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FIRE SAFETY: AN INDISPENSIBLE DESIGN CONSIDERATION IN SKYSCRAPPERS BUILDING CONSTRUCTION

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ABSTRACT

Buildings need to be designed to offer an acceptable level of fire safety and minimise the risks from heat and smoke. the primary objective is to reduce to within acceptable limits the potential for death or injury to the occupants of a building and others who may become involved such as the fire and rescue service, as well as to protect contents and ensure that as much as possible of a building, that it can continue to function after a fire and that it can be repaired. However, the design and layout of a building, in conjunction with the materials used and style of construction, play a key role in preventing the spread of flames and

Introduction

The fundamental axiom in fire safety for high rise buildings is that the building must remain intact throughout the fire and offer refuge for the occupants until they can be evacuated. There must be no structural failure should there be a burnout in any portion of the building.

The high-rise building is generally defined as one that is taller than the maximum height which people are willing to walk up; it thus requires mechanical vertical transportation. This includes a rather limited range of building uses, primarily residential apartments, hotels, and office buildings though occasionally including retail and educational facilities. A type that has appeared recently is the mixed-use building, which contains varying amounts of residential, office, hotel or commercial space. High-Rise buildings are among the largest buildings built, and their unit costs are relatively high; their commercial and office functions require a high degree of flexibility.

The design and construction of skyscrapers involves creating safe, habitable spaces in very tall buildings.

The buildings must support their weight, resist wind and earthquakes, and protect occupants from fire. Yet they must also be conveniently accessible, even on the upper floors, and provide utilities and a comfortable climate for the occupants. The problems posed in skyscraper design are considered among the most complex encountered given the balances required between economics, engineering, and construction management.

One common feature of skyscrapers is a steel framework from which curtain walls are suspended, rather than load-bearing walls of conventional construction. Most skyscrapers have a steel frame that enables them to be built taller than typical load bearing walls of reinforced concrete. Skyscrapers usually have a particularly small surface area of what are conventionally thought

smoke and in allowing the safe evacuation of people from the premises in the event of a fire. over the years, the high rise buildings, being a unique type of building have garnered significant attention with respect to fire safety, throughout the world. The multiple floors present in the high rise buildings makes great number of persons to travel long vertical distances by the stair, elevators, during an evacuation. In the course of this, the Federal, State, bodies responsible for ensuring that codes are abided with, in the erection of skyscrapers, the owners of such buildings, and even residents within and around adjoining buildings to the skyscrapers are all affected by high rise building's safety. It is to this effect that the author had chosen to highlight the indispensable nature of fire safety as a design consideration in the construction of skyscrapers. The brief introduction talks about the design and construction of the skyscraper, highlight of top design and build considerations in skyscrapers construction of which fire safety is inclusive, definition of keywords as fire, safety, causes of fire outbreak in buildings, general approach to fire safety, fire safety strategies, etc. From the aforementioned above, it has become imperative to ensure adequate fire safety in our skyscrapers building design construction hence this report.

Keywords: Fire, Safety, Indispensable, Design, Skyscrapers, Building Construction.

of as walls. Because the walls are not load bearing most skyscrapers are characterized by surface areas of windows made possible by the concept of steel frame and curtain wall. However, skyscrapers can also have curtain wall, that mimic conventional walls and have a small surface area of windows.

The concept of a skyscraper is a product of the industrialized age, made possible by cheap fossil fuel derived energy and industrially refined raw materials such as steel and concrete. The construction of Skyscrapers was enabled by steel frame construction that surpassed brick and mortar construction starting at the end of the 19th century and finally surpassing it in the 20th century together with reinforced concrete construction as the price of steel decreased and labour cost increased.

The steel frames become inefficient and uneconomic for super tall buildings as usable floor space is reduced for progressively larger supporting columns. Since about 1960, tubular designs have been used for high rises. This reduces the usage of material (more efficient in economic terms – Willis Tower uses a third less steel than the Empire State Building) yet allows greater height. it allows fewer interior columns, and so creates more usable floor space. it further enables buildings to take on various shapes.

