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The Integrated fire safety strategies for high rise buildings: A Global review

Ar. Manujit Khurana [1],
[1]Professor, University Institute of Architecture, Chandigarh University, Punjab India

Abstract. With the development and rapid growth of the cities, the construction industries are expanding at the fastest pace. Due to the high population density and increase in the price of land, High rise buildings or Tall buildings are a prominent part of the urban economy.
High-rise or tall buildings lead the various factors such as Modernization, Multi-function with intelligent building features, and with all this, it has become very important to provide the safety and security provisions for such buildings, especially in the matter of Fire.
National Building Codes and local authorities have emphasized certain guidelines and structural and design parameters that are mandatory for High Rise buildings.
These codes also express the fire and safety strategies for high-rise buildings to be incorporated while designing a building.
Council of Tall and Urban Habitat not only governs the guidelines for what defines a tall building but it also suggests safety measures and guidelines for tall, Super tall, and Mega tall structures. In History we have seen in case of fire multi-story buildings have been dangerous to their occupants and fireman in the case of the Twin Towers in New York which resulted in a casualty of 2,666 people.
Detailed case studies of the various buildings has been discussed in this paper it intends to examine that what leads to the failures of such structures.
This analysis attempts to highlight the critical elements and design approaches for the fire safety of high-rise buildings. By following the building codes and fire safety strategies it is possible to develop a criterion in design and performance for tall buildings which is safe for their occupants.

1 Introduction

In the realm of high-rise or tall buildings, fire safety measures have become important as per the usage of the building. High-rise buildings address the major and special fire-safety challenges. All the Stakeholders which includes Builders, Owners, Architects, Engineers, Contractors, Maintenance agencies, Designers, and users who are responsible for designing and using the building are liable to provide safety measures from the fire and prevention from its harmful effects. The building should be designed in such a way that it enables to sustain a prolonged fire exposure because fire and smoke tend to spread at a fast pace vertically thus it can affect a huge number of building occupants and its structure and can cause loss of life and property.
As per the Council on Tall Buildings and Urban Habitat (CTBUH), High rise buildings are defined whose height may vary as per the design, construction & use of it, at a specific region and period [1].
Other international code bodies, such as the New York City Building Code 2014 (NYCBC) define a high rise building whose occupancy of floor located more than 75 feet (23m) and it has to be above the lowest level of fire department vehicle access [1].
History of the tragic fire in tall buildings leaves a very bad and harmful impact but taught a valuable lesson, now one can easily understand the importance of fire and life safety norms, Rules & standards. Fire protection systems are intended to provide the buildings which can identify the cause of the fire and help withstand, prevent, and reduce the risk of fire outbreak.

The objectives of this study are:

1. To provide a systematic approach and strategies for fire safety in High rise buildings.
2. To ascertain the perception of fire safety in super tall, and Mega tall buildings characteristics.
3. To understand the height variation between the super tall, and Mega tall buildings with their associated risk to fire safety.
4. To ensure the fire safety strategies with effective fire emergency planning.
5. To discuss the various case studies and to understand their failures that occurred due to the fire hazard.
6. To suggest the safety measures and methods embrace the fire safety in tall buildings.

2. Fire safety: Role, Importance and Needs

1. To give the provision and set the instructions for the fire safety in buildings, it is necessary to give proper consideration to design parameters and other aspects. Prevention of Fire is better than control so Installation of systems that tell us about the prevention of fire is important such as heat sensors, and smoke alarms that can warn us before a fire sets off [2]
2. It is the responsibility of humans to prevent fire by accidents or on purpose. Proper training and education play an important role. People must be socially aware of the responsibility and prevent the occurrence of fire and the start of fire [2].
3. If a fire does occur an Individual must be aware of his role in the safety and safety of others and must know the escape route and what provisions are made on-site for fire safety management.
4. Sometimes unaided evacuation is not possible so provision should be made for this for the safety of the occupants.
5. Safety of the structure is also important and the surrounding buildings hence separation walls should be provided in the case of tall buildings and the case of tall buildings proper evacuation of surrounding buildings should be done in case the building on fire may collapse or its structural integrity may be a question.
6. Compartmentalization of the Building should be done to prevent the fire from becoming Hazardous and spreading to the entire building.
7. Proper Maintenance of the fire fighting system and strategies should be done to see if they are in check [2].

