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MULTI ROUTE EVACUATION STRATEGY AND FIRE SAFETY AUDITING OF A CINEMA THEATRE

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Abstract: The present study involves consideration of various factors influencing the determination of evacuation time of a theatre building which has a capacity of 450 people with seven internal exits. Factors like blockage of each exit as well as two adjacent exits and also human factors were considered in this study. Evacuation time in each scenario was determined both theoretically and using human movement simulation software called "path finder" and the results were compared. Based on the present study, it was observed that the theoretical calculation of evacuation time do not reflect the parameters that affect the evacuation time like blockage at the exits and human factors. However, this draw back could be improved to a certain extent with the help of appropriate software, wherein the above said parameters could be incorporated. The present study reveals that, there was an increase in the evacuation time when "path finder" was used as against the conventional method and this variation ranges from 25% to 40.5%. It is further observed that calculation of evacuation time using software based on human movement simulation helps to carry out various possibilities of evacuation strategy and hence helps to arrive at a better evacuation strategy. This study also included the Fire safety auditing of the theatre, which was done in reference to IS 4878 and NBC 2016 by adopting the methodology checklist. Emergency procedure and evacuation plan requirements has given to the theatre manager and also safety recommendation to improve the fire safety has provided.

Keywords: path finder, evacuation, theatre building.

1.INTRODUCTION

Emergency evacuation is the urgent immediate egress or escape of people away from an area that contains an imminent threat, an ongoing threat or a hazard to lives or property. Examples range from the small-scale evacuation of a building due to a storm or fire to the large-scale evacuation of a city because of a flood, bombardment or approaching weather system.

Emergency evacuation plans are developed to ensure the safest and most efficient evacuation time for all expected residents of a structure, city, or region. A benchmark "evacuation time" for different hazards and conditions is established. These benchmarks can be established through best practices, regulations, or using simulations, such as modeling the flow of people in a building. Proper planning will use multiple exits, contra-flow lanes, and special technologies to ensure full, fast and complete evacuation. Regulations such as building codes can be used to reduce the possibility of panic by allowing individuals to process the need to self-evacuate without causing alarm. Proper planning will implement an all-hazards approach so that plans can be reused for multiple hazards that could exist. With increasing complexity and decreasing motion ability, the strategy changes from "fast egress", through "slow egress" and "move to safe place inside building" (such as a staircase), to "stay in place and wait for help". The most common equipment in buildings to facilitate emergency evacuations are fire alarms, exit signs, and emergency lights.

The consequences of recent extreme events such as natural disasters and terrorist attacks have raised awareness of the importance of building design associated with safety and security. It has become clear that building design including evacuation routes needs to broaden its focus on improving safety of the building occupants during extreme events. Minimizing the impacts of emergencies is not limited to minimizing the damage to the physical structure of the buildings. Safety of building occupants is the most vital point. Therefore safe building design needs to consider needs, requirements and the cognitive abilities of occupants related to vision, sound, heat and haptic senses because it is highly dependent on characteristics of the users and their interaction with the building. Even the occupants with special needs should be considered during building and evacuation design. Within this context, the management of building occupants, sheltering and evacuation during emergency events are important .It is important to consider the design process as a whole to ensure as afe and secure building that enables efficient evacuation, controls building access etc. Such a design approach covers the three main areas of building layout and circulation design namely means of ingress, circulation, and means of egress. These design aspects need to be investigated and considered carefully with appropriate design information and guidelines to improve safety in the built environment. Considering and identifying hazard resistance methods for various natural and human-induced events should be an integral part of the design projects. Evacuation of people from the immediate danger zone is very important in places where large number of people assemble, one of such places is theatres. With the innovative ideas of architects, different types and shapes of theatres are being made and thereby gives challenges to the planners for ensuring safety in such buildings. Conventional approach for safe evacuation from such buildings may not be possible in many cases due to the complexity of the architectural planning. However, to address such scenarios many softwares are available such as pathfinder, FDS+Evac tools etc.

