JETIR.ORG
ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

AN ASSESSMENT OF ARCHITECTURAL AND STRUCTURAL ASPECTS OF SKYSCRAPERS

[1]Aradhya Nayan, [2]Mrs. Kalpana R. Thakre

[1]Final year Student, [2]Guide & H.O.D,
[1]Department of Architecture,
[1]Kavikulguru Institute of Technology and Science, RTM Nagpur University, Nagpur, India.

Abstract: Due to limited land availability in crowded places and their principal function as necessary structures in contemporary cities and capitals, the number of high-rise buildings has been rapidly expanding throughout the world. Contrary to low-rise structures, high-rise structures require a high level of structural stability for both safety and design purposes, making them far more complicated than low-rise structures. The purpose of this essay is to give readers a quick overview of high-rise structures, including their basic description, safety features, structural stability, and design difficulties. This paper is intended to help in the development and application of construction systems for high-rise buildings in the future.

***Index Terms* – Skyscraper, High-rise, Building, Shear-Load, Stability, Structure**

I. INTRODUCTION

A skyscraper is different from a high-rise building, which is typically defined as any structure taller than 24 meters. Buildings with a height of more than 45 storey or 150 meters are considered skyscrapers. Skyscrapers were created as a result of various technological and societal advancements occurring at the same time. Originally, the term "skyscraper" referred to structures with 10 to 20 floors, but by the late 20th century, it had come to refer to high-rise structures with extraordinary heights, typically larger than 40 or 50 stories and taller than usual.

Figure 1: Home Insurance building, Chicago
Source: https://www.theguardian.com/cities/2015/apr/02/worlds-first-skyscraper-chicago-home-insurance-building-history

The majority of building designs require sound structural planning, but skyscrapers require it much more because even a small probability of catastrophic collapse is unacceptable given the exorbitant cost of construction. For civil engineers, this poses a paradox: the only way to guarantee a lack of failure is to test for all failure modes, both in the lab and in the real world. But learning from past failures is the only way to get familiar with all failure modes. Therefore, no engineer can guarantee that a given structure will withstand all loads that could lead to failure; they can only ensure that there are sufficient margins of safety to make a failure tolerably rare. When buildings do fail, engineers question whether the failure was due to some lack of foresight or due to some unknowable factor.

The skyscrapers are considered icons in today's globe and are constantly being built. Below are some comparisons between recent buildings of various heights and uses. Home Insurance Building was built with metal, not merely masonry, and reached an astounding height of 10 stories (and 12 with an expansion in 1890). According to legend, Jenney, an engineer by trade and a classmate of Gustave Eiffel (the architect of the tower bearing his name), first suspected that an iron skeleton could support a building when he observed his wife place a heavy book on top of a small birdcage, which supported its weight with ease.

II. DEMAND OF TALL BUILDINGS

A building with a compact footprint, a tiny roof area, and extremely tall facade is referred to as a high-rise building. And because of its height, it is different from normal low- and medium-rise structures in that it requires specialized engineering systems (Scott, 1998) ... Later, a clearer definition was developed: "Any structure where the height can significantly affect evacuation is considered a high-rise." High-rise residential buildings have proliferated in many cities, displacing enormous swaths of traditional homes, as a necessary byproduct of increasing urbanization and population. Thinking about the lengthy history of human habitation, the housing process throughout the construction of these structures was radical. In essence, the early high-rise building was a phenomenon of the economy where business was the force behind innovation. Style was subordinate to the main considerations of investment and use because design was related to the commercial equation. The adoption of high-rise structures could be a response to issues with density and a lack of land for development. However, sometimes the adoption of tall structures is motivated more by issues of power, prestige, and aesthetics than by effective development. In these situations, tall structures help to satisfy occupier demand for large, prestigious headquarters. With the fall of the 110-story twin towers of the World Trade Center on September 11, a new era for high-rise structures has begun. Since then, there has been a conflict over the safety of tall buildings, the role of public officials in the process, and the development of engineering codes, with the conflict escalating in scope and technological sophistication.

