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Beehive (Hexagrid), New Innovated Structural System for Tall Buildings

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Biography

Dr. Peyman is Director of Structural Engineering of the global consulting engineering practice, TJEG International (Ted Jacob Engineering), and serves on the TJEG global professional board. TJEG is headquartered in San Francisco United State of America, managing a staff of approximately 900 in 20 offices around the world, including more than 100 staff members in the Persian Gulf.

Peyman is the expert high-rise designer for the super tall skyscrapers in the United States and in the Middle East. Currently he is with TJEG International, responsible for many of the high-rise projects undertaken by TJEG around the world. He is an Iranian Engineer who received his PhD in civil engineering, specializing in seismic design, from the University of Sharif Technology associated with UC Berkeley in California, USA and in addition to his educational carrier he also received the project management degree (M.Sc., PMP) from UC Berkeley, California, USA and he is a member of the Scientific Committee of University of IAU Knowledge village Dubai-UAE.

He was selected as Chairman of the Seismic Committee of High-rise & Complex Building in International Congress on Seismic Retrofitting in Iran (March 2006), and serves on several International Code Committees. He received the first World University Students Olympiad award in Mathematic and physic, University of Toronto, Canada. (Feb. 1997) And also the Article Award for his presentation on concrete deep beams using perforated steel plates at The 7th International Conference on Multi-Purpose High Rise Towers and Tall Building, in Dubai (December 2005).

ABSTRACT

Tall Buildings have been one of the most prominent symbols of economic growth for nearly a century. Yet, in the aftermath of the tragedies of September 11, “signature” Tall buildings have become the focus of much debate. The structural systems today are undergoing a major evolution to address the ability of providing flexibility in the design and use of the building together with sustainability (Green) and cost-effective system.

This paper describes a new invented structural system, evolutionary structural analysis and design of Tall buildings, which involves the entire analysis process, including conceptual and design stages and comparison with the existing Tall building. This study presents an new innovative structural system, Beehive (Hexagrid), for Tall buildings. The final results are achieved by modeling an 80 story Tall building with the optimized angle and topology of hexagon members by using a computer analysis, ETABS finite element analysis. The objective function of this system is to use one structural system in order to both maximize Eigen frequency for resisting dynamic responses and minimize mean compliance for static responses. Finite element analysis is carried out by using standardized materials. Optimal Hexagrid topologies with the highest stiffness are finally determined to resist both static and dynamic behaviors.

Holistic design integration approaches between structures and facades to save energy for environmental control are studied. Innovative design ideas to control structural motion as well as to utilize that motion to harness energy are discussed. Considering abundant emergence of tall buildings all over the world in recent years, the importance of the studies presented in this paper cannot be overemphasized for constructing more sustainable built environments.

Keywords: Tall building, Innovative, Steel-framed HexaGrid (Beehive), New System, Optimal Design Structure,

Introduction

Tall buildings have great potential of creating sustainable built environments by their own nature. Compared with the cities with low-rise buildings, those with tall buildings use land more efficiently. Early designs of tall buildings recognized the effectiveness of diagonal bracing members in resisting lateral forces. Most of the structural systems deployed for early tall buildings were steel frames with diagonal bracings of various configurations such as X, K, and chevron.

A major point of this design approach is to introduce a new structural system for Tall building.
The hexagonal and diamonds were located along the entire exterior perimeter surfaces of the building in order to maximize their structural effectiveness and capitalize on the aesthetic innovation. This strategy is much more effective than confining diagonals to narrower building cores. In the hexagrid structure system, almost all the conventional vertical columns are eliminated. Our approach is to define a unique structural system for Tall building in order to minimize additional system for lateral loads (lateral system). In this system (Beehive), members in hexagrid structural systems can carry gravity loads as well as lateral forces due to their hexagonized configuration in a distributive and uniform manner. Compared with other systems in Tall buildings, hexagrid structures are much more effective in minimizing shear deformation because they carry shear by axial action of the diagonal members, while other structures carry shear by the bending of the vertical columns and horizontal spandrels.
The hexagrid structure provides both bending and shears rigidity and does not need high shear rigidity cores because shear can be carried by the Hexagon and diamond elements located on the perimeter.

Beehive Structure

In nature, bees have a fascinating, meticulous way of forming their beehives, which serve as their homes, their protection and their source of life.

Figure 1-Natural Forms and Structures,
PA' Properties, The Structural of Peyman A. Nejad

"There is nothing new under the Sky" This does not mean that everything has been built already but that the principle behind the design already exists. By examining structures in nature we can see where the principle exists and see how these principles are incorporated in structures today. One thing we have to keep in mind when comparing natural and manmade structures is that nature uses live materials while a man uses inert ones and the two do not always behave in the same manner.

The beehive's internal structure is a densely packed matrix of hexagonal cells called a honeycomb. The bees use the cells to store food, and to house the "brood". The hexagonal shape perfectly distributes and disperses the external man-made or environmental forces thus protecting its contents. The hexagon also allows simple expandability by adding hexagon segments to the perimeter of the honeycomb. The simplicity of the hexagonal shape creates an incredibly strong and smart design which provides great stability and security for the bees.

Figure 2- the beehive's internal structure, PA's Properties, the Structural of Peyman A. Nejad

Hexagrid; Optimized Topology

In this article an optimal angle and a topology of diagonal members in a Hexagrid frame has been investigated. Hexagrid consists of intersecting the diagonal and horizontal structural components. This type of system transferred both gravity and lateral loads and eliminates the need for vertical columns on the exterior of the building. The topology of the Hexagrid system is an important design variable since the degree of an angle between diagonal members consisting of Hexagrid determines stress distribution resisting internal forces. Therefore, the effects of diagonal angles in the Hexagrid system should be considered in order to obtain an optimal Hexagrid topology with the highest stiffness in design phases. Distinctive geometric features of each project (i.e. building dimensions, story height and so on) influence an optimized Hexagrid topology, therefore the diagonal angles, number of bays of Hexagrid, Hexagrid height and etc. should be carefully determined on a project by project basis.
The Hexagrid optimization process can be achieved by finite element analyses and appropriate sensitivity studies with respect to the topology of diagonal members. The objective of the optimization process is to both maximize Eigen frequency for resisting dynamic responses and minimize mean compliance for static responses. Further investigations are necessary to understand global and topological Hexagrid mechanism and, eventually, to develop simplified and practical analysis and design tools of the Hexagrid system.

