (mm) for External Tube Frame
5	3	3	3
10	6	7	6
15	9	10	9
20	13	13	12
25	16	18	16
30	21	23	20
35	28	28	24
40	34	33	28
45	43	39	35
50	50	45	41
55	57	51	46
60	62	56	51

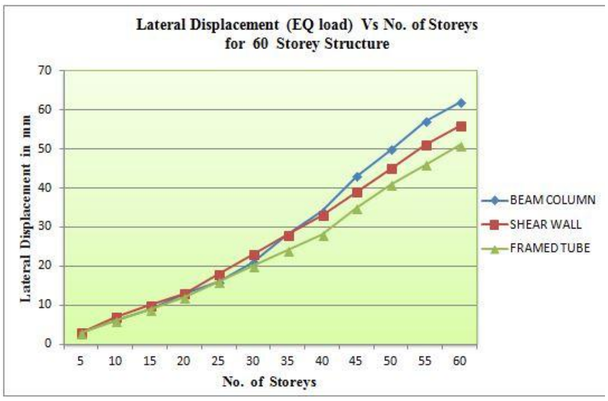

Figure 5.4b. Graph – Lateral displacement due to earthquake load Vs Number of storey

Roof Displacement in Structures due to Lateral Loads

Roof displacement due to wind load :

Roof displacement for the all the structures in the chosen problem are taken and the graph is

Represented with Lateral roof displacement due to wind load Vs storey number.

Table 5.5a. Roof displacement due to wind load

Storey	Displacement (mm) for Beam – Column Frame	Displacement (mm) for Shear wall Frame	Displacement (mm) for External Tube Frame
30 story	40	19	20
40 story	72	41	25
50 story	126	82	64
60 story	185	149	101

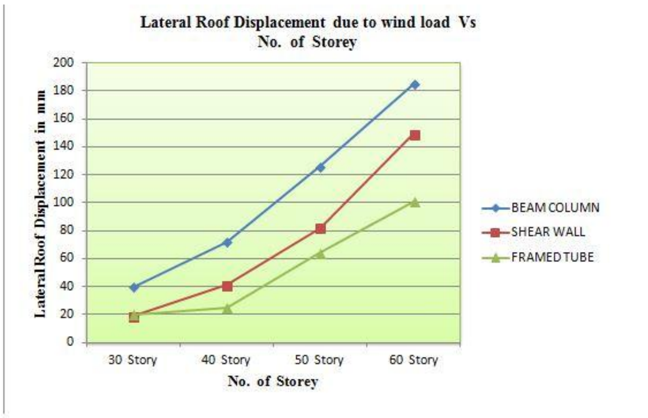

Figure: 5.5a. Graph – Lateral roof

Displacement due to wind load Vs Number of storey

Roof Displacement due to Earthquake Load

Roof displacement for the all structures in the chosen problem are taken and the graph is represented with Lateral roof displacement due to Earthquake load Vs storey number.

Table 5.5b. Roof displacement due to earthquake load

storey	Displacement (mm) for Beam – Column Frame	Displacement (mm) for Shear wall Frame	Displacement (mm) for External Tube Frame
30 storey	30	21	24
40 storey	39	30	29
50 storey	52	42	41
60 storey	62	56	51

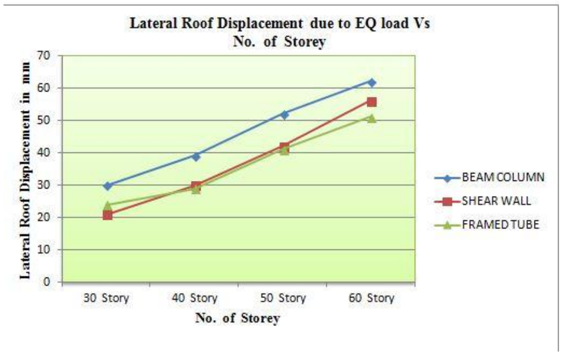

Figure: 5.5b. Graph – Lateral roof displacement due to wind load Vs Number of storey

Comparison of Roof Displacement for Wind and Earthquake Load

Table 5.5c. Roof displacement (mm) for Plain Framed Structure.