III. BENEFITS AND DRAWBACKS OF A SKYSCRAPER

Benefits:

The variety of views you may get from having multiple scrapers in your city is one of its benefits. These vistas can be so breathtaking that they attract tourists, which would help the nearby business or city by generating revenue. Space is another important benefit that is readily apparent. These buildings have so much interior room that it could accommodate multiple businesses. The building takes up less room in the city when multiple businesses are housed there. The symbolic meaning of the towers is an additional benefit. The tower's symbolism may refer to a catastrophe that occurred there and was commemorated by naming the structure after it. This might be a huge benefit for the city as it could be a major draw for tourists, who would then spend more money there. They become economically viable when they offer high-value floorspace in dense areas with an affluent populace. No one will bother them, so individuals can unwind and enjoy the serenity while gazing over the city's skyline and getting a lovely panoramic view.

Drawbacks:

The safety of the structure is one of the skyscraper's main issues. Due to their size, these enormous structures are much more likely to be damaged by a natural disaster. A serious issue could arise if there is a natural disaster and there is a problem with the foundation because larger buildings require larger foundations. The cost of the buildings is another expense that poses a major challenge for the construction of skyscrapers. People frequently believe that these buildings are not worth the money since they are so large and expensive. The high environmental cost of their construction and the lift/elevator power usage has been a drawback. The drawback might be lessened by new technological advancements. People who live in very high buildings will be cut off from their surrounds and the natural world since they won't have any contact with the roads or the ground.

IV. SKYSCRAPER'S FAILURE – A TRAGIC PAST

a. One New York Plaza was a 50-storey office building. A fire occurred on the 33rd floor on the August 15, 1970. Two guards and a telephone company employee rode an elevator to the 39th floor with the goal of alerting the occupants about the fire, but because the elevator was called to the fire floor by the fire, the elevator halted on the 33rd floor.

Figure 2: One New York Plaza, on the night of 15 August, 1970 Source: https://www.inquirer.com/philly/news/20110223_One_Meridian_Plaza__20_years_ago_the_fire_that_changed_the_world.html

Workers from the 32nd floor discovered the fire. The employee of the telephone business lived while the two guards perished. Early in the fire, the supply of the air fans had been turned off, but the return fans had continued to operate.

b. On November 21, 1980, a fire at the MGM Grand Hotel claimed the lives of 85 guests as well as hotel staff. A total of 35 firefighters sought medical assistance both during and after the incident, and another 600 people suffered injuries. early 1970s construction of the high-rise building. consisted of a big, ground-level complex with a casino, show halls, convention spaces, a jai lai fronton, and a mercantile complex, above which there were 21 floors of guest rooms. About 3400 registered guests were at the hotel at the time of the fire.

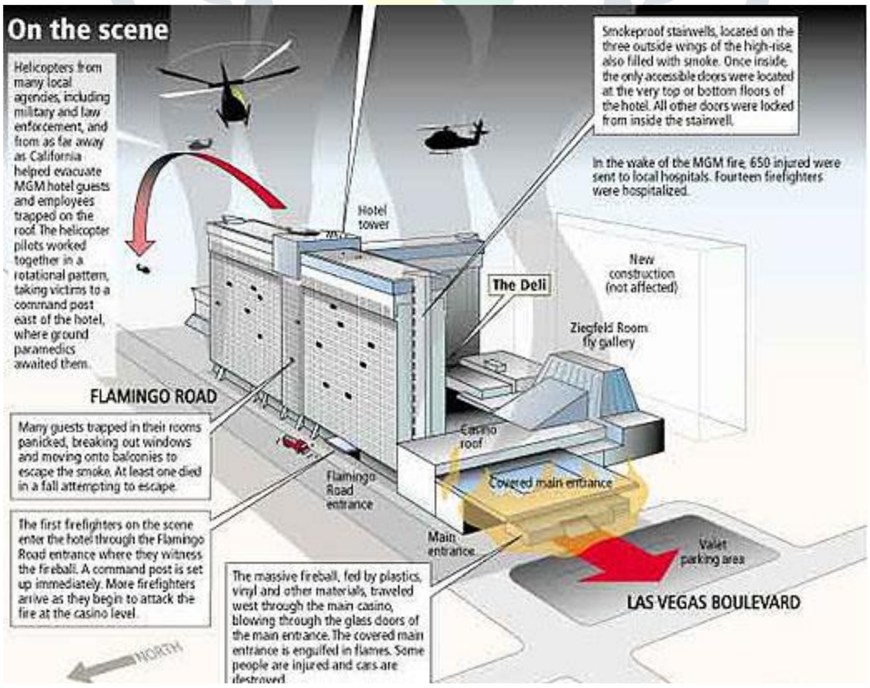

Figure 3: MGM Grand Hotel
Source: http://www.iklimnet.com/hotelfires/casemgm.html

