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Research Article

Study of Dense Crowd's Evacuation in College's Multifunctional Stadium

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Abstract: Due to economic and functional factors, forms and functions of college's multifunctional stadiums become more and more diversified. The utility rate increases. Density increases. Therefore dense crowd's evacuation should be noticed. Although many scholars have some deep researches on fire alarming and evacuation, they usually conduct only an aspect in ideal situations. The performances consider both primary disaster and secondary disaster are rare. This study, taking delaying and broaching situation in fire dense crowd's evacuation route design as background, guided by integrating analysis of fire alarming system and dense crowd's evacuation, considering relative factors, according to performance-based evacuation design, theory of accident consequence chain, clustering flow theory, etc, by calculating the delaying number quantitative modeling in travel time method, clarifies the design thoughts and clears the design principles. Meanwhile, this study proves the effects of fire primary disaster and secondary disaster and mark relative parameters. It can not only provide references for practical building designs, but also be a tool for managing and preventing the aggregations of various dangerous factors.

Keywords: College, evacuation, fire alarm, stadium

INTRODUCTION

In recent years, with the rapid development of Chinese economy, the new school regions of Chinese colleges are stepping into a new stage, with great improvements of hardware infrastructures. Due to energy- consuming and occupying, besides to get certain funds for management and mending, the functions change greatly, from operating single competitions and entraining and sports places to renting fields and multiple operations, like art performance, fashion, exchanging conference, inhibition, commercial showing and important rallies, etc (Sun, 2003). Meanwhile, with the development of building science and more and more functions needed, current stadiums tends to be complex, comprehensive and diversified (Gong, 2001). Analysis indicates, direct causes such as explosion, fire or ineffective structures will result in few casualties. But the results from that, the stamping is the root of large number of casualties (Huang, 2010). Although many scholars have some deep researches on fire alarming and evacuation, they usually conduct only an aspect in ideal situations. The performances consider both primary disaster and secondary disaster are rare. This study, taking delaying and broaching situation in fire dense crowd's evacuation route design as background, guided by integrating analysis of fire alarming system and dense crowd's evacuation, considering relative factors, according to performance-based evacuation design, theory of accident consequence chain, clustering flow theory, etc, by calculating the delaying number quantitative modeling in travel time method, clarifies the design thoughts and clears the design principles. Meanwhile, this study proves the effects of fire primary disaster and secondary disaster and mark relative parameters. It can not only provide references for practical building designs, managements and improvements.

RELATIVE THEORETIC BASIS

Performance-based evacuation design: It brings in special fire conception, proposes evacuation safety and commanding that all staff in the building should be evacuated to a safe place without any difficulty and danger. On that basis, several requirements should be met: people can be far away direct damages, including burn, smoke, etc; all the points should link at least an evacuation channel; avoid structure design errors to prevent from delaying, resulting in stamping; it should benefit for people know little about the building to find safe exits quickly.

Theory of accident consequence chain: Its representative is Heinrich's, which is mainly about mutual relations among factors of casualties and relations between factors and damages. The core idea is: accident results from series of reasons, not only a single one. Besides, damage has a chain to various reasons. It includes heritage and social environment, human's shortages, human's unsafe behavior or material's unsafe state, accident and damage. Their

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relations can be described as five dominoes. Besides, it develops Baudet accident causality chain theory, Adams accident causality chain theory and kitagawa tetsuzox accident causality chain theory.

Human-thing-material model base on body information processing: Its basic idea is: human's reactive error is a key to human's error, which may result in accident directly. Its typical applications are Willginsworth model, Siri model and Laurence model, etc.

Clustering flow theory: Delaying in evacuation is described as: set a basic cutting plane P on the evacuation direction, crowd flows into P called as inflow clustering, otherwise called as outflow clustering. If, due to some reason such as channel becoming narrow, qualities of door, stair or floor changes, delaying and disorder will happen on P. The delaying people on P are called as delaying group, which equals the difference between inflow group and outflow group.

Arching phenomenon: During the evacuation process, when clustering crowd go into exits or evacuation channels from wide space. Asides from the flow from the right direction, many people are from side's directions, which will impede the flowing, so as to increase density, forming arching flow structure. Nobody can go through in a minute in front of exit. But when the density increases to some degree, due to some side's strength is greater, the arching elapses. Some people reach exit suddenly, causing the sudden move of flow, which will be easy to lose balance and cause damages of falling or stamping, especially on the stair or floor. Soon after old arch broken, new arch will form.