2. LITERATURE SURVEY

This accident occurred on 5 December 1876 at Brooklyn, New York City state of USA.The Brooklyn Theatre was designed by Thomas R. Jackson and constructed in 1871 according to Sara Conway's specifications. Brooklyn Police Fire Marshall Patrick Keady gathered testimony and constructed a chronology of the disaster, and he said that the structure had better exits than many other public buildings in Brooklyn at that time. The theater occupied an L-shaped lot, with the Proscenium theatre occupying the 127-by-70-foot (39m× 21 m) wing fronting Johnson Street. The stage and scene doors opened onto Johnson Street from this wing. The scene doors were 20 ft. wide (6.1 m), large enough to accommodate scenic flats and large props. The stage doors were smaller but could accommodate people carrying heavy loads. These Johnson Street doors were utilitarian and little used by the public. The shorter 27-by-40-foot (8.2 m × 12.2 m) wing on Washington Street housed the main entrance to the lower floors and a separate staircase to the third floor theater gallery. They were for public use, and Jackson considered these main entry ways to be large enough to discharge a full house of 1,450 people in less than five minutes.

There were three sets of doors which Jackson designated as special exits. They led onto Flood's Alley, a small street running along the east side of the building that bisected the block from Johnson to Myrtle Avenue. Each set was six feet (1.8 m) across. The southern door closest to Myrtle Avenue opened into the eastern end of the lobby, underneath the flight of stairs leading from the lobby to the dress circle. The middle set opened onto a hallway adjoining the parquet, and the northern set opened near the stage and orchestra pit. The middle set served a stairway ascending to the second floor dress circle. These alley doors were normally locked to discourage gate-crashing. The structure had nofire escapes connecting higher storey windows to the street, but sources from the period often called these alley doors "fire escapes.

Seating, interior passages, and spaces The Brooklyn Theatre had three levels of seating. Parquet and parquet circle seating occupied the theatre's ground floor and contained 600 seats. The dress circle occupied a second floor balcony which seated 550. A third floor gallery, the family circle, extended to the south wall of the structure and seated 450. The family circle had its own entrance and ticket booth and customers for this seating did not usually commingle with patrons purchasing seating for the lowerfloors

Around 11:20 p.m., while preparations for the final act were under way, stage manager J. W. Thorpe saw a small flame on the left, or prompt side of the stage. The fire was coming from the lower part of a drop hanging below the rigging loft near the center stage border-light. The canvas was hanging, partially detached, from its frame and, Thorpe thought, somehow must have slipped past the wire mesh guard of the border lamp and ignited

While the actors were attempting to quell the panic, the head usher, Thomas Rocheford, went to the rear of the theatre to open the Flood's Alley special exit door on the east end of the vestibule, opposite of the Washington Street entrances, one of the three special exit doors designed by architect Jackson. Since the doors were rarely used, he found the locking mechanism corroded; he was initially unable to open the doors. He found a small piece of metal in his pocket and with this was able to release the doors. This action enabled the people on the floor of the theatre to evacuate the building fairly quickly, but Rocheford's action came at a cost. The open doors furnished airflow for the fire on the stage, which immediately grew in intensity.

The next foray into the building did not occur until the daylight hours. Chief Nevins had his District Engineers organize recovery parties. Except for a short segment of the vestibule, the building had mainly collapsed into the cellar and burned until the wood was consumed. What first appeared to be a great deal of rubbish in the cellar underneath the vestibule turned out to be largely human remains, a large mass of people which had fallen into twisted and distorted positions and then burned. These were mainly from the gallery and the stairway, which, in the original structure, had been above the vestibule ceiling against the south wall of the building.

Removal of these remains occupied much of the next three days. It was slow work; the conditions of the bodies were such that they would fall apart with only the slightest movement, and many had been mangled and dismembered. An exact body count was never

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obtained, given the state of forensic science in that era. With many bodies partially dismembered and scattered about by the gallery's collapse, and with faces burned beyond recognition, it was difficult to determine how many people were in a given pile of limbs, heads and trunks. The bodies could only be moved slowly. The capacity of the city morgue was quickly reached so an unused market on Adams Street was pressed into service.[77]By Friday, December 8, Coroner Simms reported that 293 bodies had been taken from the theatre site. The number was by no means definitive. Later, his own Coroner's Report would cite 283 fatalities. Much later, the memorial stone erected in Green-Wood Cemetery, would reference 278 deaths.

3. PROBLEM IDENTIFICATION

Research Gap

Conventional method of finding evacuation time giving the average value of evacuation time.In real scenario, there is a probability of 50%, that the evacuation time exceed the calculated value.In some cases one or two exits may blocked, so it is important to find the evacuation time in such cases also to determine whether the building is safe or not.