Elevators are characteristic to skyscrapers. In 1852 Elisha Otis introduced the safety elevator, allowing convenient and safe passenger movement to upper floors. Another crucial development was the use of a steel frame instead of stone or brick, otherwise the walls on the lower floors on a tall building would be too thick to be practical. Today major manufacturers of elevators include Otis, Thyssen krupp, Schindler, and Kone.

Advances in construction techniques have allowed skyscrapers to narrow in width, while increasing in height. some of these new techniques include mass dampers to reduce vibrations and swaying and gaps to allow air to pass through, reducing wind shear.

Top Design Considerations of Skyscraper Building Construction:

Here are the top key design and build constructions for high rise construction:

a. **Good Foundation:** The foundation of a high-rise building should be designed to support very heavy loads. with high rise construction, foundations are divided into two categories: shallow and deep foundations. Many high-rise buildings are constructed with a deep, pile foundation, which consists of a long cylinder of a strong material such as concrete that is pushed deep into the ground to act as a steady support. The higher the structure, the deeper the foundation needs to be.

b. **Structural Integrity:** A high rise building must be able to handle a larger load than a one or two storey house. The structural integrity of high-rise construction focuses on the ability of a structure to withstand it's intended weight (for example, 20 storeys) without breaking or deforming. The horizontal force of wind on high rise buildings should also be considered. Wind force generally grows the higher up you travel. This is why many high-rise structures use steel reinforcement inside concrete to add strength and load capacity. Steel and concrete is also designed to bend without breaking and absorb the impact of wind loads.

c. **Fire Resistance:** High-rise construction should always keep fire resistance and fire safety in mind in the design and build process. For instance, the NCC (National Construction Code) requires external walls and cladding to be non-combustible. Any attachments to the external wall must also not impair the fire resistance of the external wall. Permitted attachments may include blinds, awnings and down pipes. Other fire resistance must-haves in a high-rise building include accessible fire exits and entrances, more than one exit for each storey should one exit become unusable, fire resistance construction to limit the spread between storeys and features like fire sprinklers, smoke detectors and fire hydrants. Concrete and steel reinforcement helps to separate each floor so that fire can be contained to a floor as much as possible.

d. **Use of Pre-Fab Construction:** There is a huge Industry move towards prefabricated and modular construction, especially with high-rise buildings. The main material used in high-rise construction is precast concrete and formwork systems. Formwork technology improves the speed of construction, as well as the safety and stability of a building. These systems use reinforced steel components to ensure the structure strength.

What is the meaning of fire?

Fire is the visible effect of the process of combustion - a special type of chemical reaction. it occurs between oxygen in the air and some sort of fuel. The products from the chemical reaction are completely different from the starting material. The fuel must be heated to its ignition temperature for combustion to occur. The reaction will keep going as long as there is enough heat, fuel and oxygen.

This is known as the fire triangle.

The Fire Triangle

Oxygen, fuel and heat are needed for fire to occur. This is known as the fire triangle. Combustion is when fuel reacts with oxygen to release heat energy. Combustion can be slow or fast depending on the amount of oxygen available. Combustion that results in a flame is very fast and is called burning. Combustion can only occur between gases.

What is the meaning of safety?

Safety is a concept that includes all measures and practices taken to preserve the life, health, and bodily integrity of individuals. In the workplace, safety is measured through a series of metrics that track the rate of near misses, injuries, illnesses and fatalities. In order to improve these metrics, employers and safety officials must also conduct investigations following any incident to ensure that all safety protocols and measures are being followed or to implement new ones if needed.

Causes of Fire Outbreak in Buildings:

No single cause leads to accidental fires. Speaking broadly, fires are often the result of unintentional negligence, irresponsible behaviour, or product or technology defects. sometimes, they are unavoidable because they can be caused by an "act of God" such as lightning strike. However, the leading causes of house fires includes: -