SET FACTORS OF FIRE DISASTER

Factors of primary disaster: Many cases indicate, fire smoke's toxicity, not enough oxygen and radiation heat are the main reasons for generating casualties. Research indicates: toxic gases threaten human directly, meanwhile the smoke will reduce oxygen contents. When it reduces to 12~15%, symptoms like breathing fast, headache, etc will happen. When it reduces to 6~8%, casualties happen. Due to human's nature, the proportion of burning isn't high. But due to the close building, radiation heat will increase temperature to deadly level rapidly in a short time. If people don't evacuate timely but to delay on the entrances, toxic gases and high temperature will have quite bad effects. These are not only the reason for casualties but also the influences of evacuation. The factors and effects of primary disaster are shown as Fig. 1.

Factors of secondary disaster: By analyzing large numbers of cases, an accident results from many accident reasons. The specific process can be summarized in accident consequence chain theory, which is primary disaster causes secondary ones. However, the indication forms of secondary disaster mainly are delaying and broaching due to many reasons. It generates arching phenomenon. In that process, if accidents like falling happen, stamping is essential.

To avoid secondary disaster's happening, dense crowd's evacuation is essential. Many global scholars deduce and calculate evacuation models from different perspectives, from the simple one to complex ones,

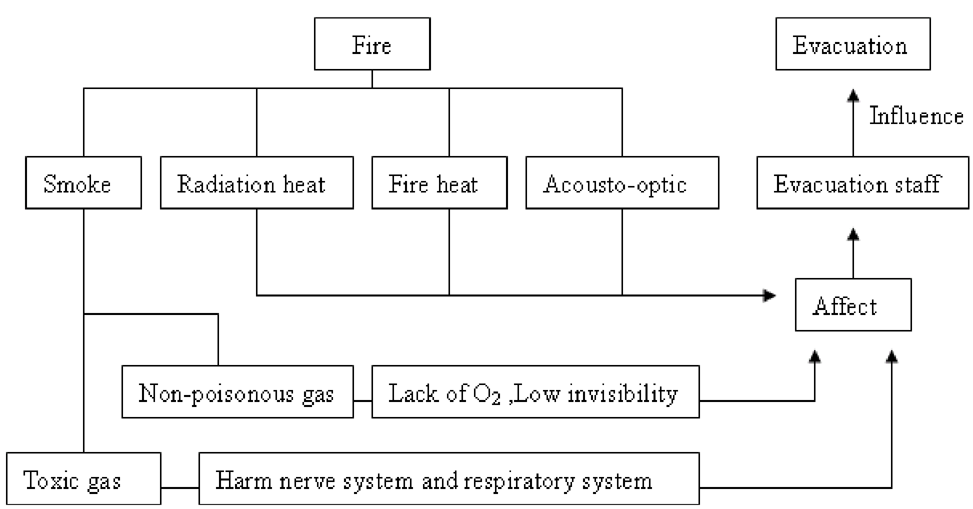

Fig. 1: Factors of fire primary disaster

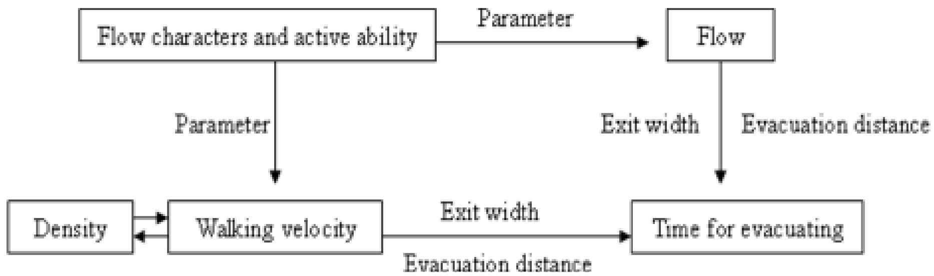

Fig. 2: Correlations among parameters of evacuation model

Table 1: Predictive velocities

Section	Evacuation direction	Walking velocity (m/s)
	Up	0.45
Stair	Down	0.60
Seat		0.50
Channel	Horizon	1.00

Table 2: Relation between walking velocity and density

Crowd density (people/m^2)	Walking velocity (m/s)
1.5	1.0
2.0	0.7
3.0	0.5
4.0	0.35
5.38	0.0

Table 3: Marginal sizes

Channel type	Width should be subtracted (cm)
Stair	15
Channel	20
Door	15

having certain performances. According to current model , the correlation among parameters of evacuation model can be drawn (Fig. 2).