Aim of Theproject

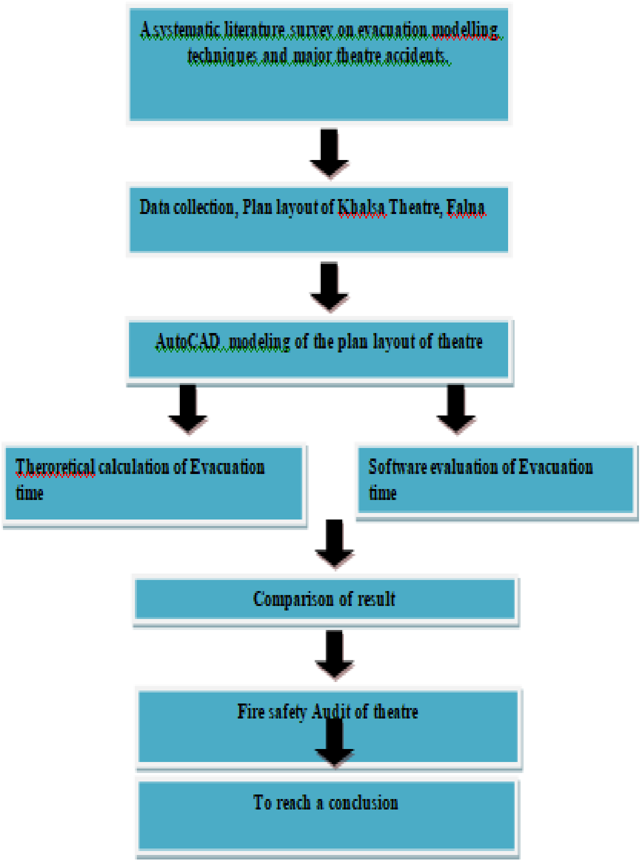
To study the various evacuation strategies possible for a safe evacuation of a theatre using a software and to compare the results with those obtained based on conventional approach.

Objectives

In order to achieve the set aim, following objectives have been framed.

1. Select a typical theatre
2. Calculate the evacuation time of theatre theoretically
3. Model the theatre using a software for evacuation study
4. Study various possibilities of evacuation using the software
5. Compare the theoretically calculated evacuation time with that obtained based on computer modeling
6. Conduct fire safety auditing of theatre
7. Arrived at suitable conclusion.

3. METHODOLOGY



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4.METHODS OF DETERMINATION OF EVACUATION TIME

Pathfinder – Simulation software

Pathfinder is an agent based egress and human movement simulator. Agent-based modeling and simulation (ABMS) is an approach for exploring the behaviors and interactions of individuals or organizations in particular situations or environments. Individuals can be any entity that behaves somewhat autonomously and interacts with other agents. Organizations can be any collection of entities whose behavior can be characterized as the behavior of a group. Examples might be sports teams, project teams, political organizations, terrorist organizations, legislatures, military organizations, or towns. An ABMS may be used to model a system and answer questions about that system, or predict the ways that the system will respond to external influences. The system being modeled may be an existing system, which is being analyzed to understand the behavior in response to specific changes in the environment, or a new system being designed or built.

It provides a graphical user interface for simulation design and execution as well as 2D and 3D visualization tools for results analysis. Pathfinder includes a graphical user interface that is used primarily to create and run simulation models. Pathfinder also includes a second program designed specifically for high-performance visualization of 3D time history. In addition to 3D visualization, Pathfinder also provides output in the form of 2D time history plots of CSV (comma separated values) out files and a text summary of room clearing times and doorway flow rates. The movement environment is a 3D triangulated mesh designed to match the real dimensions of a building model. This movement mesh can be entered manually or automatically based on imported data. Walls and other impassable areas are represented as gaps in the navigation mesh. These objects are not actually passed along to the simulator, but are represented implicitly because occupants cannot move in places where no navigation mesh has been created. Selection of simulation options, doors may also be used to explicitly control occupant flow. Stairways are also represented as special navigation mesh edges and triangles. Occupant movement speed is reduced to a factor of their level travel speed based on the incline of the stairway. Each stairway implicitly defines two doors. These doors function just like any other door in the simulator but are controlled via the stairway editor in the user interface to ensure that no geometric errors result from a mismatch between stairways and the connecting doors. Each occupant is defined by position, a profile that specifies size, speed, etc. and a behavior that defines goals for the occupant. The behavior allows scripting so that, for example, an occupant may wait at a location for a specified time and then proceed to a door. The occupant is represented as an upright cylinder on the movement mesh and movement uses an agent- based technique called inverse steering. Each occupant calculates movements independently. Occupants with special mobility needs can be modeled and evacuated by designated assistants. These models include full animation for realistic results. Separate evacuation teams can focus on assisting specific groups of individuals. The building used in this study is KHALSA THEATRE FALNA . For the study we have chosen a theatre. The data needed for creating the model using pathfinder is obtained from the floor plans of the theatre. Using the dimensions obtained from the plan a model of the respective building is created. Theatre having capacity of 450 people. It includes Population composed of young, child and older people. Population in floor is randomly distributed. The speed of each occupant varies according to region with different accessibility characteristics.