1. **Appliances and Equipment:**
   Any device that generates heat (stove, Clothes dryers, heaters) or heats up with extended use (computers, fans) is a potential fire hazard. cooking vessels that are left unattended are a frequent cause of avoidable fires.
2. **Candles:**
   Every candle comes with a warning: "a burning candle should never be left unattended." yet, many candles are often forgotten and can burn out of control. Candle fires are mostly likely to occur on Christmas day, New year day and Christmas Eve.
3. **Holiday Decorations:**
   Candles aren't alone in causing tragic fires during the Winter Holiday Season. Christmas tree lights and other lit decorations are obvious culprits. Live trees are not watered properly and left to dry out are an easy target for incineration by hot lights.
4. **Electrical Systems and Devices:**
   Any device that uses electrical power has the potential to start a fire, and overheated lightning equipment comes in at the top of the list. Shoddy electrical work within a home - poorly connected circuits, loose wires, improper grounding- is also a danger often unknown to home owners.
5. **Smoking;**
   Among the most common causes of house fires is the consequence of negligent smoking habits. People sometimes fall asleep while smoking. In doing so, they can set their bed, chair, or couch on fire, which can easily result in a fatality. Another

avoidable hazard is discarding still hot ashes into a trash can where they can ignite.

6. **Chemicals and Gases;**
   Home fires can easily be caused by sources of natural gas or propane gas. An errant spark combined with a small leak can create a combustible situation. Improperly mixed household chemicals can also trigger combustion, which is why it's important to conduct such activity outside the home setting.
7. **Lightning:**
   Lightning fires most commonly occur during the summer months when afternoon and early evening storms are at their peak. Homes in heavily wooded areas are extra vulnerable to lightning strikes that can set the surrounding landscape on fire.
8. **Children:**
   Small children unknowingly playing with fires or matches inside the home are one of the leading causes of house fires. Older kids who know what fire can do - and just want to see what happens - are equally dangerous. Though there may be no way to curb their curiosity entirely, it's possible to mitigate potential disaster by talking to children about how destructive careless behaviour around fire may be.
9. **BBQ Grill:**
   This is a larger issue in the summer than at any other time. A barbecue grill can lead to uncontrolled flame in a few different ways, such as proximity to combustibles like dry grass or because of a gas leak. Decrease the likelihood of these accidents by checking for gas leaks prior to firing up the grill, or by cooking a top stone or some other flame immune material and always keep a watchful eye on an operating grill.
10. **Normal Fires that go Awry:**
    Sometimes it can't be helped. We do everything correctly, follow all rules and wisdom, and fire still can be notoriously hard to control. One of the most common causes of house fires are, of course, that we allow fires in our homes at all. If managed responsibly, this usually isn't an issue, but a single stray ember from an active flame can catch a carpet aflame, for example be mindful around an indoor fire place, and never leave it unattended. This time could be the time when a log breaks in such a way that sends embers flying.

General Approach to Fire Safety in Skyscrapers Building Construction:

Fire safety has been a major concern in the structural design of buildings for a very long time, and today it has become an indispensable part of all types of construction works more especially for skyscrapers design.

Fire breakouts can be sudden and damage not only the building and valuable property, but also endanger the lives of the occupants. But with the growing awareness around fire safety,

engineers and architects have managed to devise methods and designs to guarantee maximum possible safety in case of fire accidents.

Naturally, the very first step in fire-resistant construction is to maximize the use of non-combustible materials. Several Indian standard (IS) codes provide the guidelines for safety protocols and the use of fire-resistant materials at construction sites. A few codes which can be referred to are: **IS codes 1644:1988,1646:1982, and 3809:1979.**

A building is a combination of various integral components. To make a building fire proof or fire resistant, it is vital to ensure that these elements stay unaffected by the impact of fire.

1. **Load Bearing Walls:**
   Load Bearing Walls are an integral part of any building, along with the foundation. These walls are responsible for transferring vertical loads from slabs and beams to other appropriate structural members and ultimately tot the foundation. Therefore, these walls should have a specific thickness to withstand the effects of fire. They should be thicker in section to act as fire barriers for a considerable time. The exact section thickness can be obtained from IS code **1642(1989).**
2. **Flooring:**
   The flooring materials are often made from bricks, concrete, stones, tiles etc as they are considered a part of fire-resilient construction. However, if the use of such materials is not feasible, wooden flooring or other floorings that are more susceptible to fire need to be used.
   For wooden floors, thicker joist should be used in the construction. Also, these joists should be placed at a greater distance apart. Alternatively, Protective coverings of insulators can also be provided on the flooring. These can include materials like bricks and ceramic tiles.
3. **Framed Structures:**
   There can be two types of framed structures, reinforced concrete and steel structures. Steel structures generally tend to twist and distort under heavy fire. Therefore, they are given a protective coating of metal lath or plaster. Bricks, Concrete or tiles may also be used, and their minimum thickness should be 10cm. In case of reinforced concrete frame members (beams and columns) should have a sufficient concrete cover to ensure their maximum performance under fire. This cover should be at least 5cm thick.
4. **Partition Walls:**
   Usually, Reinforced Cement Concrete (R.C.C), Reinforced Brick Concrete (R.B.C), Asbestos Cement Board, Hollow Concrete, etc. are used for building fire-resistant partition walls. However, when wooden partition walls are built, they are covered with metal lath and plaster.
5. **Ceilings:**
   Asbestos Cement Board, metal lath and plaster are often used in the ceiling framework to strengthen its fire-resistance. Also, the ceiling and the floor joists must be directly attached for greater stability and strength.