The hotel was partially sprinkled, however significant areas like the Main Casino and the Deli, the area of the fire origin, were not sprinkled. The heat from an electrical ground fault within a flammable concealed compartment in the deli's wall-to-wall carpeting serving station was the fire's most likely cause

V. PRECAUTIONS TO AVOID FAILURE OF A SKYSCRAPER

The biggest issue facing the construction industry is safety in towering buildings. In construction, all design guidelines and safety standards should be followed. High-rise building egress mechanisms are currently being reviewed in light of the unexpected collapse of the World Trade Center towers. The current design specifies a particular number, width, and spacing of stairways based on the building's intended use and assumed occupant weight. There is a presumption that high-rise buildings will be evacuated partially or gradually because each story's exit system is sized for the amount of people living there. Concerns were expressed regarding whether relying just on stairways to evacuate large numbers of people from a high height would be sufficient during discussions about the need for engineering the simultaneous evacuation of towering buildings. It is projected that there would be a building height beyond which stairways will comprise a considerable amount of floor surface, rendering such buildings impractical if the design of future buildings is required for simultaneous evacuation under existing exit design standards. In order to find a great structure for design, construction, appearance, and architecture and to use it for tall building construction in the future, we should be cautious about these issues in order to obtain a safe tall structure.

VI. ISSUES FACED WHILE DESIGNING A SKYSCRAPER

Structural components were intended to primarily support gravity loading in constructions built at the beginning of the 20th century. Nowadays, due to improvements in structural systems/designs and high-strength materials, a building's weight has decreased dramatically and its slenderness has increased, necessitating the consideration of lateral loads like earthquake and wind throughout the design phase. The primary design consideration still revolves around lateral loads brought on by earthquake and wind motions. The lateral displacement of these buildings must be strictly regulated, not only for the sake of the occupants' safety and comfort but also in order to prevent any unintended structural effects. There are now numerous structural systems, like rigid frame, braced frame, shear-walled frame, frame-tube, braced-tube, bundled-tube and outrigger systems that have been utilized to improve the lateral resistance in high-rise buildings.

In contrast to vertical loads, the consequences of horizontal loads on a building increase exponentially with height. In order to use fewer materials, designers have recently created a range of frame techniques for tall buildings. In high-rise buildings, frame tube systems are typically highly acceptable as an economical framework for a wide range of building heights. The building's straightforward construction consisted of deep girders at each level connecting the structure's spaced exterior columns around the perimeter. Based on traditional beam theory, this creates a system of fixedly linked jointed orthogonal frame panels that together form a rectangular tube that serves as a cantilever hollow box, as seen in Figure 4.

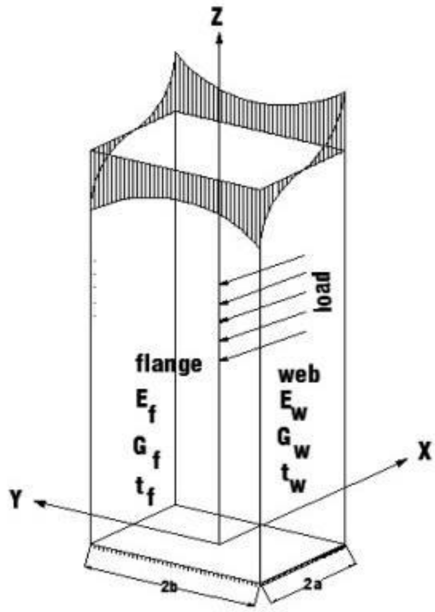

Figure 4: Framed tube, Orthotropic membrane tube and axial stresses distribution

Source: Research Paper- High Rise Buildings: Design, Analysis, and Safety: An Overview, by Imad Shakir Abbood

The axial stress in the four framed panel columns resists the lateral load's overturning moment, while the in-plane bending of the columns and beam of the two side frames resists the horizontal load's shear forces. If the frame components are very robust, the axial stresses in the columns caused by the overturning moment can be calculated using the well-recognized assumption that "plane sections remain plane." Shear and flexural flexibility of frame elements complicate the bending action of the primary beam for the framed tube due to the shear lag phenomenon, which influences the axial stresses in corner columns and inner columns while increasing axial stresses in corner columns and reducing axial stresses in inner columns while reducing the structure's lateral stiffness.