According to model parameters, global scholars give specific calculation formulas and experience coefficients:

- **Predictive velocity in different regions of the building:** Once emergency happens, walking velocity has correlation with many factors. Chinese scholars propose main reference values after practice (Table 1) (Li, 2005).

  Specific formula is shown as:

  Velocity = distance/time (m/s) (1)

- **Relation between walking velocity and density:** Crowd density indicates crowd intensity in a space, usually demonstrated in the number of crowd in unit area:

  Crowd density (ρ) = total number/area (人/m2) (2)

  The relation between density and velocity is show as Togawa *et al*. (1955):

  $$u = u_0 \, . \, \rho^{-0.S} \quad (3)$$

  where,
  ρ = Crowd density.
  u_0 = A constant 1.34 m/s.

  Their relations are shown as Table 2 (Liu and Liu, 2004).

- **Subtraction of marginal sizes to different channels:** Exit width is very important. Therefore, relative parameters should be ruled. Fire-fighting engineering handbook from American fire-fighting engineer association proposed effective width subtraction (Huo and Yuan, 2003). In practical calculation, relative marginal sizes must be subtracted. Then the width is effective (Table 3), (Li, 2011).

- **Crowd flow coefficient:** Crowd flow coefficient (people/m/s) is a criterion for utility efficiency. The specific formula is shown as:

  Flow rate = flow number/(time×width) (people/m/s) (4)

  According to relation model between flow coefficient and density deduced by Liu *et al*. (2002),*f* calculation formula is:

  $$f = 2.27\rho^{0.5} - 0.374\rho^{1.5} \quad (5)$$

  ρ = Density on the exit.

SAFE EVACUATION TIME

In a fire, whether the evacuation is safe depends on contrast of two character times. One is time for a person to safe area, called as end time T_{RSET}; the other is time for danger coming, called as available time, which is danger coming time T_{RSET}. They can judge whether the evacuation is qualified.

If the result is $T_{RSET} > T_{RSET}$, people can be evacuated safely. Otherwise, bottle neck exists and some judgments and improvements should be done.

T_{RSET} is not only the time from start to end. According to real situation and performance-based evacuation principles, it should include: alarming time T_A, responding time T_R and evacuation move time T_M. It is shown as:

$$T_{RSET} = T_{A+}T_R + T_M \quad (6)$$

T_M should adds up uncertain factors in evacuation. Therefore some scholars advise, after calculating the time from start to end, multiple that of a safe coefficient. Usually it is 1.5~2. T_M is solved.

PROJECT ANALYSIS

Considering scales of college multifunctional stadiums already reaching one or two fire-resistant level, stands are mainly on the sides of fields. Therefore the object chooses these two points as main reference.

Review: This stadium is multifunctional, including main stadium and exercise stadium. The main stadium has two layers. The mobile stands on the first layer can contain 1520 people. The fix stands on the second layer can contain 2000. There are 6 exits. The widths of stairs between first layer and second layer are 2.30 m-2.50 m. The fire-resistant level is one. The stadium mainly takes on teaching, competition, commercial performances and rallies, etc.

There are eight exits on the first floor to main evacuation channels, whose width is 1.5 m and 5 exits linking outside, without obvious bottle necks. Therefore, key nodes method can be used to estimate the evacuation time, the formula is:

$$\text{Evacuation time (T)} = \frac{N}{AB} \quad (7)$$

where,

N = Total number of evacuation audiences
A = The access of single group
B = The number of group; the number of group depends on the width of exit and the access of single group depends on the channel.