6. **Doors:**

   The doors and windows act as the escape points in case of a fire emergency, and therefore, ensuring their integrity during construction is very crucial. They must be glazed and fitted with reinforced glass panels, as they have a higher thermal resistance than normal glass panels. Using metal frames for doors is also one step towards providing fire safety.

7. **Stairs:**

   For one storey or two-storey buildings, windows and doors provide adequate escape routes in the event of a fire. But, in case of multi-storey buildings the location of the staircase is essential. it should be equally accessible from different points of the buildings. As far as the material is concerned, it is advisable to use R.C.C for building stairs. Also enclosure walls made up of fire-resistant materials should be built around the staircase hall for further safety.

8. **Roofs:**

   A flat roof is always better from the fire safety point of view. This is due to the fact that fire spreads more rapidly on a sloped surface in case of unfavourable wind condition. However, if constructing a sloped roof is required, then the ceilings should be built or coated with fire-resistant materials.

Fire Safety Strategies:

The main design options to ensure fire safety are:

1. **Prevention:** Controlling ignition and fuel sources so that fires do not start.
2. **Communication:** If ignition occurs, ensuring occupants are informed and any active fire system are triggered.
3. **Escape:** Ensuring that occupants of buildings and surrounding areas are able to move to places of safety.
4. **Containment:** Fire should be contained to the smallest possible area, limiting the threat to life safety and the extent of property likely to be damaged.
5. **Extinguishment:** Ensuring that fire can be extinguished quickly and with minimal consequential damage.

Prevention:

The three components that are required for fire to start are an ignition source, fuel and a supply of oxygen. Since it is difficult to exclude oxygen from a building, fire prevention tends to concentrate on the other two components.

Ignition prevention:

To reduce the risk of ignition, designers can:

- Design out ignition sources
- Enable buildings to be managed in such a way that the risk of ignition is eliminated.

There are a number of possible causes of ignition:

Natural Phenomena:

This includes earthquakes, forest fires etc. but the risk most relevant to life in the UK is lightning. Lightning damages buildings as an electrical current passes through building materials or along crevices between them, and energy is dissipated with heat reacting with the water content of building materials to produce very hot gases.

Buildings most at risk are those with tall towers and chimneys, as well as those at high altitudes, on hilltops or hillsides and generally in isolated positions. Such structures should be provided with a lightning - conductor system to dissipate the electrical shock directly to the ground.

Human Carelessness:

Human carelessness is the most common cause of ignition and the most difficult to design against. Fire may be started by cigarettes, candles, matches, cooking and other appliances. Deliberate acts of arson are also very difficult to design out.

Technological Failure:

Building services in particular present a major ignition risk. Plant rooms, laboratories, boiler houses, and large kitchens should be sited where their threat is minimized.

In the short term, services and installations should be correctly designed, specified, constructed, checked and commissioned. in the long term, checking and replacement cycles should be in place so that correct operation can be maintained.

Fuel Limitation:

Limiting the amount of fuel available will help to reduce risk in two ways:

- Fire load: By controlling the amount of materials which will burn and release heat to feed the growth of a fire.
- Smoke Load: It will also reduce the amount of smoke which can be produced.

Communication:

Once a fire is detected (either by occupants or by automatic means), it is necessary to communicate the location of the fire centre such as the fire and rescue service. This will allow an assessment of the correct response to be undertaken, and if necessary, include alarms to be sounded, a controlled evaluation, triggering of smoke control system or sprinklers.