4.1 Collection of Data

For the fulfillment of the present study regarding the planning of the evacuation strategy of the theatre KHALSA THEATRE , the plan, layout and other relevant information of the building and its premises were required. The basic two dimensional plan of the theatre was essential for the simulation of evacuation time using pathfinder software, as well as for calculating the theoretical time. After obtaining the 2D drawing of the building from authorized person sty engineer, other relevant information was gathered by physical verification at the building premises.

2D plan was then developed into 3D image for the easiness of study and simulation. The simulation using –Thunderhead pathfinder‖ software requires importing of 2D cad file in to it. Figure 4.1 shows the general layout of the theatre considered for the present study.

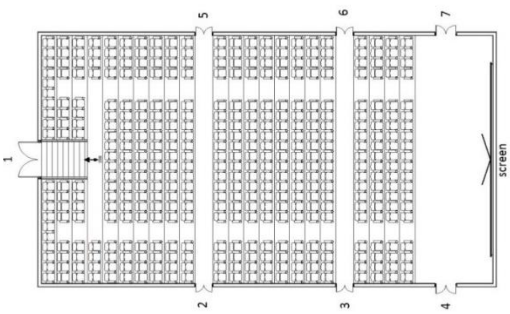

Figure.4.1General layout of the Theatre

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This theatre has 450 fixed seating capacity and has 7 exits (1, 2, 3, 4, 5, 6,7). The width of all exits of the theatre is 2m (Exits 1 to 7).

Evacuation Modeling

Evacuation modelinghasbeen carried out using softwarecalled–Pathfinder‖.

Pathfinder is an emergency egress simulator that includes an integrated user interface and animated 3D result. Following are the salient features of the model considered for the present study.

Modeling method: movement model

Structure of model: The model provides a simulation of the evacuation to visually present the location of the occupants as a function of time.

Perspective of model and occupants: The model views the occupants as individuals. The model has the capability of tracking individual's movement and positions through the simulation. The model views the population through a global view only to access the density of certain areas of the building. The occupants, on the other hand, have a global view of the building because of their route choices. They can choose the shortest route to the exit or the shortest evacuee route.

Occupant behavior: No behaviour

Occupant movement: The occupant move toward the exit under the constraints of the speed reduction based on the density of the space and the capacity of the doors and stair ways. The primary areas of analysis focus on the movement in open space, on stairways, and through doorways. The user specifies initial occupant loading by specifying the density in the areas (by noting the occupancy of the room) or by giving discrete number of occupants.

4.2 Generating Model

The detailed 2D autocad file was imported into the pathfinder software for the simulation of evacuation time. Necessary doors and openings were provided for the passage of people. Thus seven internal exits (1 to 7) were provided for exiting out the theatre. Seating arrangement were drawn according to the plan. The dimensions of the aisle, width of seats, and intra seating spacing were also figured according to the original dimension as give in the plan.

The stage was made by selecting a new z-plane having sufficient height from the seating surface. The two platforms stage and the lower floor were connected using stairs having sufficient width and slopes. The number of people considered for the present study is 450 and they were arranged randomly inside the theatre. Figure 4.2 shows the respective model of the theatre and the random distribution of people in the theatre simulated in–pathfinder‖.

Each individual is composed certain characteristics that may influence his evacuation time. The characteristics include direction of flow, speed of movement, reaction time, delay caused by different components. Each and every evacuee has been assigned these parameters for the efficient and quick evacuation process.