3. Background

3.1 High Rise or Tall Buildings

Tall buildings are increasing in number with each passing year every country impressing its domain with a mega structure in technology and height. As per the Council of Urban Habitat "the tallest building was Taipei 101 stood at 508 meters then Burj Khalifa at 582 meters and the recent 600 meter plus buildings in height have led to the term of mega tall buildings till 2010 [3].

The CTBUH has an international standard for Tall buildings and has recognized some of the World's Tallest Buildings [3]. A tall building can be relative to context as in the urban habitat seen in Hongkong where a 14 storey building is not considered tall [4].

Proportion can be another criterion for Tall buildings as shown in Figure 1, few buildings are not called or considered a tall buildings but particular in the slender form, it is enough to look as tall.

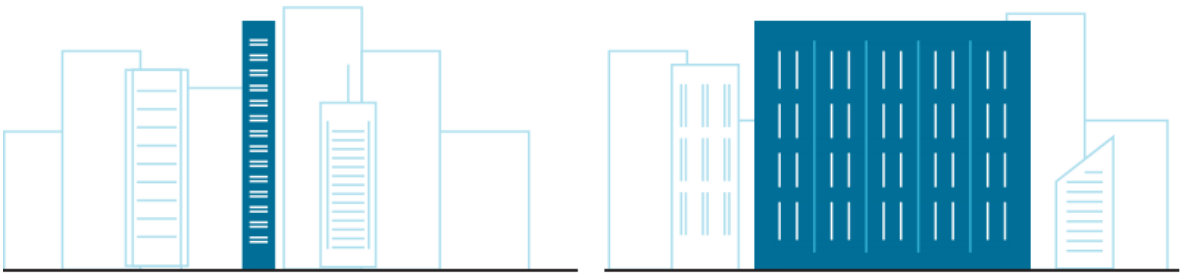

FIGURE1: Graphical representation shows the building proportions [4]

Technology can be another attribute for Tall buildings such as structural technology or services technology Petrona towers is an example of that.

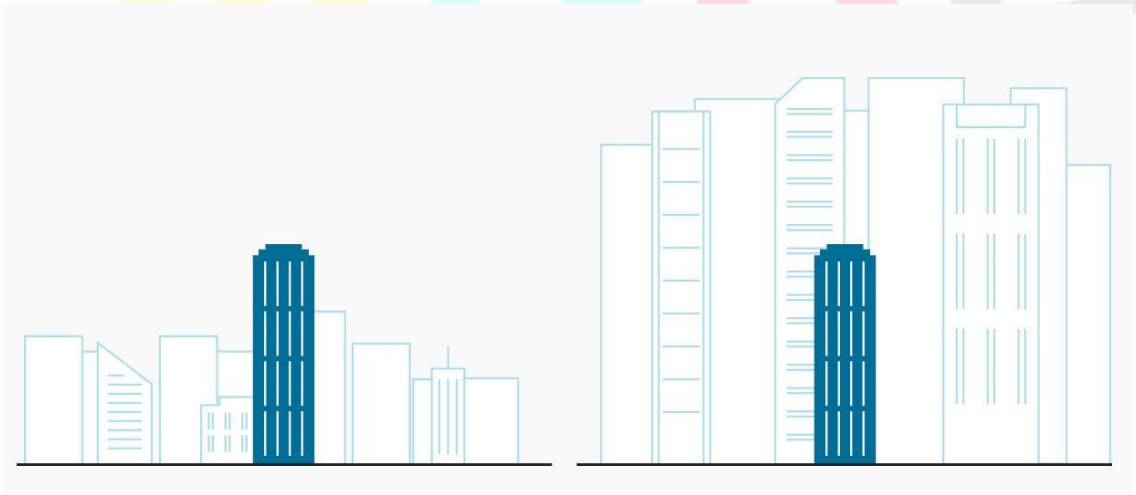

FIGURE 2: Graphical representation shows the building proportions in the context of urban scale [4]