Set safety coefficient as 1.5. By calculating, the evacuation time for staffs on the first floor is T_M (1520/8)×1.5 = 285s. Considering alarming time and responding time, the evacuation end time T_{RSET} should be controlled within 400s. It conforms to basic requirements of relative rules for Chinese building evacuation. Therefore, this study doesn't discuss the evacuation problem on the first floor.

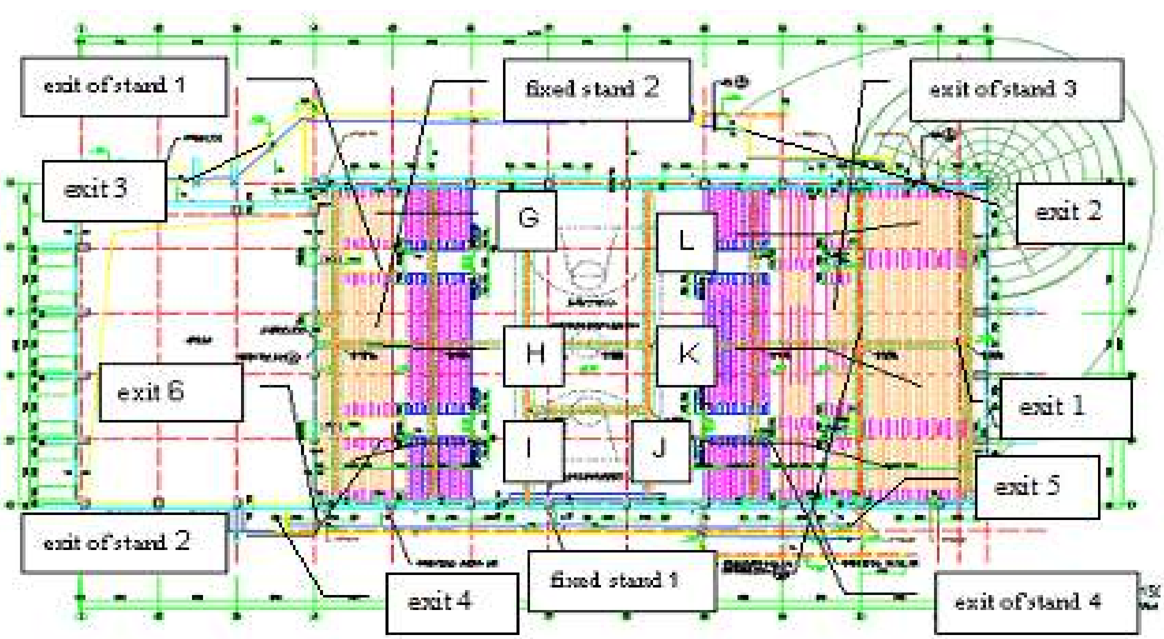

Fig. 3: Plane on the standard height of 15.000 m

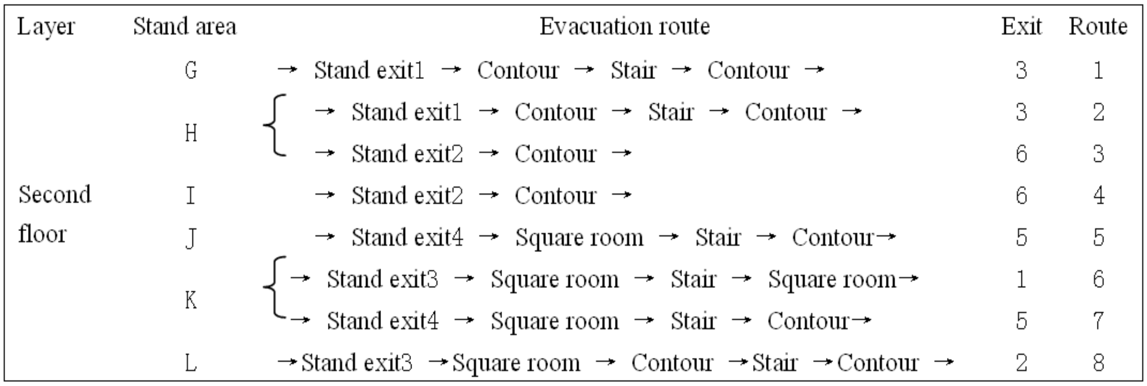

Fig. 4: Different evacuation routes

Table 4: Evacuation times of different routes

Route number	1	2	3	4	5	6	7	8
Number of evacuation people	100	150	150	100	350	400	400	350
Evacuation time (s)	168	168	303	303	429	414	429	426

There are four exits to evacuation channels on the second floor, whose widths are 2.6~2.9 m. The specific structure is shown as Fig. 3.

