Research Journal of Applied Sciences, Engineering and Technology 5(15): 3946-3950, 2013
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: December 28, 2012 Accepted: January 01, 2013 Published: April 25, 2013

Study of Fire Evacuation in Big Stadium Base on Performance

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Abstract: From economic perspective, the form and function of big stadium becomes diversified. Its utility and density increase. The fire evacuation becomes the common safety problem we all have to face. It is also the core of fire fighting design for big stadiums. Current researches focus on the development of evacuation model and behaviors during the evacuation. With the technical development, smart evacuation command already has the basis for realization. This study, on basis of performance evacuation, fire safety evacuation judgment and clustering behaviors, proposes fire detection-alarming-smart evacuation system design. Its result, on one hand, provides references for current big stadium to make evacuation plans and build fitting facilities. One the other hand, it can provide thoughts for fire-fighting safety design. It has widespread applicant prospect and abundant theoretic and practical significances.

Keywords: Evacuation, evacuation design, performance-based, smart building stadium

INTRODUCTION

With the rapid development in recent years, to meet social requirements, the investment in infrastructure building increases year by year. With the holding of Olympic Games, Asian Games and National Games, the big stadium's building steps into a new stage (Liang, 2010). Meanwhile, its forms and functions become diversified. Its utility is also increased. The fire evacuation problem is a common safety one (Zhang *et al.*, 2006). With the development of computer technology, to solve the dense crowd evacuation problem, many scholars and engineers develop building character model on different conditions. They study the fire primary disaster and secondary disaster. Nowadays, its study focus on following two aspects: redeveloping evacuation model and improvement of model predictive ability; effects of staff reactions and smoke toxicity on staffs.

With reference to current situation and results, although computer technology providing technical promise for corresponding simulation, it is essential to face some hypothesizes and limits. In a real fire, these are doubted. Once they are broke, the design shortage will come up, resulting in large loss (Zhu, 2010). Meanwhile, due to not enough considerations on the initial designs, the key points like evacuation channel shortages would exist. It is impossible to rebuild such channels. On that condition, the effective way to that problem is commanding. But relative researches are rare. Only a few papers clarify such problem in perspective of enhancing management and education, which don't conduct studies on commanding. This study will, on the basis of performance-based evacuation theory, according to effects of fire development on evacuation, proposes a smart evacuation imagination base on computer controlling in fire. It provides references for designing stadium and modeling calculation. It also provides thoughts for current evacuation design.

THEORETIC BASIS

Performance-based evacuation design: It brings in conceptions of special fire, proposes evacuation safety. It proposes the command that, on the condition of fire, all staff can be evacuated to safe places without any difficulty or danger. According to such basic principle, several requirements should be conformed to: the staff in the building can avoid direct damages, including burn or smokes, etc; any point at least links an evacuation channel; avoid the structural design error to reduce stranding, so as to avoid stamping; it should benefit for people who don't know about building to find the safe exits fast (Huo and Yuan, 2002).

The logic relation of its organization frame can be considered as a repeated design procedure: design-prove-redesign-reprove, until reaching the real requirements. Two basements exist: fire simulation and evacuation. The specific flowing chart is shown as Fig. 1.

Criteria for fire safe evacuation: Several indexes can judge the acceptable environment, which are visibility, toxicity, heat radiation and thermal convection. If any parameter doesn't meet its criteria, environment will