HexaGrid; Structural Analysis Procedures

Hexagrid structural system consists of Hexagrid perimeter which is made up of a network of multi-story tall hex-angulated truss system. Hexagrid is formed by intersecting the diagonal and horizontal components. This innovation transfers both gravity loads and lateral loads by redirecting member forces, and eliminates the need for vertical columns on the exterior of the building. Architecturally the absence of columns in the corners of the building provides great panoramic views from the interior.
Structurally, the degree of an angle between diagonal members consisting of Hexagird nodes is a significant design variable to determine stress distribution resisting internal forces into Hexagrid as well as a building system. In addition, the stress distribution changes depending on the height and span of a given building and the member size like thickness of Diagrid. Most of all, connectivity among the hexagrid members linked to member angles is the first considerable element for hexagrid analysis, since investigation of connectivity, i.e. topology provides us with global systematical mechanism. In order to measure hexagrid member analysis and compare the results, in the comparison presented here, diverse pined supports for boundary condition are deposited into a given initial design space.
Pined support positions are modeled by initial domain distributions of density which is referred to as design variables. The column-shape, and beam-shape, which depend on initial topologies into design space, i.e. angles of Pined supports. Positions where relatively large stress acts are structurally weak, and therefore material supplement needs to be properly stiffened there. The optimal density assignments are equal to stress distributions as shown in Fig.   As can be seen, stress at the center node position which is produced by a horizontal load is larger than that by a vertical load. It means that material reinforcement for resisting a horizontal load is more necessary than one for a vertical load. The largest stress acts to the node part in all the angle models, and therefore a node part or a connection of diagonal members is the most significant reinforcement component with respect to structural safety in Hexagrid systems. The following points are highlighted regarding analysis of Hexagrid system;

- The Hexagrids are redundant and load path following.
- The Hexagrids combines the benefits of a hollow tube with those of a truss and its chords.
- The angled setting of the columnar elements allows for a natural flow of forces through the structure.
- In this manner, both gravity loads and lateral loads are transferred through the Hexagrid to the ground below
- Loads are able to follow the hexagons through the structure as it naturally resists vectors of forces through its hexagonal shapes.
- Load paths are continuous and uninterrupted
- Vertical gravity loads follow the structure of the tube from top to base along the hexagonal members of said tube
- The same vertical gravity loads are able to transfer from one columnar element to another in the rare or designed case of an interruption

- The exploitation of steel's compressive and tensile abilities creates a need for less steel in a building using the Hexagrid system.

HexaGrid; Architectural

Here is an example of the design research project, Beehive Tower's Design at London, Designed by Rory Newel & Lucy Richardson, the 220m high Beehive Towers. It's a vertical farm inspired by the hexagonal forms of the honeycomb in Heron Quay, London. Each hexagon is 8 stories high and contains 8 duplex apartments. A number of the hex cavities are dedicated to gardening and face in different directions so that each element gets a fair share of sun.

The structure features a number of sustainable systems such as an army of wind turbines that sits atop it and a rainwater collection system to water the crops within it.

Figure 3- 3D Model of Beehive Tower, London. The Architectural of Rory Newel & Lucy Richardson

HexaGrid; Structural System

Temporarily ignoring the box shape, one can simplify the structure shown here into a series of hexagons - connected at 'nodes' - and rings – that intersect the hexagons at the 'nodes.'

– What can be seen then is a hexagonated, ring perimeter framed system - the **HexaGrid.**

– In this image the Hexagrid is rendered in different colors (due to the different young modulus and section for the structure)

– "it acts as a rigid shell, and for structural purposes can be considered a very thin, deep beam"

– both the hexagons and the rings are here formed from wide flanged rolled sections that are welded or bolted for full restraint (they can be constructed from other materials as well)

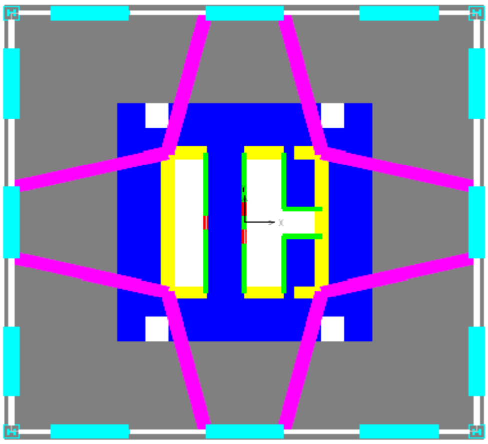


Figure 4- 3D View of Analysis Structural Model PA's Properties, The Structural of Peyman Nejad

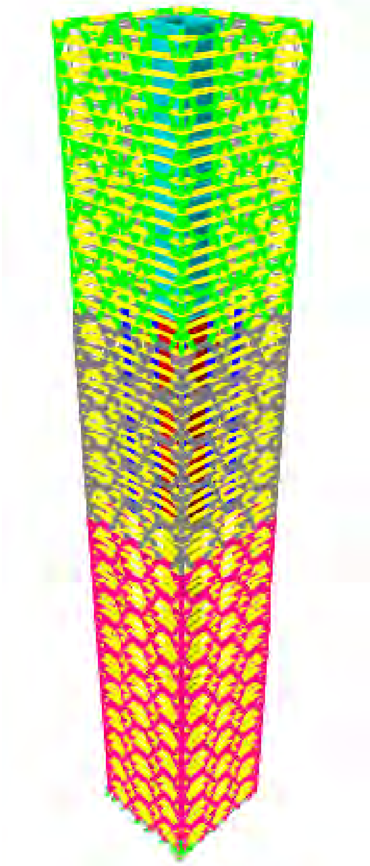


Figure 5- 3D Plan of Analysis,PA's Properties The Structural of Peyman A. Neja.

HexaGrid; Nodes + Load Path Transference

The Hexagrid system offers several advantages in addition to eliminating perimeter columns. Most notably it optimizes each structural element. Typically, columns are used to provide vertical-load-carrying capacity, and diagonals or braces provide stability and resistance to large forces, such as wind and seismic loads. But here hexagons and diagonals are participating in the vertical load transfer, and the lateral load under ideal assumptions in a typical high-rise. In a hexagrid system the two functions are working together, such as couple. The hexagons and diagonals are all one.