Evacuation route description and evacuation time: The theoretic evacuation route on the second floor is shown as Fig. 4:

Due to complex evacuation environment, specific evacuation times for various evacuation routes are calculated in travel time method (Table 4). Set safety coefficient as 1.5.

Travel time method:

$$T = N_a / fB_{\min} + l_{\max} / v \tag{8}$$

where,

- T = Evacuation time
- N_a = The total number of people waiting for evacuating
- f = Crowd flow coefficient (people/m/s)
- B_{min} = Minimal effective width of evacuation channel
- $l_{\max}$ = Maximum walking distance from various regions to safe place
- v = Crowd's moving velocity

The result shows, considering both alarming time and responding time, the end times of different routes are among 288~549s. The end time of route 5, 6, 7, 8 are within 534~549s, higher than the basic requirements of common fire risk level.

According to accident consequence chain theory and clustering flow theory, considering the effects of primary and secondary disasters, calculate the evacuation time on the second floor in formula 5. The result shows, if no commanding exists, the probability of secondary disaster on stand 1 and 2 is high. If design according to performance-based evacuation requirements, it is easy to find that the safety hazard is high.

Fire alarming design: Fire alarming time, to some degree, can get time for reducing primary disasters and preventing from hurting by secondary ones. Several aspects should be seriously considered in the design; 1. The place is easy to catch fire, such as electricity controlling room, storage, etc, to reduce the finding time as possible as it could. 2. Evacuation channel, to manage and command timely when the responding appears, preventing the disturbances due to knowing little about building and situations; 3. The materials and its surroundings easy to catch fire, alarming ahead help reduce the time for hiding from high temperature and toxic gases.

According to current studies, in western developed countries, as an important son of automation system of smart building devices, smart fire auto alarming system is mature. Although our studies are late, the rapid increasing of requirement quantities, stimulate its technical innovations and enhance its vigorous development. Social human power, material power, financial power and technology are invested in its development, study and applications. And performances are flashing. The fire auto alarming system in wireless communications are more and more important. Due to its easy installation, harmless works, fine flexibility and easy to expand, etc, it is applicable to many fields, such as scenic spots and historical sites, stadiums, museums, exhibitions, buildings under construction and hospital, etc. The smart refers to fire judge and management. Generally are scattering, centralizing and distributed. Scattering system consists of smart controller and several smart detect nodes. The judge is done by detect nodes. Centralizing system consists of smart controller and several intelligent detect nodes. The detect node only sent parameters to controller and fire states are judged by controller; both controller and detect nodes of distributed system are smart, which is also the future development directions of fire auto alarming system.

Current fire alarming system already fits the basic requirements. Therefore, install the system according to relative results and conforming to basic requirements, to find fire signal as soon as possible. Conduct saving and evacuating activities. Meanwhile the routes should also be considered. Try to mark the routes by alarming devices to avoid the flows in different directions existing due to knowing little about the building and situations.

CONCLUSION

This study, taking delaying and broaching situation in fire dense crowd's evacuation route design as background, guided by integrating analysis of fire alarming system and dense crowd's evacuation, considering relative factors, according to performance-based evacuation design, theory of accident consequence chain, clustering flow theory, etc, by calculating the delaying number quantitative modeling in travel time method, clarifies the design thoughts and clears the design principles. Meanwhile, this study proves the effects of fire primary disaster and secondary disaster and mark relative parameters. It integrates formulas of relevant models, considers practical requirements of various parameters fully. By analyzing cases, with many calculation methods, find the bottle neck and design the evacuation routes. Meanwhile design fire alarming system according to specific situations, with definite rules. The result can provide references for practical building designs. It is also a tool for managing and preventing the effects of various dangerous factors. At last, it should be stressed, base on human-thing-material model of body's information processing, human's function is very important. Therefore, human's fire-fighting mind and knowledge should be enhanced to decrease fire's happening. Besides, prevent human's error due to their wrong reactions.

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