3.2. Super Tall Buildings –Mega Tall

Super tall and Mega tall buildings are divided into two main categories a building that is 300 meters high (984 ft.) is called a super tall building and buildings that are 600 meters (1,968 feet) taller are called a Mega tall building. As of now, there are 173 supertalls and only 3 mega tall completed worldwide [4]. The advancement in technology, design, and engineering has led to the creation of building to unimaginable heights such as Petronas Towers, and Burj Khalifa. As design Philosophies evolved structures also evolved to greater heights and inspiration such as the Bank of China and the Gherkin In London known for its hybrid Diagrid Structure Initially the form and design of super Tall buildings were structurally driven, Jhon Hancock towers, Famous for its braced Tube structure By Fazlur Ahmed Khan. Earlier more than 75% of the tallest buildings were in North America but now the trend has shifted as a result of economy and technology toward Asia and the Middle East.

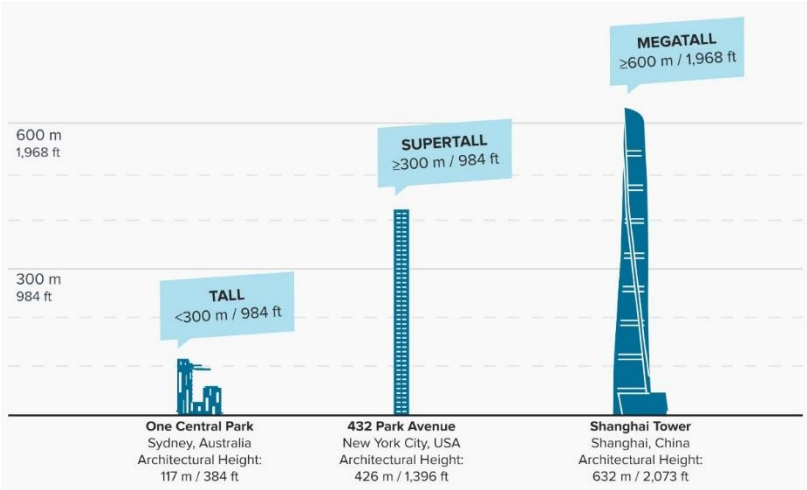

FIGURE 3: Graphical representation shows the height variation in between buildings [4]

4. Case Studies

It is discussed through the case studies the major fire events that occurred in the history which gives a valuable lesson and sets the objectives to integrate and strategically adopt the fire safety norms and regulations in tall buildings.

4.1. World Trade Centre

One of the deadliest fires in history was the New York World Trade Centre Fire, shown in Figure 4 the result of an attack of two airplanes hijacking which eventually destroyed the Twin towers (110 Storey). The reason for the occurrence of fire was due to the two airplanes hitting the Twin Towers and compromising the structural stability of the structure resulting in the death of 2,666 civilians and many firefighters. The Twin towers had been designed to take lateral loads 30 times the weight of the aircraft and that day there were normal wind conditions on September 11. The Perimeter columns were stressed to only 1/3 of their permissible 200MPA design load but they still collapsed. The Only Component that has the same strength as that of the perimeter columns in the airplane is the Keel Beam at the bottom of the aircraft.

FIGURE 4. The world Trade Centre's twin towers which stretched above the New York City skyline for 28 years, were levelled by a terrorist attack in 2001 [5]

The Huge Impact of the Airplane destroyed many perimeter columns and the entire load shifted to the core columns making it uneven and resulting in pancake collapse Adding to it was the fuel of the Airplane 90,000Litres gallons nearly 1/3 the weight of the Airplane which resulted in the fire.

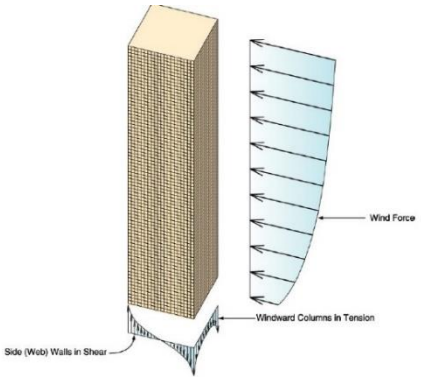

FIGURE 5. Structure tube behavior [6]