Storey	Beam – Column Frame WIND LOAD	Beam – Column Frame EQ LOAD
30 STOREY	40	30
40 STOREY	72	39
50 STOREY	126	52
60 STOREY	185	62

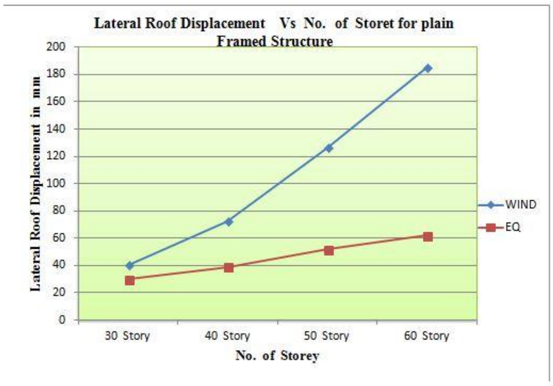

Figure 5.5c. Graph – Lateral roof displacement Vs Number of storey for Plain Frame Structure

Table 5.5d. Roof displacement (mm) for shear wall structure

Storey	Beam– Column Frame WIND LOAD	Beam– Column Frame EQ LOAD
30 STOREY	19	21
40 STOREY	41	30
50 STOREY	82	42
60 STOREY	149	56

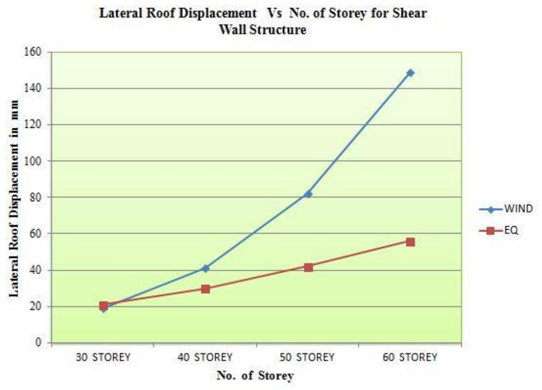

Figure 5.5d. Graph – Lateral roof displacement Vs Number of storey for Shear wall structure

Table 5.5e. Roof displacement (mm) for framed tube structure.

Storey	**Beam – Column Frame WIND LOAD**	**Beam – Column Frame EQ LOAD**
30 STOREY	20	24
40 STOREY	25	28
50 STOREY	64	42
60 STOREY	101	51

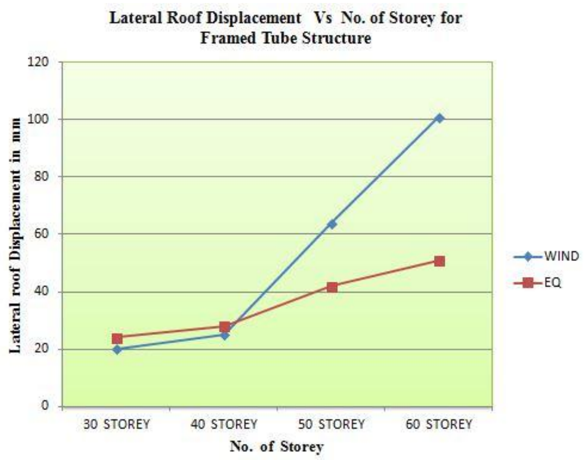

Figure: 5.5e. Graph – Lateral roof displacement Vs Number of storey for Framed Tube Structure

Base Shear due to Lateral Loads

Base Shear is calculated for all the structures, that is for the structures with different lateral structural systems and a graph is presented Base Shear Vs number of storey.