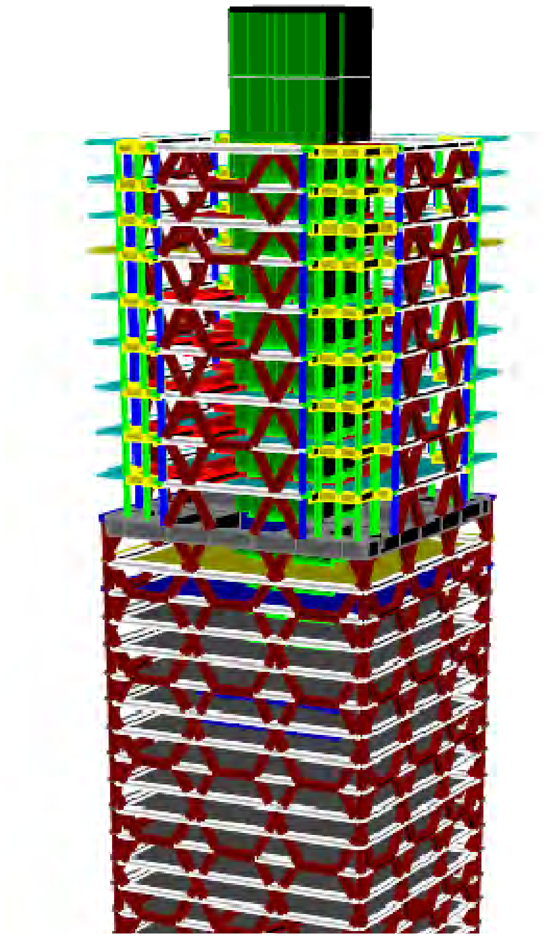


Figure 6- 3D Analysis Model, PA's Properties.

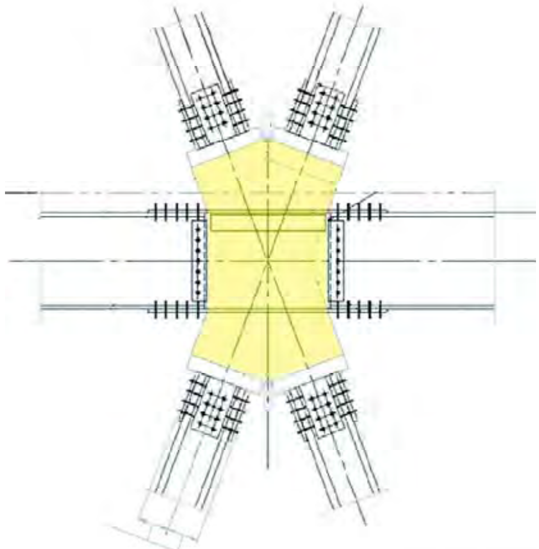


Figure 7- Nodes & Load Path.

The Structural of Peyman A. Nejad

HexaGrid; Comparison Analysis

The following graphs represent the results of comparison analysis between current innovated system, Hexagrid, adapted to the existing structural system, perimeter framed tube with a core shear wall plus out-riggers wall which is located in the Dubai Marina and It's a 90-story tall and it has been build already.

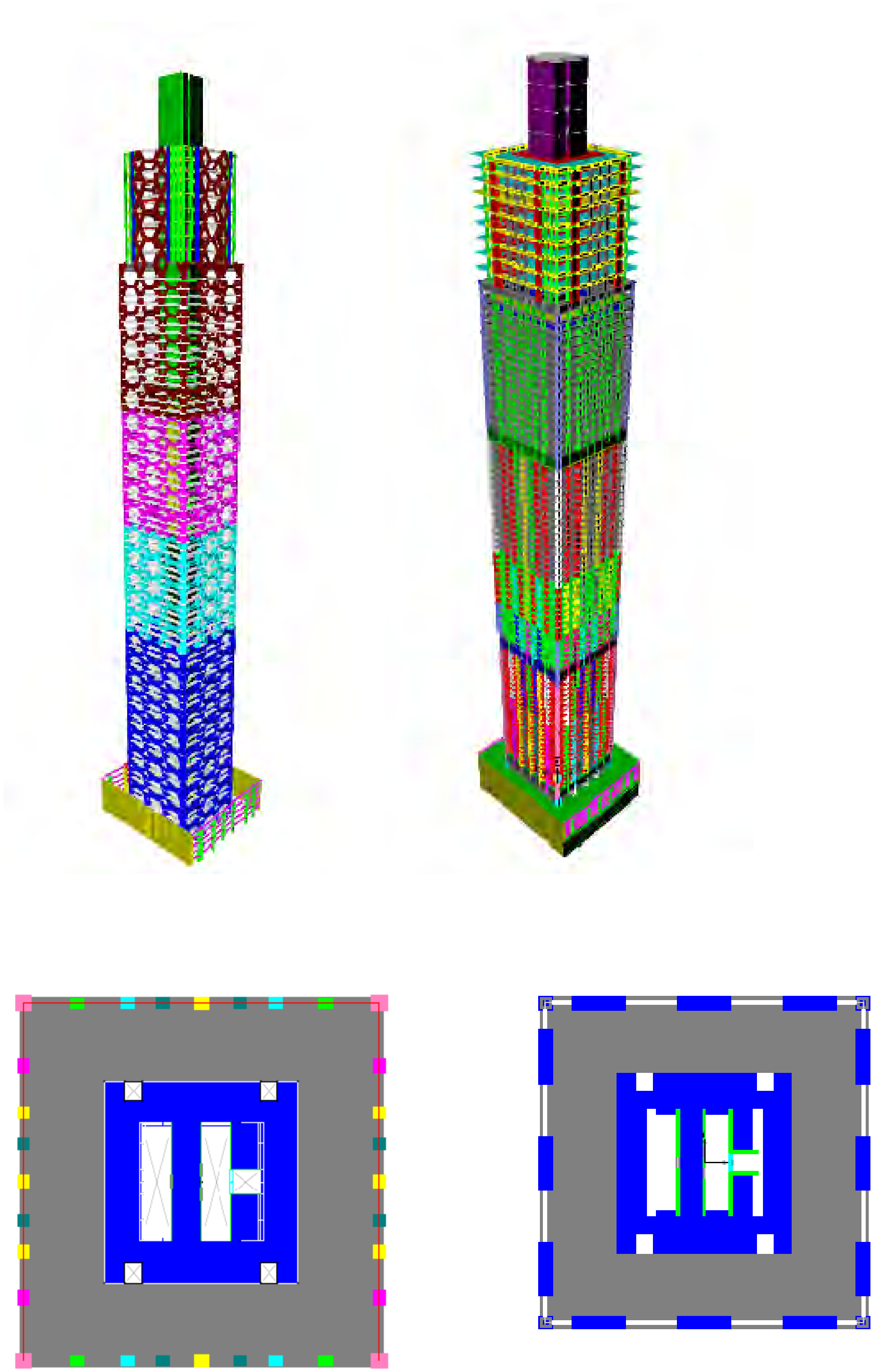


Figure 8- Three Dimensional Analysis 3D View & Plan of Structural Analysis Models). PA's Properties, The Structural of Peyman A. Nejad.