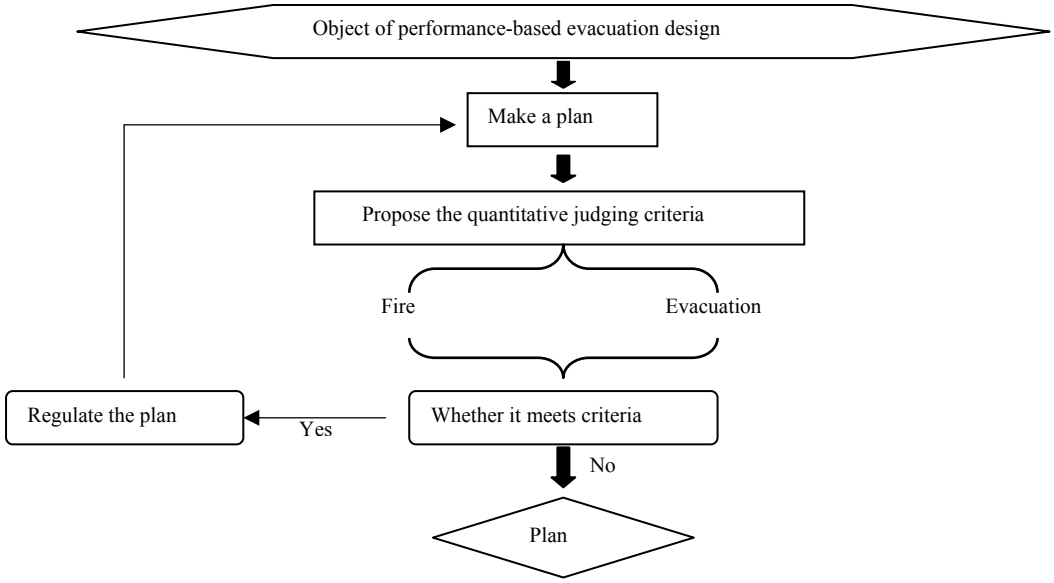

Fig. 1: Design flowing

Table 1: Effect of bad fire products

	5-min expose time		30-min expose time	
Bad product	Number of ability loss	Casualty	Number of ability loss	Casualty
CO (ppm)	6000	12000	1000	2500
HCN (ppm)	150	250	90	170
HCL (ppm)	500	16000	200	<12%
Organic irritations of gas (K^+)	1.2	7	1.2	1.2

K+ is light attenuation coefficient of smoke. To wood and plastic burning, K≈7.6×103 ms. ms is the density of smoke particles in air, kg/m3

Table 2: Body heat limit

Temperature and water content	60°C<, vapor saturation	60°C, water content <1%	100°C, water content < 1%
Tolerance time	>30 min	12 min	1 min

have bad effects, maybe resulting in casualties. Before the end of evacuation, if the environment becomes unacceptable, the plan needs to be regulated to promise the people evacuated to safe exits.

The fire smoke includes toxic gases (such as CO, HCN, CO2 and SO2) and non-burning solid particle products. After reaching certain density, toxic gas will lead to casualties. The damages of parts of fueling products are listed in Table 1 (Li, 2010).

Research shows, nearly 70% heats off fire goes into smoke layer in convection. If the smoke can't be exhausted timely, when its temperature reaches a high degree (generally reaching 600℃), it will radiate lots of heats functioning the objects unburned to make them to divide burning gases. When the gases become enough, most combustible materials will burn in a short time, which is called as flashover.

Flashover indicates that, the heat of fire mainly comes from heat radiation of smoke layer. Therefore gas's temperature controlling is important. Research indicates, the body's undertaking limit is more than 5 min with less than 2.5kW/m^2 intensity. The 200℃ black body's radiation is about 2.5 kW/m^2. Therefore, generally, 200°C is considered as the up limit of gas temperature.

The air for staff breathing is heated by fire and smoke. The heat air exchanges heat with body especially respiratory system in convection. The experiment indicts, breathing too hot air will result in heat shock (heatstroke symptoms result from hot temperature to make the heat exhaust failed) and respiratory burns. Table 2 shows human's heat-resistant qualities in some situations.

- **Clustering behavior law:** So-called clustering crowd refers to, aggregating because of a same purpose, human's collection with certain scale. Although a common purpose (reach outside of stadium from stand exits and evacuation channels as soon as possible), due to personal differences (including between persons, person and crowds), potential contradictions exist, which will result in unpredictable crowd's behavior (Zhang, 2010). Meanwhile, when primary accident happens, once it happens, evacuation should be executed at once. However, at that time, the crowd is highly dense. If disturbance happens in the crowd, it will affect all the crowds, which must expand the influences of primary accidents to some degrees. Finally, the

damage area and degree will increase, which is difficult to control.