Escape:

Buildings must be designed so that occupants can escape safely if a fire break out. They must be able to reach a place of safety without being overcome by heat or smoke, and so the time taken to escape needs to be shorter than the likely time it will take for fire or smoke to spread.

This can be achieved by controlling fire spread and by ensuring that escape routes are easily accessible and neither too long nor too complex. People with mobility problems who may need assistance must be considered.

Escape strategies might include:

- **Egress:** Simple direct escape from a building when an alarm is sounded

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- **Refuge:** The use of the fire containment to provide a place of safety within a building.
- **Rescue:** This is a last resort.

Containment: The ability of a building's design to contain a fire once started is critical to the protection of the property, the lives of the occupants and also surrounding people and buildings. It is the 'tactic' most clearly covered by legislation and also one which insurance companies are most concerned with. Containment should address both heat and smoke risk. It is possible to design passive and active fire containment measures.

Passive measures concern the nature of the building structure, subdivision and envelope. They are the properties of a building construction which serve to limit the spread of fire and smoke in case of a fire such as a half hour door.

Active measures are those which have to be activated either automatically or manually. This includes sprinklers, fire hydrants, extinguishers and smoke detectors. In the event of a fire, they will be activated by some agent or form of communication, informing people or equipment of the presence of fire and instructing them to take measures to contain it's spread.

Passive Fire Resistance: The fire resistance of an element of construction is a measure of its ability to withstand the effects of fire in one or more ways as follows:

- Resistance to collapse, i.e. the ability to maintain load bearing capacity (which applies to load bearing elements only).
- Resistance to fire penetration, i.e. an ability to maintain the integrity of the element.
- Resistance to the transfer of excessive heat, i.e. an ability to provide insulation from high temperatures.

Some materials have inherent fire resistance; others need to have steps taken to improve this resistance.

There are three main methods of doing this:

- **Oversizing:** Deliberately increasing the size of an assembly so that part of it can be destroyed without affecting the structural performance of the rest.
- **Insulation:** The provision of a layer of insulating materials around the assembly to protect it from the heat of a fire.
- **Dispassion:** Ensuring that heat applied to an assembly is rapidly dissipated to other materials or to the air, so that the temperature of the assembly is not raised to a critical level.

Passive Structural Protection: The level of fire protection appropriate to structural elements depends on:

- The need for escape (to get occupants out)
- Extinguishment (how long it will take to put out)

According to the building regulations approved document B, the structural elements which require fire protection are those which support a roof, but this does not

normally include single-storey buildings. Exceptions to this are where an element of structure provides support or stability to elements, such as:

- A separating wall.
- A compartment wall.
- An external wall which must retain stability to prevent fire spreading to adjacent buildings.
- A support to a gallery or roof which also forms the function of a floor.

Once the length of time a structure must survive has been established, it is possible to design the structural elements to provide that degree of safety.

Passive Compartmentation: The spread of fire can be restricted by sub-dividing buildings into a number of discrete compartments. These fire compartments are separated from one another by compartment walls and compartment floors made of a fire resisting construction which hinders the spread of fire.

Fire Compartmentation

- Prevents the rapid spread of fire which could trap the occupants of a building.
- Reduces the chance of fires growing and minimises the danger to occupants, fire and rescue services, and people in the vicinity of the building.
- Limits the damage caused to a building and its contents.

The degree of sub-division that should be provided by fire compartmentation will be dependent on:

- The use of the building.
- The fire load in the building.
- The height of the building.
- The availability of a sprinkler system.

Passive Envelope Protection:

This aims to limit the threat posed by a fire to adjoining properties and people outside the building as well as to limit the possibility of a fire starting as a result of a fire in the adjoining building.

Attention needs to be focused on the roof and external walls. Once alight, a roof can discharge flaming particles carried by convection currents, which pose a hazard if they land on other buildings. It is easier to design a roof that will resist penetration and fire spread than to ensure that a roof will not cause this problem.

External walls need careful consideration as heat radiated through them from a burning building might ignite adjoining buildings if they are too close. The danger of radiant heat can be reduced by restricting the number of openings in the external walls of a building if it is close to other buildings.