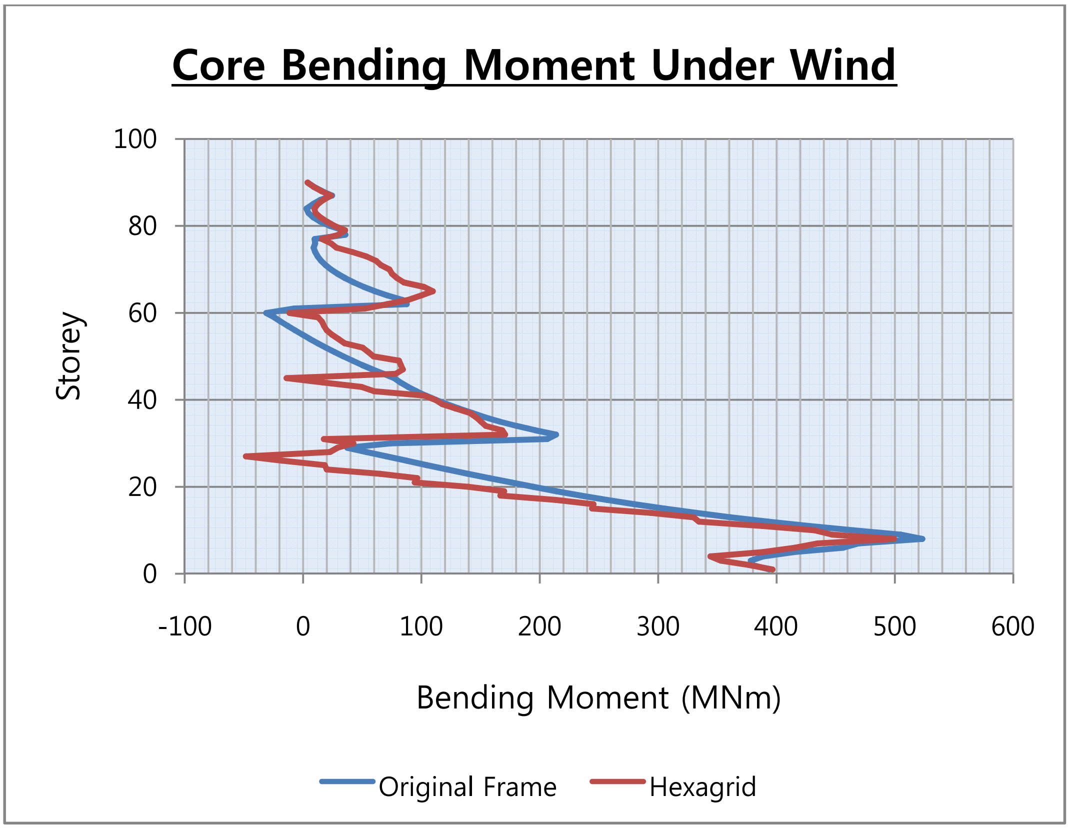


Figure 9- Bending Moment Diagram, PA's Properties, The Structural of Peyman A. Nejad

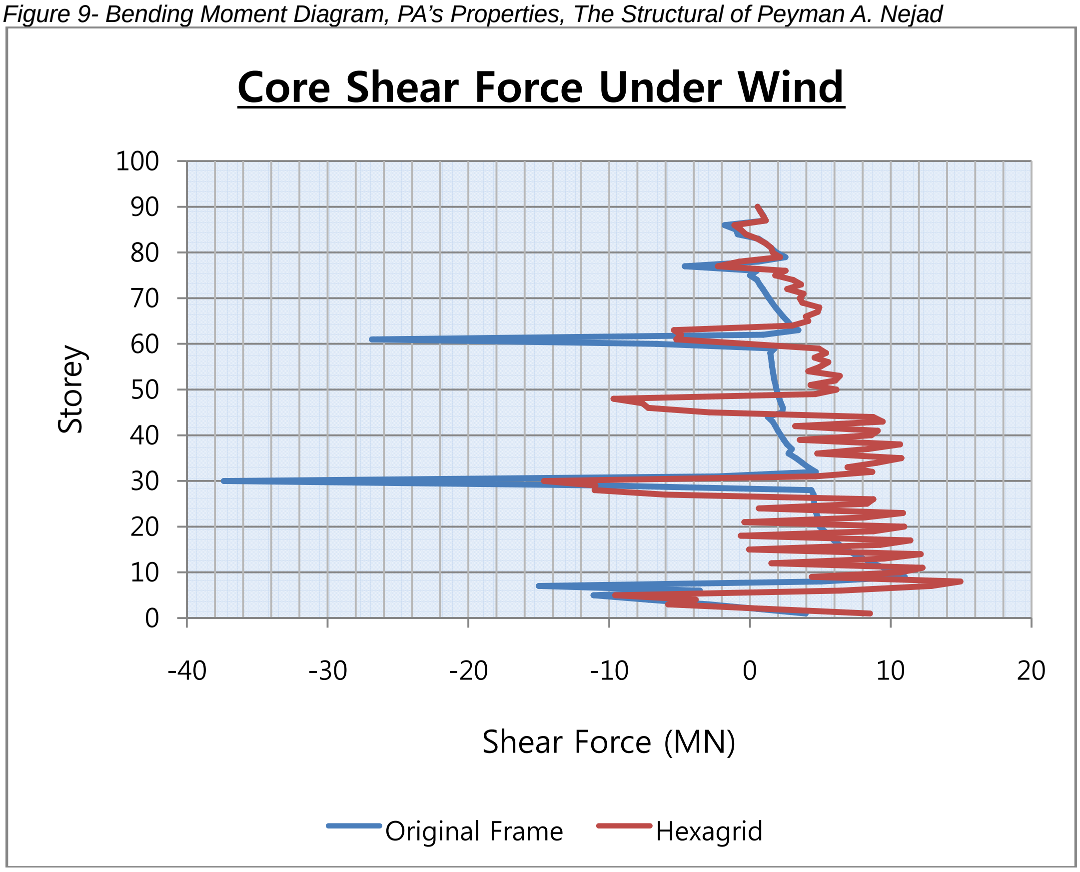


Figure 10- Shear Force Diagram, PA's Properties, The Structural of Peyman A. Nejad