- **Clustering crowd's behavior law in panic:** Panic is a crowd behavior often happens. It refers to some behavior shouldn't be done, due to person's panic. Its reasons are a lot. Besides, it runs fast among the crowd. It can transmit to the whole crowd in extremely short time. Once the whole crowd is in panic, person's behavior will have following features (Helbing *et al.*, 2000; Fell, 2003):
- Human's nerve becomes extraordinary excited. He will be very nervous. Then he will do something blindly. For example, he doesn't make his own judgment but to follow.
- Human always ignore the restrictions of law and morality. He wills behavior approximately crazy.
- Each person of the crowd tries to move with his maximum velocity.
- The between physical functions and body contacts will increase rapidly. The broaching will exist.
- Mutual forces between crowds maybe reach 4450 N/m. That wills curves steel rod or breaking walls.
- If anybody falls or hurts during evacuation, it will form obstacle, so that the velocity will decrease.
- While crowd crossing bottle neck, they are in quite panic.
- The crowing degree increases greatly on exits, adding mutual frictions and broaching forces among crowd, the velocity will decrease, generating "fast resulting in slow" and form arching block distribution.
- Although more than 2 exits can provide evacuation, evacuation crowd will aggregate on one exit, ignoring the other one.
- Just due to the characters above, the crowd in panic (mainly on the stand exits and evacuation channel) at bottle neck is easy to behavior like that, stopping the usual evacuation.
- **Arching phenomenon (Liu *et al.*, 2004):** In the evacuation process, when the crowd goes into the exits or evacuation channel from big space, asides from the flow in the right direction, usually many people from side directions, it will stock the flowing in the right direction, so as to increase aggregation density and form arching flow structure. So anyone couldn't cross in front of the exit. However, when the density reaches some degree, due to the strength of some direction bigger, the arching will elapse. Some people suddenly reach the exits causing flow moves suddenly, which will result in falling or stamping due to loss of balance, especially on the stair or floors. Soon after old arch elapsed, new one will generate.
- **Counter crowd flow:** Generally, if in panic, crowd from different directions will broaching to exits or crossing point in the same time; due to mutual conflicts and blocks among crowds from different directions, crowding is easy to happen. At that time, people on the ends of team couldn't know about the situation timely. They will unconsciously enhance the broaching, which will make the front line or the middle one elapsed. Then the head line stocks and can't notice the people behind. The strength will increase continuously. Stamping will be easy to happen.
- **Crowds flow with same direction and different qualities:** When all people in the crowd moves to an exit or channel in certain velocity, the crowd flow at that time is stable. However, in general, the crowd's structure isn't single, including old, weak, sick, disable, women and children, whose velocities are different. Meanwhile, each person in the crowd tries to move in the shortest routes they think. The people with faster velocity will go through or broach others. Just such psychology and behavior, crowding and collision even part flow stalking will happen, which extremely results in accidents.

EVACUATION DESIGN FOR BIG STADIUM

Evacuation time: In a fire, the staff's safety depends on contrast relation between two characteristic times. One is time for person evacuated to safe area, called as evacuation end time T_{RSET}; the other is time until danger happens, called as available time, which is danger arriving time T_{ASET}. They can judge whether the evacuation is qualified. If the result is $T_{ASET} > T_{RSET}$, the staff can evacuate safely. Otherwise, some improvements should be made on evacuation route, commanding and potential evacuation bottle neck, etc.

According to Guide for building engineering performance-based fire-fighting design and evaluation written by fire control bureau of public in august, 2006 and British standard BS7974-Part6, the time needed by evacuation T_{RSET} consists of detective time, alarm time, recognition time, reactive time and motion time from the beginning to reaching safe place. The formula is:

$$T_{REST} = T_{dec}+T_{ala}+T_{rec}+T_{res}+K \bullet T_{trav} \quad (1)$$

In formula:

T_{dec} = Detect time, which is from the beginning to detecting fire, S

T_{ala} = Alarm time, which is from detecting fire to noticing the staffs, S

T_{rec} = Acknowledging time, this is from hearing or seeing fire to realizing taking measures,

T_{res} = Initial responding time, which is from reacting, such as looking up fire, putting away luggage or calling on families, until the beginning of evacuation activity, S

T_{tray} = Motion time, which is time from the motion's begin to its end, including motive time and waiting time, S

K = The safety coefficient, usually 1.5-2. It will be larger when it is applied to water power model.

Table 3: Basic constants in different situations

	Evacuation delaying time (min)		
	Alarm type		
Building type and internal staff's characters	W1	W2	W3
Officer, commercial or industrial factory, school (inhabitants are clear, know well about building, alarm system and evacuation measures)	<1	3	>4
Shop, exhibition hall, museum, entertainment center and other public buildings (inhabitants are clear, know little about building, alarm system and evacuation measures)	<2	3	<6

W1-the lively broadcast in controlling room from closed circuit television, or real-time instructions from workers who are well qualified, all staffs can see or hear these workers and instructions; W2-non-instuctive voice information, such as recorded voice broadcast system or visible alarm marks or worker after exercising. W3-use alarming system like bell, alarm whistle or other facilities

In general analysis, we call the acknowledging time and initial responding time as pre-move time, which is:

$$T_{pre\text{-}move} = T_{rec} + T_{res} \quad (2)$$

Aggregate formula 1 and formula 2, T_{REST} formula usually used in engineering will be:

$$T_{REST} = T_{dec} + T_{ala} + T_{pre\text{-}move} + K \bullet T_{trav} \quad (3)$$

Guiding thoughts: In performance-based evacuation design, T_{ASET} is constant. According to building's scale and building materials, etc, set the safe time limit. Besides, the fire type and place of fire starting should be considered. For example, a stadium heated by burning natural gas, if some burning point is broken, fire will be caused and T_{ASET} will be shorten. According to reasons above, while conducting evacuation design, especially for stadium built, the evacuation tactic and routes should start with shortening T_{RSET}.