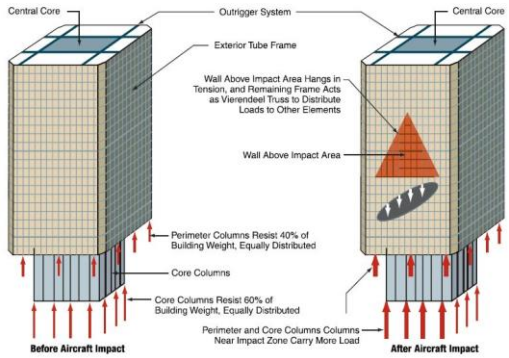

FIGURE 6. Redistribution of load after aircraft impact [6]

The impact and uneven load distribution and fire due to airplane fuel of 90,000-liter gallons resulted in the melting of the lightweight steel trusses and structure and causing a pancake collapse as shown in figures 7 & 8. The jet fuel ignited a fire to a temperature of more than 2000 degrees Fahrenheit which was sufficient enough to weaken the integrity of any building.

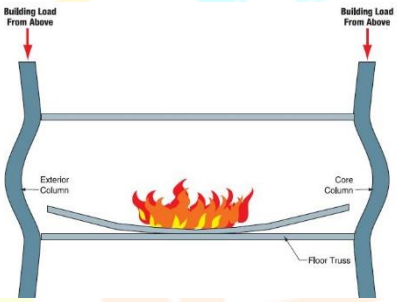

FIGURE 7. Buckling of columns initiated by failure of floor framing and connections [6].

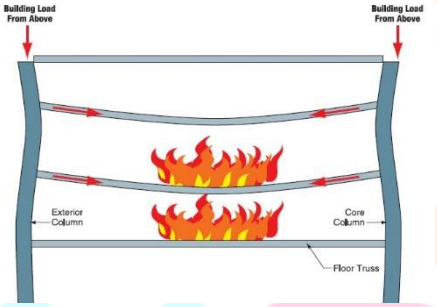

FIGURE 8. Column buckling failure [6]

The Twin Towers were designed in a framed Tube Structure and the fireproofing was destroyed due to high temperature. The reason is that the jet fuel and the Framed tube structures' outer perimeter columns joints were compromised by the impact and heat.

Result: Steel has replaced cast Iron and Refinement in the structural integrity of the systems is also done the joints are welded now not riveted. The tube structures of Fazlur Ahmed Khan are designed to withstand great lateral impacts.

4.2. Federal building in Oklahoma

The Bomb Explosion outside the Federal Office Building in Oklahoma on 19th April 1995 was caused by 4500 pounds of explosives in a truck that was parked outside the building. The 24 feet rental truck was used and was parked on the North side of the building. This explosion resulted in the uneven collapse of the structure and fire in the building causing 169 fatalities and 680 casualties.

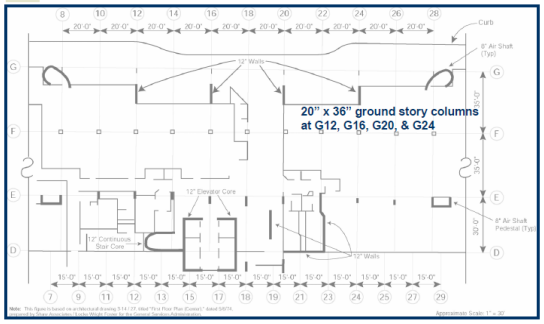

FIGURE 9. First Floor plan [7]

The Federal Building is a Nine storey structure with each floor thirteen feet high the floor slabs of the structure were 6 inches thick and spanned 25 feet east and 35 feet west these slabs were supported on massive columns of Reinforced cement concrete 48 inches by 20 inches four of these columns were destroyed by the blast which was facing the Northside G12, G16, G20, G24. This resulted in disproportionate distribution of weight and fire. Due to the blast, the load on other columns increased and the fire further decreased their strength. The Federal Building had Reinforced concrete columns and moment frame structure and a concrete core [7]

Result: Shear walls were introduced and the column sizes were increased to increase the stability of the structure.

4.3. The Triangle Shirtwaist factory fire

It was one of the deadliest fires in the history of New York, and Industrial Fire took place in a garment factory on March 25, 1911. It resulted in the death of 146 workers and 71 injuries. The fire occurred on the 8th and 9th 10th floors of the Asch building in lower Manhattan. The fire quickly spread from one floor to another being a garment factory with combustible goods and through openings in floors.