HexaGrid; Analysis – Stiffness

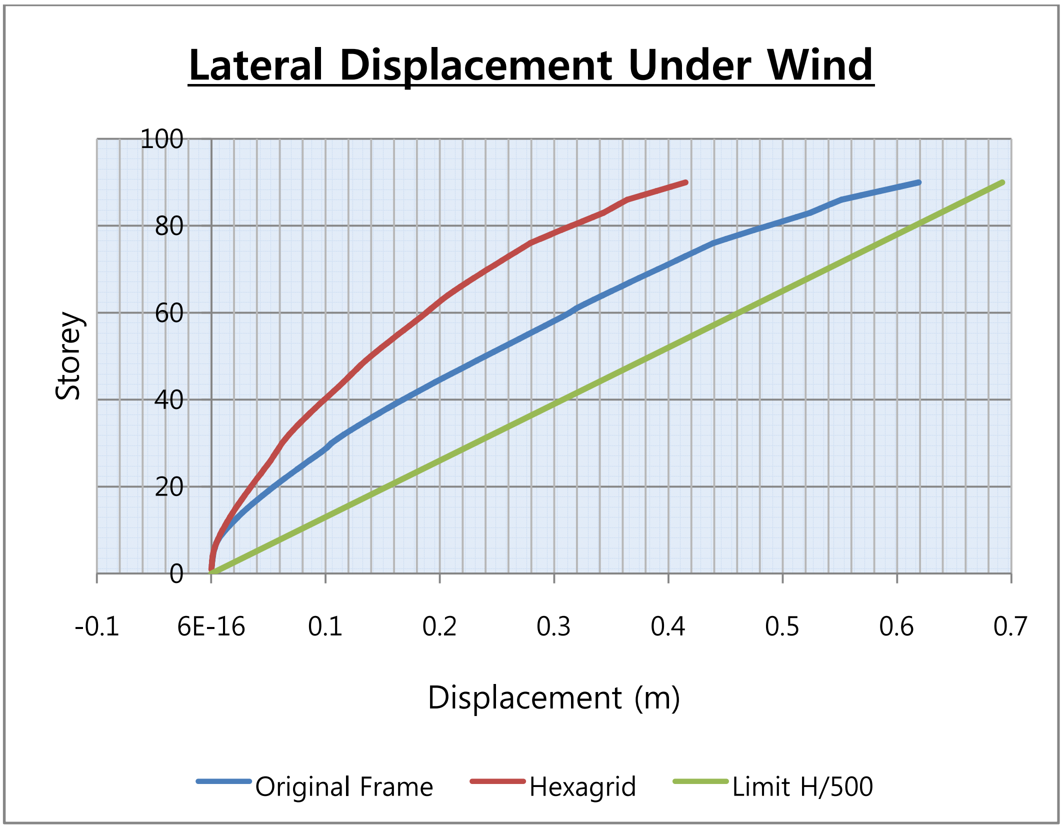


Figure 11- Lateral Displacement Diagram, PA's Properties, The Structural of Peyman A. Nejad

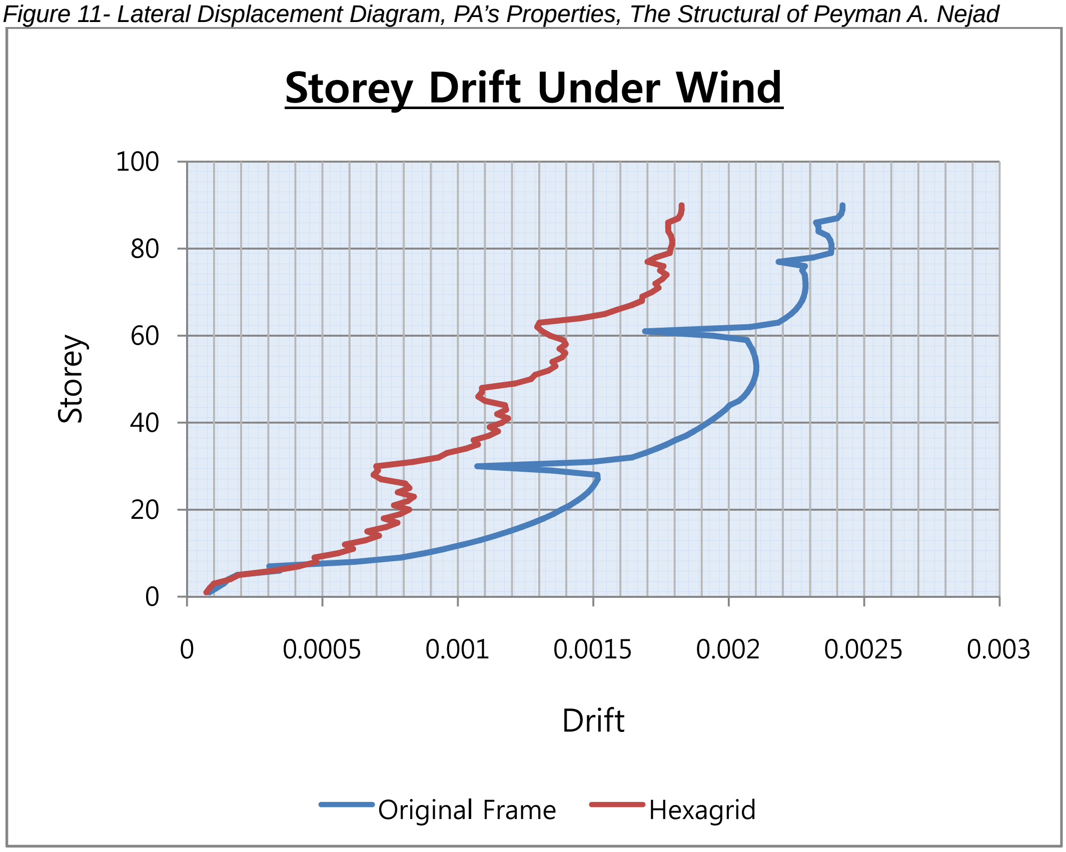
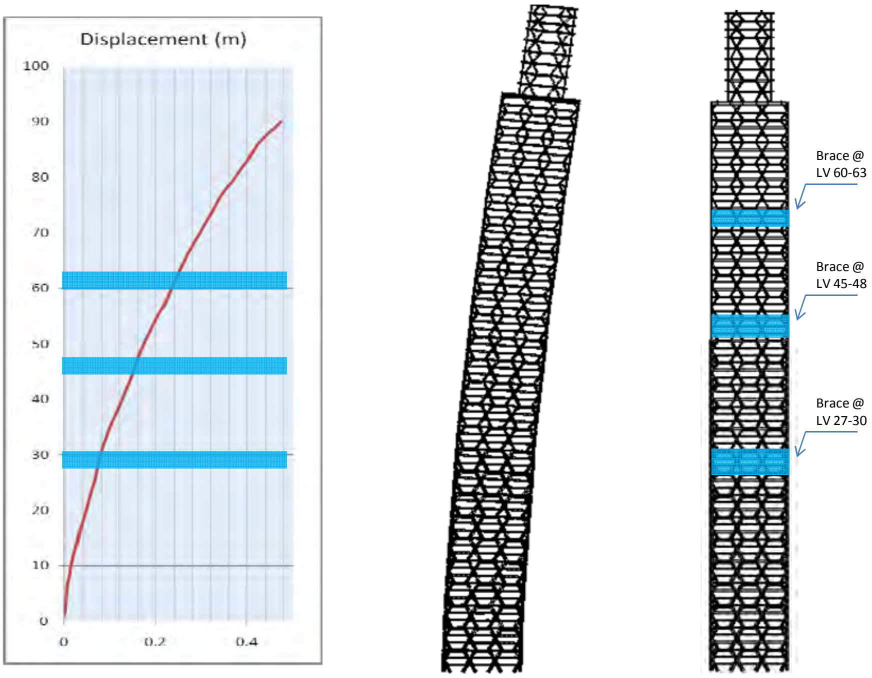