Active Measures:

These are measures that operate only in the event of a fire. They are mostly concerned with the particular problem of smoke control and the limitation of the spread of smoke throughout a building.

Active Pressurisation:

Even when well designed, it is inevitable that doors on escape routes will have to be opened and that smoke will therefore flow into the protected area. This danger can be reduced by using lobby access to staircases which provide a form of airlock where only one door will be open at any time. An alternative approach is to pressurise protected areas such as corridors and stairs. Fresh air is supplied to the area to be kept smoke free and the air pressure is maintained above that of surrounding rooms. If a door into the pressurised area is opened, air will flow out rather than smoke flowing in.

Active Venting:

The simplest way of stopping smoke spreading within a building is to allow smoke to escape to the outside. This will not extinguish the fire but it will tend to contain smoke to its area of origin and gain time for people to escape and for measures to extinguish the fire to be taken.

In a single-storey building, this can be done through roof vents. In multi-storey buildings smoke ventilation systems using mechanical vent extraction can be used.

It may be possible to assume that initially smoke will exit directly through roof vents. But as the fire grows, a layer of smoke will build up beneath the ceiling or roof. This layer will get thicker as the fire grows and the smoke level will gradually descend.

Smoke venting system must be designed to ensure that the smoke being added to the smoke layer is exactly balanced by that being expelled through the vents so that the depth of the smoke layer remains constant and does not descend to a level where it endangers the occupants (2.5m clear height).

Limiting the horizontal spread of smoke can be achieved by installing smoke curtains which are barriers that come down from the ceiling and create smoke reservoirs. Smoke curtains may be permanently in place or triggered to fall by fire.

Extinguishment:

The most common extinguishing agents are:

- Water
- Foam
- Carbon dioxide
- Dry powder
- Clean agents
- Inert gases

These agents can be applied either by the occupants themselves, through auto-suppression systems, or by the fire and rescue service.

Conclusion:

Effective fire protection provisions in buildings are reliant on competent design, construction and management. In order to facilitate the appropriate development and implementation of fire protection provisions, clear communication on the division of

those roles and responsibilities is essential between parties in a construction project. Many causes have been identified to be responsible for fire outbreak in most buildings, such as through appliances and equipment, candles, holiday decorations, electrical systems and devices, smoking, chemicals and gases, lightning, children, BBQ Grill, normal fires that go away etc.

To ensure adequate fire safety design, in our skyscrapers, the load-bearing walls, floors framed structures, partition walls, ceilings, doors, stairs, roofs, etc are built and coated with fire-resistant materials.

However, for an all-inclusive fire safety strategy in skyscrapers building construction, there must be a ***Prevention*** – which has to do with controlling ignition and fuel sources so that fire do not start,

Communications - Should in case ignition occurs, ensuring occupants are informed and any active fire systems triggered, ***Escape*** - ensuring that occupants of buildings and surrounding areas are able to move to places of safety, ***Containment*** - fire should be contained to the smallest possible area limiting the threat to life, safety and extent of property likely to be damaged, ***Extinguishment*** - ensuring that fires can be extinguished quickly and with minimal consequential damage, using sprinklers, fire hydrants, extinguishers and smoke detectors.

References

Neenu S.K, Fire and Safety features of high-rise buildings and structures.
https://www.designingbuildings.co.uk/wiki/firesafety-design
https://www.livingspace.net/interviews-and-articles/safety-considerations-for-the construction-of-high-rise-buildings
https://the constructionor.org/building/basic-design-considerations-fire-safety-structure/47278/?amp=1
https://www.designingbuildings.co.uk/wiki/createa-new-article
https://app.cronenico.uk/topics/fire-safety-building-design/indepth)
https://www.britanica.com/technology/construction/hgh-rise-buildings
https:enom.wikipedia.org/wiki/skyscraper
https://www.sciencelearn.org.nz/resources/747-what-is-fire
https://safetymanagement.eku.edu/blog/10-most-common-causes-of-house-fires
https://theconstructor.org/construction/fire-safety-features-high-rise-buildings-structures/17381/?amp=1
https://www.safeopedia.com/definition/1104/safety-occupational-health-and-safety.