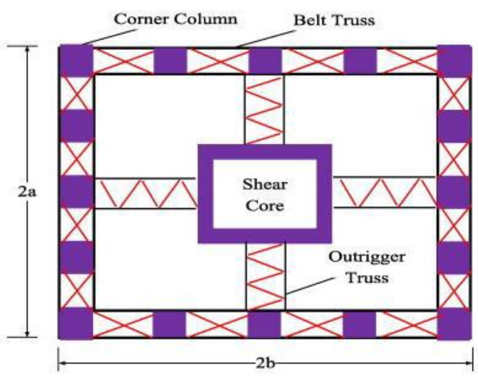

Figure 5: Schematic plan of combined system

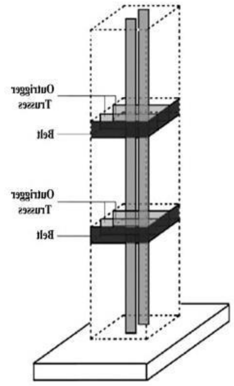

Figure 6: Outriggers system

Source: Research Paper- High Rise Buildings: Design, Analysis, and Safety: An Overview, by Imad Shakir Abbood

VII. Structural Stability

The stability under various load circumstances must be guaranteed as a crucial factor in structural design. Under loading, all structures experience numerous form changes. Internal forces created by load action in a stable structure tend to restore the structure to its original shape after the load is removed since the deformations brought on by a loading are often minimal. Massive deformations caused by loading in an unstable structure typically continue to grow as long as the loads are present. On the other hand, an unstable structure won't produce internal forces that would usually cause it to assume its original shape. When loaded, unstable constructions frequently collapse totally and instantly. Making certain the suggested structure actually comprises a stable configuration is the structural designer's primary task. A good illustration of the instability of the frame construction under horizontal loading is shown in Figure 7. Any horizontal loading can cause deformation, and it is evident that the structure lacks both the ability to endure the horizontal loading and any mechanism that would normally cause it to revert to its original configuration shape after the horizontal loading has been removed. A few techniques are already in use to increase structural stability. The techniques include strip modelling, steel bracing modelling, and steel plate shear walls.

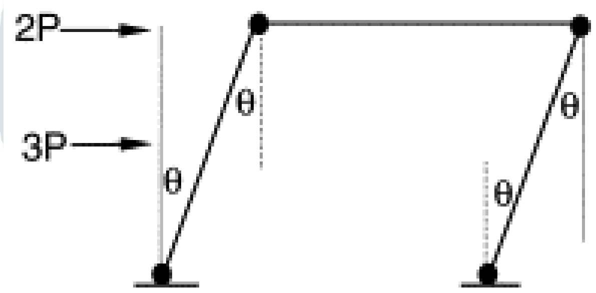

Figure 7: Instability of frame structure under horizontal loads

Source: Research Paper- High Rise Buildings: Design, Analysis, and Safety: An Overview, by Imad Shakir Abbood

7.1. Thin steel sheets are contained by steel beams and columns, which may be multi-story in height and width of one or more bays, with either a simple shear or moment-resisting connection from the beam to the column. This method is a practical and affordable way to protect structures against horizontal loads caused by earthquake and wind activity. Buildings in Japan and the United States used steel plate shear walls. When RC walls are an option, the steel plate shear wall system has also been adopted since it has a lower foundation cost than a moment-resistant frame. "Steel plate shear walls" offer the following additional features: quick construction and expanding usable space. According to current design standards, the wall's capacity is limited by the plate panels' elastic buckling strength

7.2. In Figure 6, the strip model is displayed. Thorburn et al. created it for steel plate shear walls after realizing that the inclined tension field governs the post-buckling behaviors and that infill plate buckling does not accurately represent the system's maximum capacity. The pre-buckling shear strength of the infill plate will be disregarded in favor of the tensile yield strength for plate material, which is thought to be the limiting stress. The infinite rigidity of the border beams suggests that there are opposing tension fields above and below the modelled panels. The strip model has been used as a reliable analytical technique to contrast model predictions with experimental findings.