Figure 12- Story Drift Diagram, PA's Properties, The Structural of Peyman A. Nejad

Hexagrid Lateral Displacement under Wind

Hexagrid Lateral Displacement under Wind (X-Direction)



Hexagrid Lateral Displacement under Wind (Y-Direction)

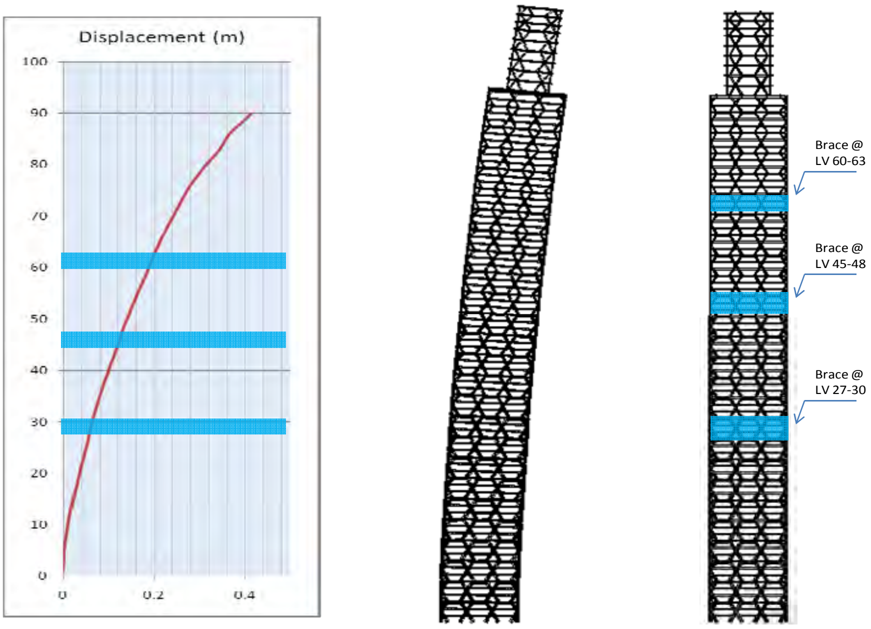


Figure 13- Lateral Displacement Diagrams, PA's Properties, The Structural of Peyman A. Nejad

Analysis – Lateral Stiffness, MEP Level

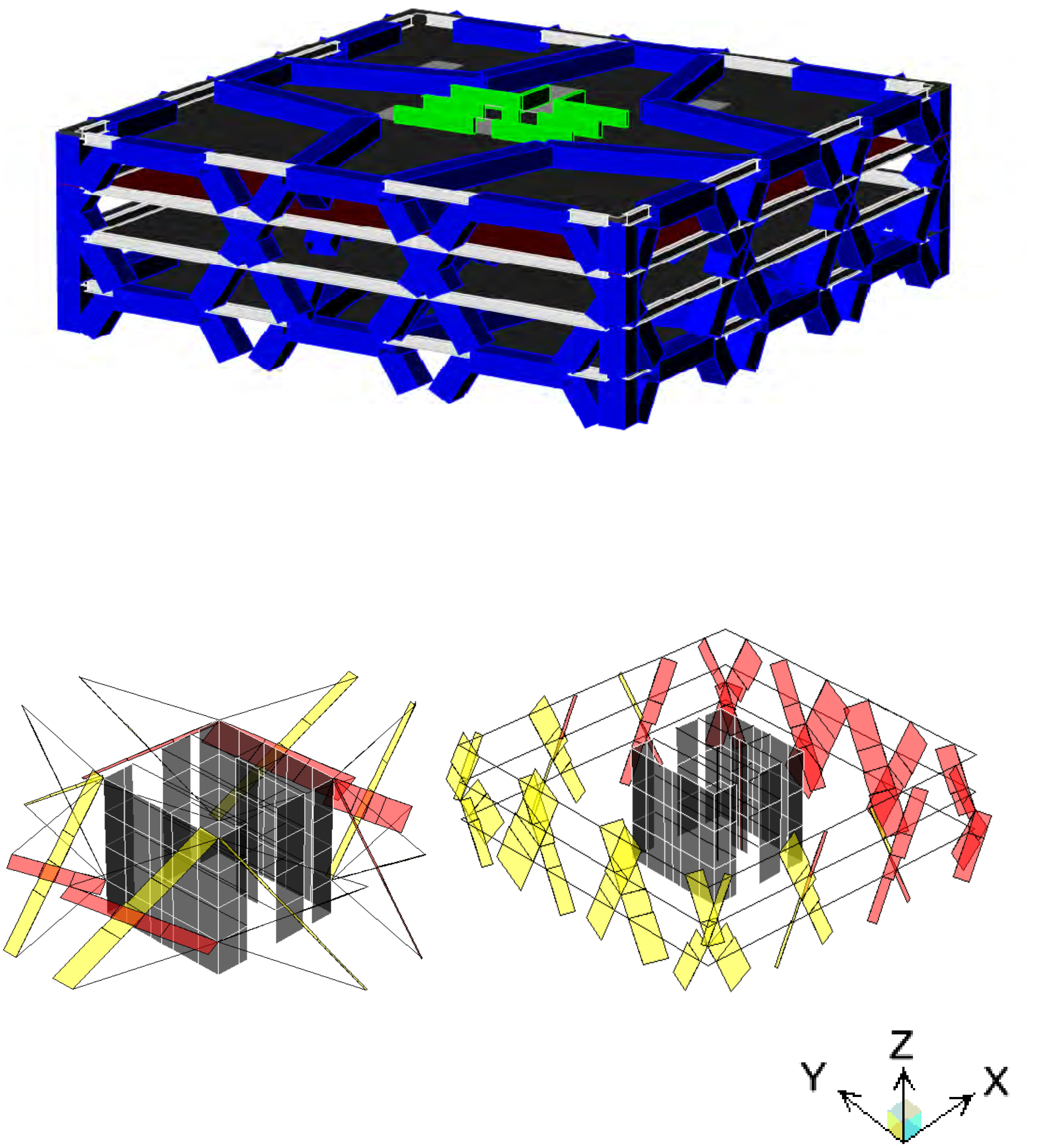


Figure 14- MEP Level Lateral Bracing & Hexagrid Axial ForceDiagrams under Wind X, PA's Properties, The Structural of Peyman A. Nejad.