T_{dec} is influenced by detect methods. In modern building fire-resistant design, the methods can be classified into two kinds: auto detect (such as smoke/temperature detector, gas detector, auto moistener, etc): detect time depends on detector type (ability to detect fire), fire type (definite heat or smoke), distance between fire and detector (the time for heat/smoke from fire source to detector), etc; self detect (like visual recognition): detect time is solved by integrating various feels. Generally, people near fire source can feel by various orphans: eyes, nose, ears and skins, etc. That relates to size of fire source, distance, house height, quantity of smoke and crowding degree, etc, which is complex.

T_{ala} depends on specific management plan and procedures. Several situations exist: if an alarm signal sent from smoke detector, the staffs, who have received emergency processing educations, will run to the fire area directly, according to its instructions. Then make sure whether fire happens; if manual alarming button pressed, to make sure whether it is true, workers will go to the scent or look up through surveillance system; if auto moistener started, fire is true. Because error is impossible, the alarm should be sent without any delaying. All in all, after receiving the first alarming signal, it should be confirmed in several minutes.

$T_{pre\text{-}move}$ includes confirming time and responding time. Current research indicates delaying time relates to alarming type. Confirming time mainly refer to the time for staff starting to react after alarming. In such time, human maybe undertake their study before alarming, like work or have a break, etc. It closely relates to building type. In a building with good management, it is very short. Staff's reacting time relates to his acknowledges of surrounding environments, from several seconds to tens of minutes. During that time, people already stop their previous study, starting to know about fire situation to make sure the next motion. According to different alarm type, basic constants for staff's confirming time and responding time in different situations are shown as Table 3:

T_{trav} relates to personal characters and building's characteristic time closely. Personal characters include physical energy, social relationship with other people in the building, whether he needs help, etc. building's characters are mainly relevant to numbers of evacuation channels, widths of evacuation channel, distance of a evacuation channel, lighting level and instruction marks. Besides, motion time also relates to psychology, such as habitual psychology, photo-tactic psychology, nearby psychology and majority psychology, etc. Due to complex analysis of evacuation motion time, global has series of researches and develops various models for simulating evacuation motion time.

Evacuation tactics: With the energetic development of Chinese smart buildings and continuous improvement of fire-fighting system, the application and study of fire auto alarming devices are well developed. Since July, 1st, 2009, revised edition of intelligent building design standard GB/T 14, proposed by China construction department and national quality examination bureau, functioned in 2006. It holds that, smart building is an environment, which owns several systems such as information facilities, information application, building devices management and common safety, etc, with the building platform. It provides safe and creditable, effective and convenient, energy-saving and environmental and healthy and comfortable environment. FAS are very important. There is a saying that, prevention is more important than putting on fire. But prevention can't avoid fire totally. If happens, a fire

can be found timely and effective measures can be taken, the loss can be minimal. But to current situation, the function only is fire detect and sending out alarm, without any benefits for other sections. In recent years, the rapid development of computer and network technology has provided possibilities for realizing smart system, which can complete the fire, detect-alarm-commanding. Considering essential shortages, we can set some key points in smart system, to interfere manually.

Such system bases on wireless sensor network, which utilizes sensor network, GSM network and computer network, to meet the requirements. Fire auto detect and alarm has already developed into a high level, by combining auto detect devices and manual detect alarming, the time for fire detect and alarming can be shorten as possible as it could. It can give people more time to evacuate. The specific principles and design thoughts are not talked here. The following is a discussion on specific structures and functions of commanding system.

According to relative theories above, with the performance-based idea, interfere and command according to primary disaster and secondary disaster. The system depends on evacuation routes calculated by modeling, which can be got by software like BuildSGEN. After making sure the route, when fire happens, by computer simulation, close the evacuation routes near fire point. Meanwhile propose reasonable evacuation routes. When delaying and broaching situations happen on some exit, such information can be sent to computer by wireless network switch. The computer recalculates the evacuation routes. The states of people limit the language commanding system. Therefore, pilot lights can be installed on the walls. Green light is passing and red one is blocking. They are controlled wirelessly by computer.

CONCLUSION

Multifunctional stadium, to some degree, decides the relative centering of utilization. But parts of designs don't consider the evacuations comprehensively, which increases the probabilities of accidents. Current stadium smart system mainly design on detect and alarm. Researches on commanding are rare.

This study, with references to specific functions for Chinese stadiums, guided by smart evacuation commanding, according to current theories, damage parameters of fire and psychological features in evacuation, studies the fire evacuation in big stadiums. It proposes a new smart system, which includes fire detect-alarming-evacuation, conforming to ides of smart buildings, start with shortening T_{REST}, makes evacuation tactics and routes. With the help of sensor network, GSM network and computer network, set manual intervention on key points. This study provides some effective thoughts and intelligence references for evacuation designs for big stadiums.

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