Table 5.6 Base Shear due to lateral loads

BASE SHEAR FOR STRUCTURES WITH OUT INNER CORE			
Base Shear	**Beam – Column Frame kN**	**Shear wall Frame kN**	**External Tube Frame kN**
30 Storey	9554	12270	11992
40 Storey	10740	13884	14931
50 Storey	11824	15004	15710
60 Storey	13566	15449	16521

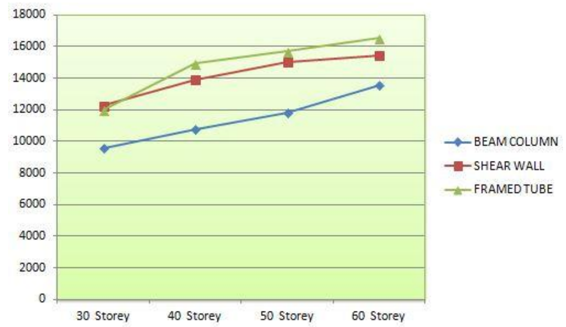

Figure: 5.6. Graph – Base Shear Vs Number of storey

DISCUSSIONS

In the present work a Plain Frame or Beam Column System, Shear wall Frame System and Tube System are considered for 30, 40, 50 and 60 storied Structures. The Internal forces (Support reactions, Bending Moments and Shear Forces) of members, joint displacements have been compared. Based on the results obtained from the work the following discussions are presented.

Comparison of Lateral Displacements due to Wind Load

30- Storey Structure

From table 5.5a and graph 5.5a. It can be illustrated that among the 30 storied structures the structure with Shear wall and Framed tube have got almost similar deflection (difference of about 1 mm) due to Wind load. Maximum displacement is obtained for the dead and wind load combination in all the cases due to wind load.

Roof displacement in shear wall structure is reduced by 52.5% compared to that of plain frame structure. Roof displacement in Framed Tube structure is reduced by 50.0% compared to that of Plain Frame structure.

40- Storey Structure

From table 5.5a and graph 5.5a, It can be illustrated that among the 40 storied structures the structure with Framed tube has got least deflection due to Wind load.

Roof displacement in Shear wall structure is reduced by 46.9% compared to that of plain Frame structure.

Roof displacement in Framed Tube structure is reduced by 65.2% compared to that of Plain Frame structure.

50 – Storey Structure

From table 5.5a and graph 5.5a, It can be illustrated that among the 50 storied structures the structure with Framed tube has got least deflection due to Wind load.

Roof displacement in Shear wall structure is reduced by 34.9% compared to that of plain Frame structure.

Roof displacement in Framed Tube structure is reduced by 49.2% compared to that of Plain Frame structure.

60 – Storey Structure

From table 5.5a and graph 5.5a, It can be illustrated that among the 60 storied structures the structure with Framed tube has got least deflection due to Wind load.

Roof displacement in Shear wall structure is reduced by 19.9% compared to that of plain Frame structure.

Roof displacement in Framed Tube structure is reduced by 45.4% compared to that of Plain Frame structure.

Comparison of Lateral Displacements due to Earthquake Load

30 – Storey Structure

From table 5.5b and graph 5.5b, It can be illustrated that among the 30 storied structures the structure with Shear wall has got least deflection due to Earthquake load.

Roof displacement in Shear wall structure is reduced by 30% compared to that of plain Frame structure.

Roof displacement in Framed Tube structure is reduced by 20% compared to that of Plain Frame structure.

40 – Storey Structure

From table 5.5b and graph 5.5b, It can be illustrated that among the 40 storied structures the structure with Shear wall and Framed tube have got almost similar deflection (difference of about 1 mm) due to Earthquake load.

Roof displacement in Shear wall structure is reduced by 23.1% compared to that of plain Frame structure.

Roof displacement in Framed Tube structure is reduced by 25.6% compared to that of Plain Frame structure.

50 – Storey Structure

From table 5.5b and graph 5.5b, It can be illustrated that among the 50 storied structures the structure with Shear wall and Framed tube have got almost similar deflection (difference of about 1 mm) due to Earthquake load.

Roof displacement in Shear wall structure is reduced by 19.2% compared to that of plain Frame structure.

Roof displacement in Framed Tube structure is reduced by 21.2% compared to that of Plain Frame structure.

60 – Storey Structure

From table 5.5b and graph 5.5b, It can be illustrated that among the 60 storied structures the structure with Framed tube has got least deflection due to Earthquake load.