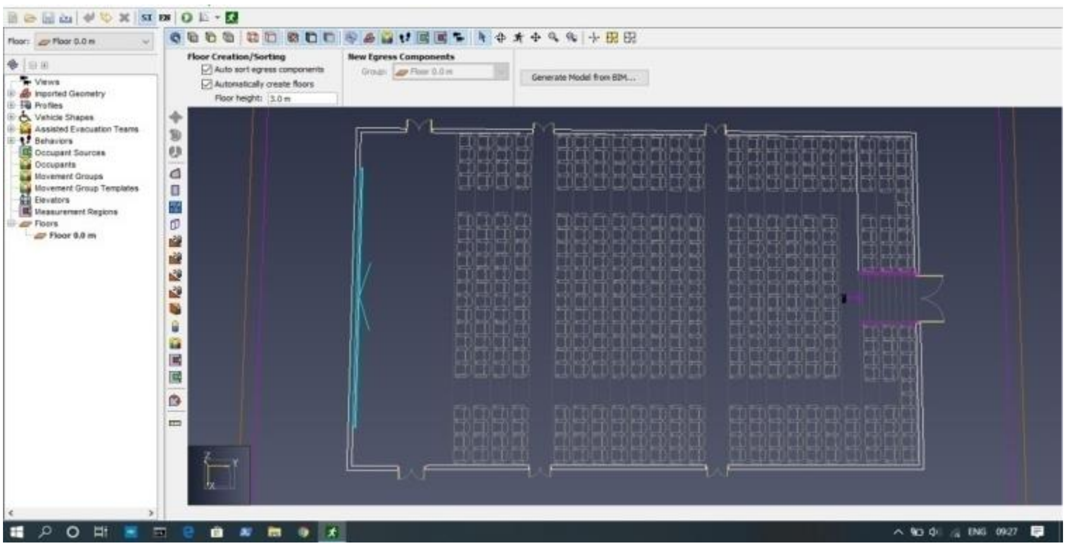

Figure.4.2 Model of the theatre made in pathfinder

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Figure.4.3 Movement Of The People Towards Various Exits During Evacuation Process

Path finder software is also composed of assigning different behaviors of the people, in which preference for usage of certain exits for an evacuee can be assigned. After including each and every components and obstructions inside the theatre, simulation can be made to run. The results of these simulations show the evacuation time, which is the time required by the last person to get out of building. Figures 4.3 show the screen shot showing the movement of people during the evacuation process.

Now in a real scenario one or two exits may be impassable and as a result, the evacuation time may be extended comparing a case where all exits counted for their full capacity.

Hence, for the present study, the effect of discounting one of the exit (out of 1 to 7) of the theatre at a time as well as by discounting two adjacent exits successively (out of 1 to 7) on evacuation time has been considered.

4.2 Theoretical Calculaton Of Evacuationtime

The time required to evacuate the building can be theoretically calculated based on two approaches.

a. Based on the maximum travel distance and speed ofmotion.

b. Based on the traffic clearing capacity of theexit.

For the present study, the first approach has been considered to determine the evacuation time of the theatre.

Evacuation Time Based on Maximum Travel Distance

The stream of people in an evacuation route can be divided into three, namely Unary stream, Primary stream, Complex stream. In general unary streams merge into primary streams and primary streams merge into complex stream. Figure 3.3 shows the different types of stream of people in a typical assembly area like theatre.

From fig.3.6, it may be observed that, Unary stream (1) form between the rows of seats. Unary stream merge in the aisles between the rows of seats to for primary stream (2). The primary streams merge in the foyer to form complex streams (3). The complex streams from the foyers flows towards the exits.

The building evacuation time with respect to maximum travel distance can be calculated without considering the possibility of hindrances to the movement of people or by considering the possibility of hindrances to the movement of people. For the present calculation, the time delay due to hindrances has not been considered. Hence the evacuation time from a premise is the time taken by an evacuee who is located farthest to reach theexit.

Considering the plan dimension of the theatre, the maximum travel distance to an exit is 11.65m. This distance could further be divided into 3.9m of unary stream, 4.5m of primary stream and 3.25m of complex stream.

The speed of motion of people along an evacuation route vary depending on many factors like type of stream, stream density, age, gender and other physical conditions of the people. The generally accepted values for the calculation of evacuation time of a premise for maximum stream density conditions are 0.667m/s, 0.4m/s and 0.267m/s, respectively for unary, primary and complex streams. If the evacuation route is divided in to different segments based on the speed of motion, the time required for the last evacuee to reach an exit can be represented by the equation,

te=to+ ΣL/V

Where,

t_e= Evacuation time (in sec)

t_o= Time delay to start the evacuation (in sec)

L = length of the segment (in m)

V= Speed of the motion (in m/s)

So, if an initial time delay of about 3 seconds is assessed to start the evacuation, the time required for an evacuee, who is located at the farthest point from an exit could be calculated as,

Evacuation Time=3+(3.9/.45)+(4.5/.32)+ (3.25/.21)

= 41.2 seconds

Similarly, the evacuation time for the theatre was calculated by considering each exits as non-functional and by assessing two adjacent exits non-functional.