FIGURE 10. Triangle shirtwaist factory [8].

The workers in the factory many of whom were women have perished in the fire as a result of neglected safety features. There was only one fire escape staircase that collapsed, and most of the doors were locked. There were no fire extinguishers or sprinkler systems installed to control the fire or smoke detectors or alarms to evacuate the evacuees [8].

Result: Within three years 36 new state laws were made in New York regarding Fire safety strategies.

4.4. New York fire in Bronx

The Camber Property building is an Affordable property building in the Bronx which already had 14 Fire Violations against it in Jan 2022 Seventeen people including eight people nearly after three decades in a deadly fire showing us the concern and safety measures being violated and their importance to protecting human life. The smoke alarms went off the residents believed that someone was smoking in the stairwell so it set off the alarm and the building continued to burn. The building had self-closing doors on the door system failed which resulted in choking the seventeen residents to death while escaping. This kind of lapse shows that even if we have the firefighting systems and regulations in place periodic check and maintenance is mandatory the sprinklers were present only in the trash compartment and laundry room. The Fire was started by a room heater that was on for several days a person's lack of social awareness resulted in the death of 17 people and then lack of maintenance added to that further [9]

4.5. Shanghai Fire 2010

The Great Shanghai Fire that happened on 15Th November 2010 in the 28 storey building killed 50 people and injured more than 70 started from the sparks being done by the welders on site done by unlicensed welders thus resulting in a massive uncontrollable fire.

FIGURE 11. Shanghai fire, [10]

The fire started from the scaffolding and soon engulfed the whole building the building Housed 440 people mainly educators who tried to escape through the scaffolding due to the intense smoke caused by the fire in the building**.** As per the Shanghai authorities it sets the new regulations aimed at better official supervision of construction companies for the safety of its citizens after this deadly fire [10].

5. Fire safety approaches: an example from Hong Kong

Hong Kong is the most populated city in the world where 7 million of population residing in an area of 1,108 square kilometres. Maximum high rise and super tall buildings are in Hong Kong and due to this, it has a major concern for Fire safety [11].

In super tall structures fire detection is divided into five zones when a fire incident happens the alarm goes off in all zones to alert the occupants. In the Performance-based approach, the fire detection is divided into four zones when a fire incident happens the alarm is activated only on the Fire floor, one floor below and two-floor above alarms will not be activated unless total evacuation is required [11]

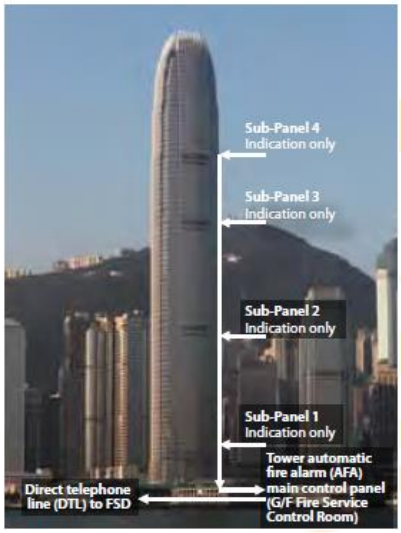

FIGURE 12. Schematic diagram of the design of the fire detection system of super tall buildings A. [11]

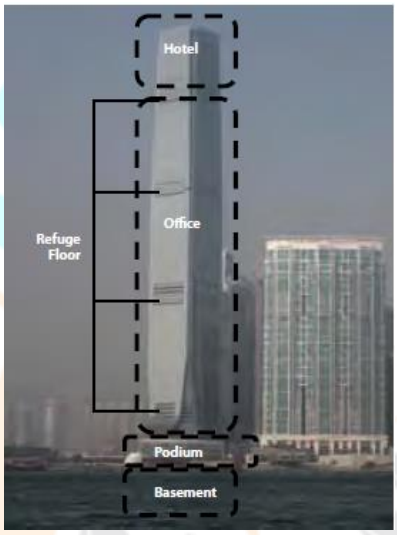

FIGURE 13. Different zoning orders of the fire detection system in super tall buildings B. [11]

5.1. Evacuation

In case of fire incident in high rise or tall buildings, there are different approaches and methods are used in the evacuation.