Roof displacement in Shear wall structure is reduced by 9.7% compared to that of plain Frame structure.

Roof displacement in Framed Tube structure is reduced by 17.8% compared to that of Plain Frame structure.

Comparsion of Lateral Displacements due to Wind Load and Earthquake Load For Similar Structural Systems

Plain Frame Structural System

30 – Storey Structure

From table 5.5c and graph 5.5c, It can be illustrated that for the 30 storied structure with the plain Frame system, the lateral displacement due to wind load is dominant over that of Earthquake load. Lateral displacement due to wind load is greater by 33% of that of the Earthquake load. Maximum displacement is obtained for the dead and Earthquake load combination in all the cases due to Earthquake.

40 – Storey Structure

From table 5.5c and graph 5.5c, It can be illustrated that for the 40 storied structure with the plain Frame system, the lateral displacement due to wind load is dominant over that of Earthquake load. Lateral displacement due to wind load is greater by 84% of that of the Earthquake load.

50 – Storey Structure

From table 5.5c and graph 5.5c, It can be illustrated that for the 50 storied structure with the plain Frame system, the lateral displacement due to wind load is dominant over that of Earthquake load. Lateral displacement due to wind load is greater by 142% of that of the Earthquake load.

60 – Storey Structure

From table 5.5c and graph 5.5c, It can be illustrated that for the 60 storied structure with the plain Frame system, the lateral displacement due to wind load is dominant over that of Earthquake load. Lateral displacement due to wind load is greater by 198% of that of the Earthquake load.

Shear Wall Structural System

30 – Storey Structure

From table 5.5d and graph 5.5d, It can be illustrated that for the 30 storied structures with Shear Wall system, the lateral displacement due to wind load and that of Earthquake Load are almost similar with a difference of about 4% in between them.

40 – Storey Structure

From table 5.5d and graph 5.5d, It can be illustrated that for the 40 storied structures with Shear Wall system, the lateral displacement due to wind load is dominant over that of Earthquake load. Lateral displacement due to wind load is greater by 36.6% to that of the Earthquake load.

50 – Storey Structure

From table 5.5d and graph 5.5d, It can be illustrated that for the 50 storied structures with Shear Wall system, the lateral displacement due to wind load is highly dominant over that of Earthquake load. Lateral displacement due to wind load is greater by 95.2% to that of the Earthquake load.

60 – Storey Structure

From table 5.5d and graph 5.5d, It can be illustrated that for the 60 storied structures with Shear Wall system, the lateral displacement due to wind load is very much dominant over that of Earthquake load. Lateral displacement due to wind load is greater by 166.6% to that of the Earthquake load.

Framed Tube Structural System

30 – Storey Structure

From table 5.5e and graph 5.5e, It can be illustrated that for the 30 storied structures with Framed Tube system, the lateral displacement due to Earthquake load is dominant over that of Wind load. Lateral displacement due to Earthquake load is greater by 20% to that of the Wind load.

40 – Storey Structure

From table 5.5e and graph 5.5e, It can be illustrated that for the 40 storied structures with Framed Tube system, the lateral displacement due to Earthquake load is dominant over that of wind load. Lateral displacement due to Earthquake load is greater by 16% to that of the Wind load.

50 – Storey Structure

From table 5.5e and graph 5.5e, It can be illustrated that for the 50 storied structures with Framed Tube system, the lateral displacement due to Wind load is highly dominant over that of Earthquake load. Lateral displacement due to Wind load is greater by 56% to that of the Earthquake load.

60 – Storey Structure

From table 5.5e and graph 5.5e, It can be illustrated that for the 60 storied structures with Framed Tube system, the lateral displacement due to Wind load is highly dominant over that of Earthquake load. Lateral displacement due to Wind load is greater by 98% to that of the Earthquake load.

Comparison of Base Shear

Base Shear is maximum lateral load resisted by the Structure at the base of the structure. From the table 5.6 and graph 5.6 the following discussions are drawn.

30 – Storey Structure

Base Shear is maximum for the Shear wall structure, It is increased by 28.4 % to that of Plain Frame system.