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5.RESULTS AND DISCUSSIONS

5.1Evacuation Time For Thetheatre

Table 5.1 shows the time required to evacuate the theatre under different scenarios using the computer program –Pathfinder‖as well as by theoretical approach by considering all exitsand by discounting one of the exits.

Exits considered for evacuation	Evacuation time calculated using	
	Software (s)	Theoretical approach(s)
1,2,3,4,5,6,7	66.2	41.2
2,3,4,5,6,7	85.0	63.7
1,3,4,5,6,7	82.1	57.7
1,2,4,5,6,7	79.6	49.5
1,2,3,5,6,7	74.5	44.3
1,2,3,4,6,7	82.1	57.7
1,2,3,4,5,7	79.6	49.5
1,2,3,4,5,6	74.5	44.3

Table 5.1: Time Required To Evacuate The Theatre Under Different Scenarios.

The condition considered in this scenario was that one of the exits is impassable for evacuation.

From Table 5.1, it could be observed that in general, the computer model provided a higher evacuation time compared to theoretical model and this could primarily due to the additional features built in with the software like effect of crowding at exits. This variations range from 25% to40.5%.

It may be noted from the Table 5.1 that, while all the exits are considered, the evacuation time required was 66.2 seconds. This time increased to 85 seconds when exit number 1 was blocked for the evacuation. This means that, the evacuation time required was increased by 28.4%, when exit no.1 was blocked. Table 5.2 shows the evacuation time calculated by discounting two exits.

Exits considered for evacuation	Evacuation time calculated using	
	Software (s)	Theoretical approach (s)
1,4,5,6,7	103.4	79.4
1,2,5,6,7	89.5	72.1
1,3,4,6,7	98	72.4
1,3,4,5,7	94.4	71.3

1,3,4,5,6	92.3	75.4
1,2,4,5,7	92.7	75.1
1,2,4,5,6	88.7	74.1
1,2,3,5,6	102.6	76.2
3,4,5,6,7	106.7	78.4
2,4,5,6,7	98.9	75.3
2,3,5,6,7	97.2	74.9

Table 5.2 Evacuation Time Of Theatre By Discounting Two Exits.

From Table 5.2, it may be noted that the evacuation time required increased to 106.7 seconds when the exits 1 and 2 were considered as impassable. It may further note that, in this case also, computer model predicts higher evacuation time as against theoretical model and the maximum variations is about 26.5% for the case when exit 1 and 2 were discounted. In either case considered (one exit or two exit discounted), the required to evacuate the theatre is less than the allowable time of evacuation, which is 150 seconds for buildings with ―Type 1 construction‖ (As per NBC:2016, part 4)

6.SUMMARY AND CONCLUSIONS

6.1 Summary

An attempt has been made to understand the various factors influencing the determination of evacuation time of a building in the present study. An theatre with a capacity of 450 people has been considered. The theatre had seven internal exits. Various evacuation strategies like blockage of each exits as well as two adjacent exits were considered for the present study. The evacuation time in each scenario was determined using theoretical approach as well as with the help of a human movement simulation software by name—path finder‖ and theresults was compared.
Fire safety auditing of the building has been carried out in reference to IS 4878 and NBC 2016 by using the methodology checklist. It helps to find out the lagging measures and the hidden hazards in premises.

CONCLUSIONS

Based on the present study carried out, following conclusions could be arrived.

1. The evacuation time calculated based on the theoretical approach do not reflect the parameters like congestion at exit points and other human factors affecting evacuation time in a building.
2. A better prediction for the evacuation time in a building could be made with the help of a software based on human movement simulation.
3. Based on the present study and with 450 sitting capacity of the theatre,there was an increase in the variation of evacuation time from the theoretical calculation and it ranged from 25% to 40.5% when calculated using the software considered.
4. It is important to consider different scenarios for the determination of evacuation time like discounting one or two exits for a better and realistic approach.
5. Evacuation time calculated at all multiple evacuation strategies comes under 150 sec. so the theatre is considered to be safe for evacuation.
6. From the fire safety audit it is revealed that theatre doesn't have any evacuation plan and emergency procedure and also lagging from so many fire safety measures. Emergency procedure and evacuation plan requirements has given to the theatre manager and also safety recommendations to improve the fire safety has provided.

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