5.1.1. Fire Staircase

Evacuees may escape through a pressurized staircase or open staircase. In Hong Kong staircases are accepted as means of egress or escape in case of a fire incident. Several studies were conducted on evacuating through the staircase and results were formed that it does not ensure the safety for evacuating a large number of evacuees.

5.1.2. Refuge Areas /Floors

As per the Fire safety code of Hong Kong, refuge floors has become mandatory for the Non-Industrial buildings which are above in 25 stories. It has mentioned that Industrial buildings are higher than 20 stories, whereas Residential buildings extends up to 40 stories. An intermediate floor as a refuge floor after every 10 floors could also be used. An area of 1.5X1.5 meters protected area at the staircase for people with disabilities should be provided. The area of refuge is calculated based on evacuation time and RSET. As per the Hong Kong Fire safety Code 50% of the gross floor area on a refuge, floor is dedicated to the refuge area [11]

5.1.3. Smoke and fire Spread

Smoke and fire have a detrimental effect on a high-rise building, particularly at high levels. Numerical approximation calculated by the software used in considering all fire dynamics external wind loading and fire whirl in a single model would have been a challenging task. The stack effect and the pressure difference between the building enclosure and the surrounding when the air temperature changes affect the smoke movement. Hence tall buildings need to be pressurized to an amount to prevent the stack effect [11].

5.1.4. Fire Load and Heat Release

Fire safety arrangements are integrated into tall buildings and super tall buildings. It is designed in such a way that it addresses high fire load on dense commercial floors. For example, stationery and paper cartons in office buildings are risk hazards and add to fire load, that will be uncontrollable, similarly evacuating hotels can take longer and add to fire loads. Hence Hong Kong has provided restrictions on the mixed occupancy in the tall buildings and does it very selectively and systematically to control extreme fire loads [11].

5.1.5. Barrier free Evacuation

Since 1997 Barrier free evacuation has been enforced, the updated 2008 design manual for barrier free access adds the provision for barrier free access in tall buildings accommodating the growing elderly population [11]. Barrier-Free access enable speaks of that every 1in 200 can be disabled hence barrier-free access must be provided in a building to provide easy access and egress. Only Hospitals and care homes have a tailor-made manual for barrier-free access and egress, but every building has its prototype of barrier-free access.

6. Conclusion

High-rise buildings present a challenge to Architects, and engineers when it comes to Fire strategies and their control and evacuation, and they must be addressed with reasonable care and precaution for the safety of the building integrity and its occupants. The building should be designed in such a way that will be able to take the effect of fire and smoke to protect its occupants and allow safe evacuation. The building should prevent the spread of fire horizontally or vertically therefore different categories can be divided into different zones. The Active fire Systems could not be active hence the building should be designed in such a way that it is self-sufficient and does not depend on Ground utilities.

A full evacuation is not possible in High rise buildings, thus alternative strategies should be in place. One must remember that height is of concern in tall buildings when it comes to smoke and fire hence fire fighting operations are very difficult in it. Thus it has been found that the help of emerging technologies and strategic planning can help to mitigate fire hazard issues. An example from Hong Kong has been discussed in this paper. It shows the strategic planning to deal with the fire hazard as the tall buildings have been divided into different zones with a different set of fire alarm system which works accordingly. Different types of activated evacuation routes have also been planned in case of Fire Hazard.

Despite the Fire and collapse of the World Trade Centre in 2001, the life and fire safety in tall buildings has set the priorities, inhabitants, and users' demands for the safety & precautions to be provided in the buildings. The major incident of 9/11, has left a bad impression on society and raises a lot of questions in terms of safety and security, which leads the political pressure and explanation of events. Which resulted in a guide and strategy design for tall buildings and provided safety solutions.

Design parameters have been set by adopting the performance-based design for tall buildings, which helps to provide the solutions. High-rise buildings can make an assessment plan individual to each building type to give the provision for the relevant fire safety as per the nature of the building. Because high-rise buildings tend to have more occupants and a longer distance to the exit discharge, fire prevention, and fire protection are essential**.**

7. Acknowledgments

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