Base Shear Framed Tube system is increased by 25.5 % to that of Plain Frame system.

40 – Storey Structure

Base Shear is maximum for the Framed Tube structure, It is increased by 39.1 % to that of Plain Frame system.

Base Shear for the Shear Wall system is increased by 29 % to that of Plain Frame system.

50 – Storey Structure

Base Shear is maximum for the Framed Tube structure, It is increased by 32.9 % to that of Plain Frame system.

Base Shear for the Shear Wall system is increased by 26.9 % to that of Plain Frame system.

60 – Storey Structure

Base Shear is maximum for the Framed Tube structure, It is increased by 21.8 % to that of Plain Frame system.

Base Shear for the Shear Wall system is increased by 13.8 % to that of Plain Frame system.

Internal forces in Column(C 12)

A column on the lee-ward side, located at the 24m from the face along positive x-axis is considered for all the models and their internal forces are studied.

Axial force is found to be the least for the column in the structure with the Framed Tube system, this is due to the close spacing (2 m) of columns compared to other two structures.

Shear in the column is least in the Shear wall structure, as much of the shear is taken by the shear wall in the outer periphery and thus leading to reduced shear in the column.

Moment in the column is least in the Shear wall structure, as much of the moment is taken by the shear wall in outer periphery and thus leading to reduced moment in the column.

CONCLUSIONS

In the present work three lateral structural systems i.e. Plain frame System, Shear wall System and Framed tube system are considered for 30, 40, 50 and 60 storey structures. Based on results obtained from the work, the following conclusions are drawn.

The lateral roof displacements in the 30-storey structures with Shear wall system and Framed tube system are very close (difference of nearly 2%).As the shear wall system is economical compared to the Framed tube system, Shear wall system is preferred. The shear wall acts as a vertical cantilever for the building, the wall is stiff for shorter lengths but as the length goes on increasing the stiffness of the wall decreases, hence it gets ineffective for much higher heights. Roof displacement in Shear wall system is reduced by 52.5% where as in Framed tube system it is reduced by 50% compared to the Plain frame system.

For the 40, 50 and 60 storey structures the framed tube is very much effective in resisting lateral loads (both Wind and Earthquake loads) compared to the Shear wall structures. Framed Tube system is able to resist higher percentages of wind loads compared to the earthquake loads. The decrease in the lateral displacements in the 60 storey Tube structure due to wind load combination is 45.4% whereas due to earthquake load combination is 17.8% compared to the Plain frame structure.

For the structure with framed tube, the maximum support reactions for outer periphery Supports are much less compared to that of the Shear wall structure as the columns are very close to each other.

Maximum Base shear for the 30 storey structure is observed for structure with Shear wall system. Maximum Base Shear for 40, 50 and 60 storey structures is observed for structure with framed tube system.

SCOPE FOR FUTURE WORK

- Slabs can be modeled by using plate bending elements.
- Other structural systems such as Tube in tube and Bundled tube can be considered.
- The effect of parameter of height – Width can also be studied.
- Reinforced concrete and steel concrete members can be taken and a comparison Can be drawn between them.
- Analysis can be carried out by considering infill walls.

REFERENCES

[1] Ali, M. M., The Art of Skyscraper, Genius of Fazlur Khan, Rizzoli International Publications, Inc., New York (forthcoming), 2001.

[2] A.L. Salama, A. Badawi (2005), “Structural Repair and Seismic Upgrading of severely Damaged Bearing Wall Structure, proc. of “Tall Buildings – From Engineering to Sustainability, Hong Kong (www.eproceedings.worldsci.net).

[3] A.M. Chandler. R.K L .Su, and P.C.W Wong (2005). "Application of Strut and Tie Method on Outrigger Braced Cone Wall Buildings", proc. of "Tall Buildings-From Engineering to Sustainability, Hong Kong(www.eproceedings.worldsci.net).

[4] Aysin Sev (2005), "Tubular Systems for Tall Office Buildings with Special cases From Turkey, “proc. of "Tall Buildings – From Engineering Sustainability, HongKong.(www.eproceedings.worldsci.net).