Hexagrid Elevation with Axial Force under Wind X

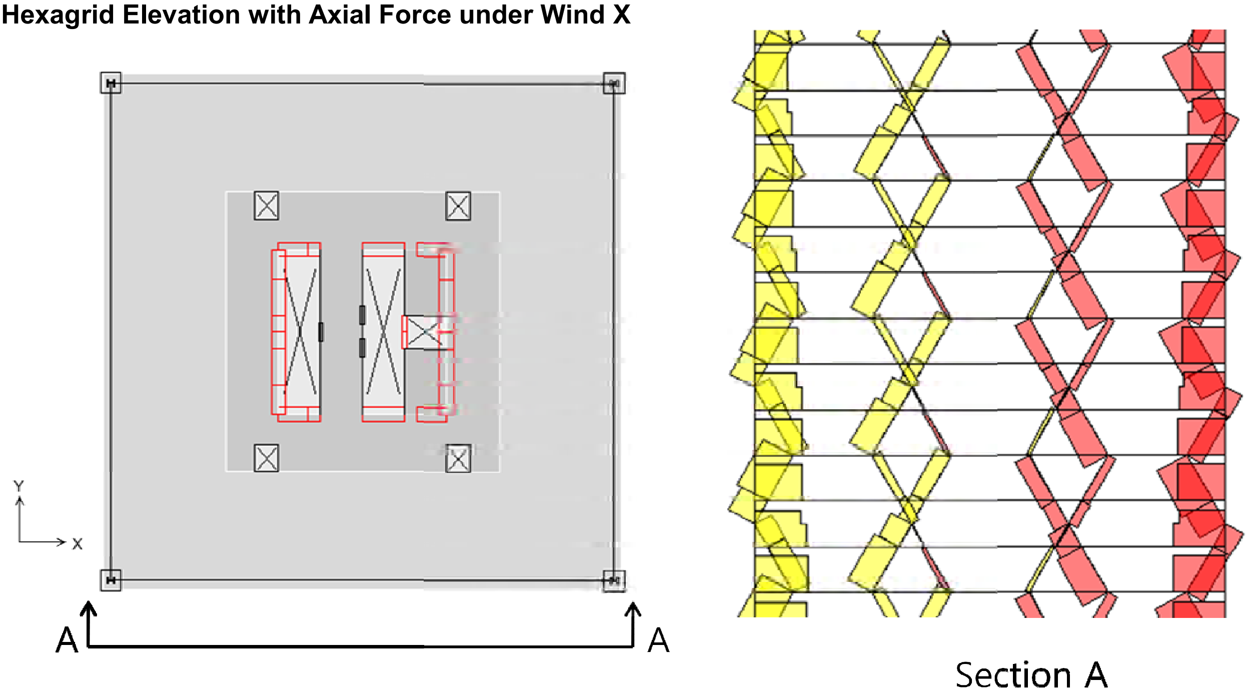


Figure 15- Axial Force Diagram, PA's Properties, The Structural of Peyman A. Nejad

Hexagrid Elevation with Shear Force under Wind X

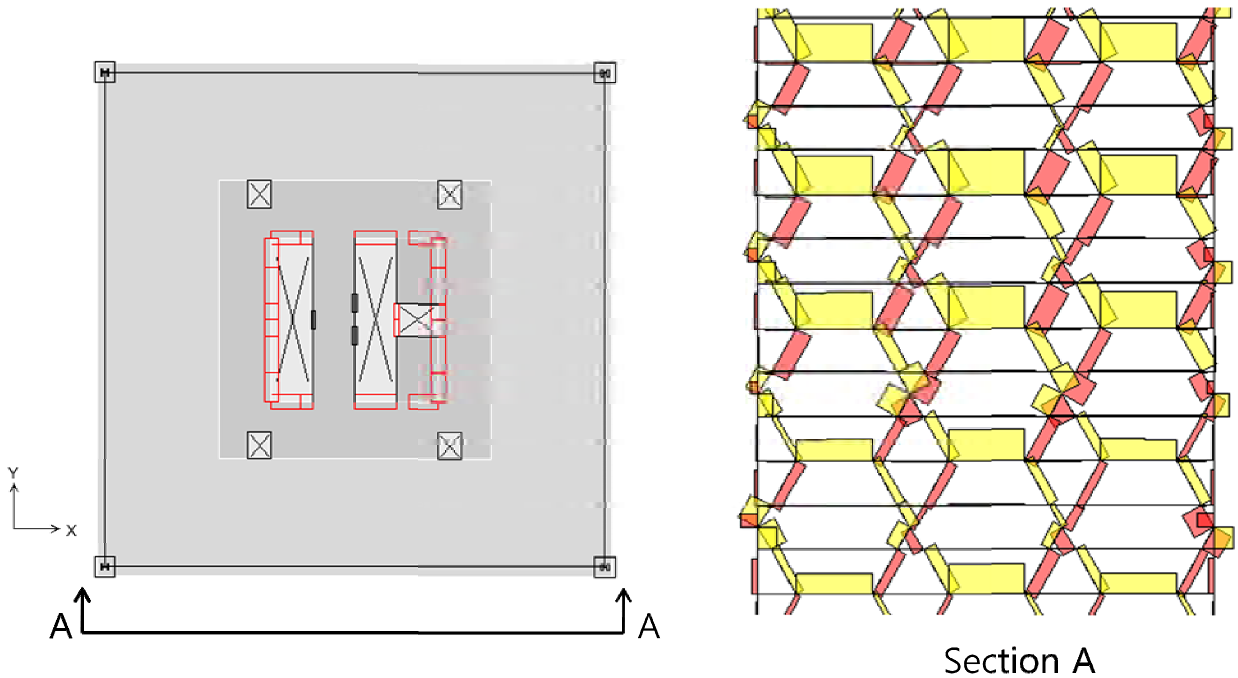


Figure 16- Shear Force Diagram, PA's Properties, The Structural of Peyman A. Nejad