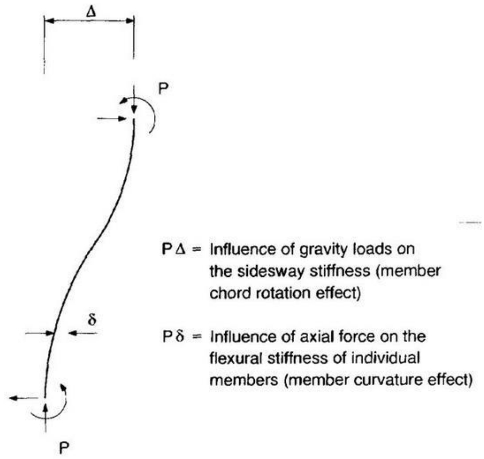

Figure 8: Strip model as shear wall

Source: Research Paper- High Rise Buildings: Design, Analysis, and Safety: An Overview, by Imad Shakir Abbood

7.3. In order to provide stiffening and strengthening to existing buildings against lateral loading caused by seismic activities, steel bracing systems as diagonal bracing for seismically inadequate steel frames or reinforced concrete frames are examined. The building may occasionally be braced as a preventative measure or as part of repairing construction after seismic damage. An efficient structural system for buildings exposed to lateral seismic or wind loading is a steel braced frame. Columns and beams with steel braces behave similarly to vertical and horizontal truss elements in steel braced frames.

VIII. Linear and Non-Linear Analysis

Since the linear analysis is based on an undeformed formation and has no iteration process, the material is assumed to be rigid and there to be no load movement. Additionally, the math to get the results is not as complex as the second order analysis. First order analysis is another name for linear analysis. The effects of the system's finite deformation and displacement are estimated in the nonlinear analysis in order to create the equilibrium equations. A straight elastic bar with both vertical and horizontal loading is seen in Figure 9 near the bar's edge. Due to the presence of lateral force (P), the axial force (P) operating on top of the bar was relocated after the displacement in the deformed shape that was employed for the subsequent iteration process. This only happens in nonlinear analysis which is also called 2nd order analysis.

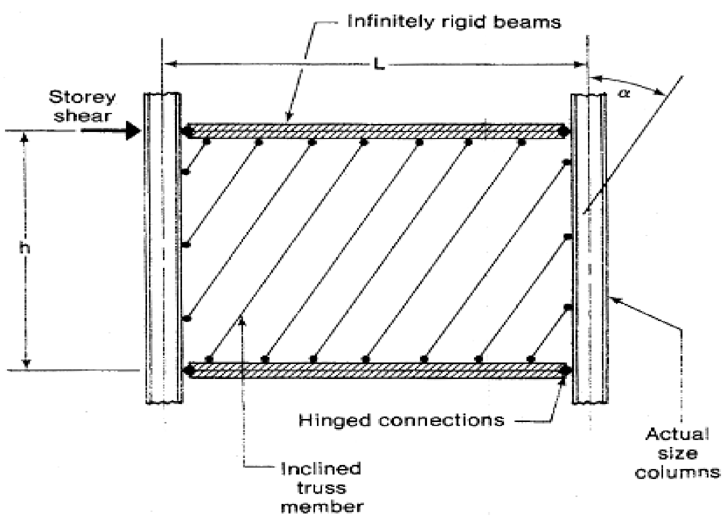

Figure 9: Schematic drawing of the bar with 2nd order effects

Source: Research Paper- High Rise Buildings: Design, Analysis, and Safety: An Overview, by Imad Shakir Abbood

According to Cook et al, in structural mechanics, the kinds of nonlinearity involve the following criteria:

✓ Material nonlinearity, in which the properties of materials are functions of the state of strain or stress. Examples involve nonlinear elasticity, creep, and plasticity.

✓ Geometric nonlinearity or second-order effect, in which the deformation is large enough that the equilibrium equation must be written regarding the deformed structural geometry. Furthermore, the load may shift the position as it increases

IX. Wind Loading

Numerous constructions have fallen victim to an instability that requires second-order analysis (P-Delta). One of the issues was brought on by wind loading. Building surfaces are subjected to outward and inward pressures brought on by the wind, depending on how flat the surface is. This pressure causes the building's elevation in some areas to rise, forcing it to isolate if it cannot sustain the wind loading. The connection between the column and the beam in a rigid or pin-ended frame, therefore, must be taken into account for a logical design in order to overcome this problem. If the structure could not support a particular loading, whether from imposed, dead, or wind loads, as well as other natural risks like earthquakes, it would be structurally unstable, which means losing some situations and nearing collapse like swaying and buckling. Ankireddi and Yang hypothesis that wind load will rise steadily as a function of building height, as depicted in Figure 8. In contrast, BS EN 1991-1-4:2005 operates as the center of the building and permits a 50% reduction, which makes the analysis simpler. Since the load is considered to be static, even the majority of software has the ability to assess the structure because of dynamic load. These two alternative methods of determining the lateral load resulting from the wind effect would significantly alter the results of the P-Delta analysis.