[5] Bo Li, Kejia Yang, Mingke Deng , Xingwen Liang(2005), "Displacement-Based Seismic Design of Shear Wall Structure in Tall Buildings", proc. of "Tall Buildings - From Engineering to Sustainability, Hong Kong. (www.eproceedings .worldsci.net).

[6] Bungule S. Taranath, "Structural Analysis and Design of Tall Buildings", McGraw- Hill Book Company, Singapore, p 1-30 311-340, 1988.

[7] Colaco, J. P., (1971) "Preliminary Design of Shear walls for Tall Buildings", ACI journal, 3rd January.

[8] CTBUH, Architecture of Tall Buildings, Council on Tall Buildings and Urban Habitat, Monograph 30, M. M. Ali and P. J. Armstrong, eds., McGraw-Hill, Inc.New York, 1995.

[9] Electronic Journal of Structural Engineering , Jan-2001

[10] El Nimeiri, M. M. and Khan, F. R., "Structural Systems for Multi-Use High-Rise Buildings, “Developments in Tall Buildings, Van Nostrand Reinhold Company, New York, p. 221, 1983.

[11] Elzner, A. O., “The First Concrete Skyscraper," The Architectural Record, June, p. 515, 1904.

[12] Harries, K. A., "Reinforced Concrete at the Turn of the Century, " Concrete International, January, 1995, pp. 58-62.

[13] Huxtable, A .L. "Reinforced Concrete Construction: The Work of Ernest L. Ransom 1884-1911,” Progressive Architecture, v.38, September, 1957, pp. 138 – 142.

[14] P. Jayachandran, “Design of Tall Buildings, Preliminary Design and Optimization", Proceedings of seventh International Conference on Computational Structures Technology, Lisbon Portugal, September 2004.

[15] Jiemin Ding, Si Chao, Jianbin Chen (2005), “Design and Research for a Tall Building of Concrete Filled Square Steel Tube", “, proc. of “Tall Buildings – From Engineering to Sustainability, Hong Kong.(www.eproceedings. worldsci.net).

[16] Journal of Structural Engineering, ASCE, 131(1): 75-84, 2005).

[17] Khan, F. R., "Influence of Design Criteria on Selection of Structural Systems for Tall Buildings," Canadian Structural Engineering Conference, Montreal, Canada, March 1972.

[18] Khan F. R and Sbarounis (1964), “Interaction of Shear Walls and Frames”. Journal of the Structural Division, Proc., ASCE.

[19] Khan, F. R. and Sbarounis, J. A., “Interaction of Shear Walls and Frames in Concrete Structures under Lateral Loads, “Journal of the American Society of Civil Engineers, 90 (ST3), June 1964.

[20] Khan, F. R. and Rankine, J., “Structural Systems,” Tall Building Systems and Concepts, Council on Tall Buildings and Urban Habitat/American Society of Civil Engineers, Vol. SC, p. 42, 1980.

[21] Khan, F. R ., “Future of High Rise Structures , “ Progressive Architecture, October 1972.

[22] Malinwski, R. and Garfinkel, Y., 1991. "Prehistory of Concrete: Concrete Slabs Uncovered at Neolithic Archaeological Site in Southern Galilee," Concrete International, March, 1991, pp. 62-68.

[23] NIST, USA, "9/11 Commission report to the public interest" – Jan 2004.

[24] X. G HE (2005), “Behaviour of Concrete Frame – Core wall Structure with Non- Continuous Exterior Frame Beams” proc. of "Tall Buildings – From Engineering to Sustainability, Hong Kong. (www.eproceedings.worldsci.net)

[25] IS: 1893- 2002 - "Criteria for earthquake resistant design of structures “Indian Standards, New Delhi.

[26] IS: 875-1987 Part-3, - "Code of practice for design loads (other than earthquake) for structures", Indian Standards, New Delhi.

[27] www.emporis.com

[28] www.eproceedings.worldsci.net

[29] www.greatbuildings.com

[30] www.istructe.com

[31] www.skyscrapers.com