Core Elevation with Axial Force under Wind X

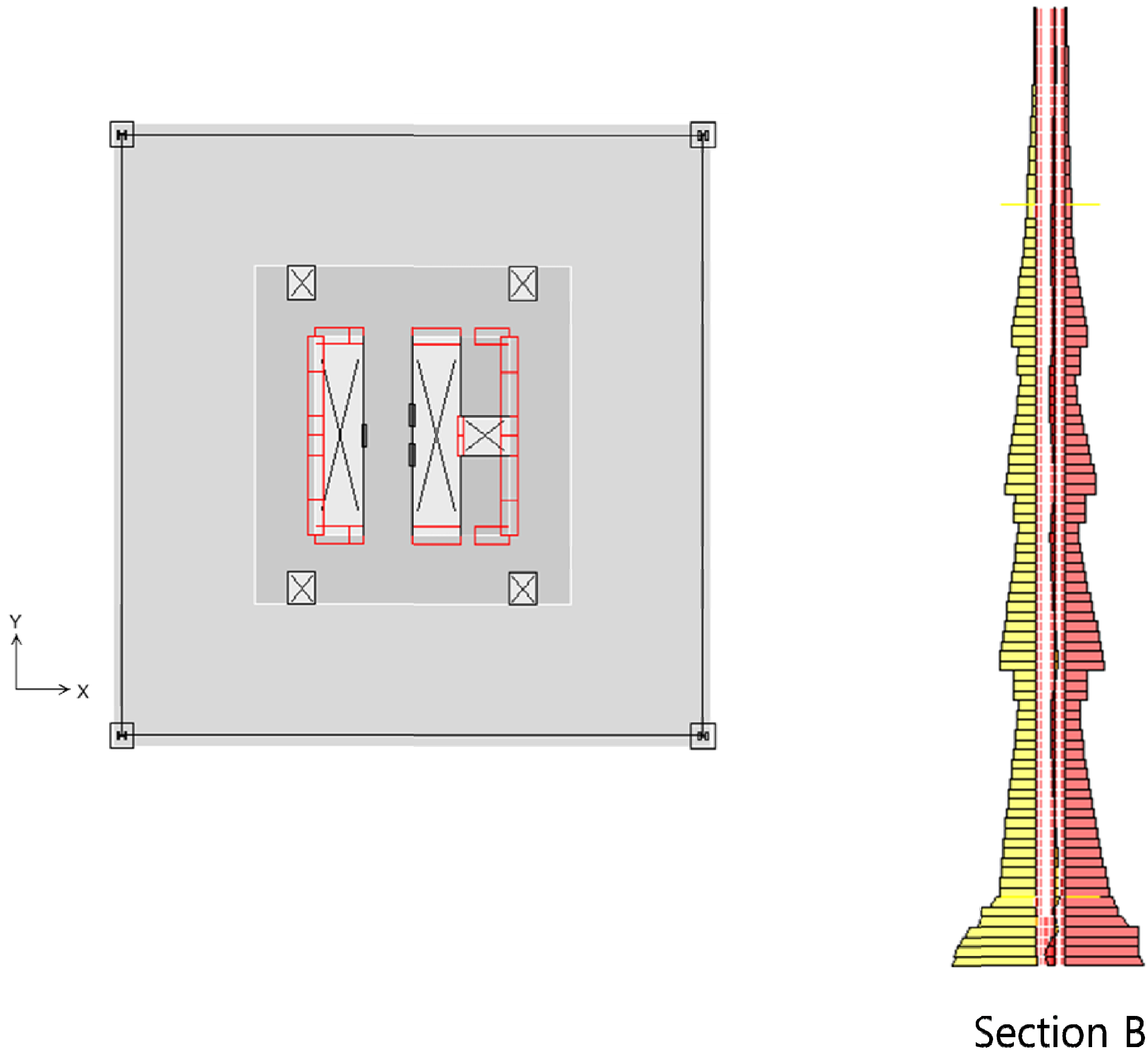


Figure 17-Core Axial Force Diagram, PA's Properties, The Structural of Peyman A. Nejad

Swiss Re by Foster as an Example

Figure 17- The Diagrid Node after assembly construction for use on the Swiss Re

This is an obvious indication of the importance of these elements in the Hexagonal frame– the stand alone of a diagrid. The advantage of having diagrid within our hexagonal frame creates needs for less steel in our structure. Diagrids employ configurations of members such as to take full advantage of said members' inherent ability to resist compression and tension. Due to this reason, most diagrids employed today are constructed of steel, such as the Swiss Re Tower.

HexaGrid Implementation

- Thorough use of material leads to ability to express organic form in anew(er) structural system.
- Most structural forms that can be created with a hexagonal form (within reason) can be assumed possible.
- Note that floor plates must not be regular - they can change from one level to the next.
- As long as the structural skin employed in a Hexgrid is mostly continuous, the structure can rather safely be assumed acceptable and more stable.
- Most cladding and enclosure types available on typical skyscrapers are available on a Hexagrid.
- Form can be derived from the Hexagrid or the Hexagrid can be derived out of necessity from the form.
- Materially, there are multiple choices of material for use when employing a HexaGrid, such as; Steel (the most common), Wood, Composite (Concrete &Steel). But Steel is the typical material of choice due to its high abilities to resist both tensile and compressive forces.

HexaGrid: Advantages

- Mostly column free exterior and some but not all, interior.
- Generous amounts of day lighting due to dearth of interior columns and structure
- Less Material, Roughly %10 to %15 reduction in steel possible.

- Global systematical mechanism.
  petitive, Hexagrid Frame Connections between Floor.
  nple construction techniques (although they need to be perfected yet)
- Full exploitation of the structural material
- Similar design/construction tolerances as a typical moment frame construct.
- Free and clear, unique floor plans are possible
- Aesthetically dominate and expressive.
- Redundancy in the HexaGrid design is obvious.
- Skyscraper structural failure, as it is such an important/ prominent topic, can be minimized in a HexaGrid design.
- A HexaGrid has better ability to redistribute load than a Moment Frame skyscraper. Therefore, there is deserved appeal for the HexaGrid in today's landscape of Tall building.
- Lighter Building → Less Foundation Materials.

HexaGrid: Disadvantage

- Construction crews can be an issue, having little or no experience of creating a hexagrid.
- It is hard to design windows that create a regular language from floor to floor.
- Execution, the Hexagrid is heavy-handed if not executed properly.

Conclusion

- It is a self reliant structure – the core of the typical residential building has little effect on a hexaGrid.
- Similar to a typical moment frame, the hexagrid effectively spreads its mass from its center and thus develops strength and resistance ability to forces from multiple sources and directions.
- The main departure then from a moment frame is the ability of a hexagrid to resist lateral forces due to the stiffness inherent in its simplicity and shape.
- The use of the hexagrid in skyscraper design is a relatively new idea. As such, a new or more explored language of the structural system has yet to appear.

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