X. Conclusion

This paper has presented the basic concept of a skyscraper along with its history such as about the first building ever to be called as a skyscraper and the rising demand and needs of skyscraper in the near future as scarcity of land could be a major problem. It also covers certain pros and cons of a skyscraper as it could enhance the infrastructure of a city as well as could cost immensely high for its construction. The most important thing to keep in mind while construction of a skyscraper would be about its structural safety and in the past a number of high-rise or tall buildings have failed due to this which is included in this paper, where the thorough discussion of the disaster has been done which helps in understanding and designing a structurally safe skyscraper. Then this paper also covers safety features, design issues, structural stability, linear and nonlinear analysis for both static and dynamic procedures resulting from wind and seismic activities. Brief descriptions of various structural systems that are available in both literature and the public domain are reported. A critical evaluation of the existing simplified models as well as the seismic energy base design are also provided.

Additionally, this research paper could provide a strong platform for other works. Research on this design direction is anticipated to become very important to both practice and academia in light of the growing interest in sustainable architecture that includes energy-efficient design. The cutting-edge and new systems could be regularly improved for the benefit of academics and industry experts. Researchers need to pay more attention to serviceability issues such floor vibration, lateral sway, and occupant comfort as high-rise buildings are created more frequently employing lighter members. For the future generation of sustainable megastructures and extremely tall buildings, novel structural solutions must be created.

Due to the recent increase in demand of this typology, more and more countries want their major cities to construct a skyscraper of their own which would act like the landmark of the city as well as the country. The ideas and technologies are evolving gradually through each level, which is encouraging for skyscrapers. As technology advances quickly, even more development is taking place. Even as technology advances, construction methods do as well, with sufficient safety precautions being taken and skyscrapers being built without significant worker accidents. Skyscraper concentration would have an impact on the microclimate and urban environments. The connection to the urban environment and social context is impacted by living in skyscrapers, which provide the impression that one is outside of an urban setting, and by flying aloft. Skyscrapers can be used effectively while taking into account any negative effects they may have. They should be further investigated in order to produce greater results and be used effectively.

XI. References

[a] *"A Study of Challenges in Designing and Construction of Skyscrapers"* by Ar. V. Vijaysree, professor at School of Environment Architecture and Design, SRM Institute of Science and Technology, Chennai, India. *Volume 8, Issue 12. Published in December 2019.*

[b] *"High Rise Buildings: Design, Analysis, and Safety: An Overview"* by Imad Shakir Abbood, Mohammed Ahmed Jasim and Sardasht S. Weli, designated at various positions at the university of Iraq. Published in International Journal of Architectural Engineering Technology, 2021, 1-13 by Avanti Publishers.

[c] *"A study of optimal design process for complex-shaped skyscrapers' structural systems in United Arab Emirates"* by Chuloh Jung, Riyad Awad and Jihad Awad all of who are associated with the College of Architecture, Art and Design, Ajman University, United Arab Emirates. This paper was published in Ain Shams Engineering Journal.

[d] *"Skyscrapers: Origin, History, Evolution and Future"* by Pinak Ray and Subham Roy associated with Jadavpur University, Kolkata, India. It was published in Journal on Today's Ideas – Tomorrow's Technologies, *Vol 6, No. 1, on June 2018.*

[e] *"Skyscraper Design and Behaviour of Steel Structures and Connections Complexities from Constructability Perspectives"* by Manikandan M published in Journal of Architectural Engineering Technology

[f] *"The Origin of the Skyscraper"* by Gerard Peet, who is a lecturer at Rotterdam University of Applied Sciences. The paper was published in CTBUH Journal, 2011, Issue 1.

[g] www.iklimnet.com/hotelfires/casemgm.html

[h] www.inquirer.com/philly/news/20110223_One_Meridian_Plaza__20_years_ago__the_fire_that_changed_the_world.html

[i] www.theguardian.com/cities/2015/apr/02/worlds-first-skyscraper-chicago-home-insurance-building-history