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Research Article

Study of Evacuation Model for Multi-Functional Sports Stadium in Colleges

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Abstract: The international universal calculations of the time for evacuation have their own features and limits and their effective areas have to be noticed. This study analyzes different ways to calculate the evacuation time, according to the relative indexes and rules for evacuation of Chinese sports stadium. According to the specific calculation in a university, it has safety hazards. On condition of not changing the hardware structures, this study proposes the notes and measures for safety evacuation and provides references and advice for its real application.

Keywords: Evacuation times, stadium, travel time

INTRODUCTION

With the Chinese economy developing rapidly, the hardware construction for national colleges step into a new stage and various stadiums have been accomplished and applied. Their functions become varied, gradually taking on many tasks like competition, teaching, rally (Xu *et al*., 2007). The number of people involved becomes larger and larger as the functions added. In view of emergencies like fire and chaos, the evacuation has become an essential public security problem (Zhang, 2012). Until now, Chinese researchers usually study such problem in fire evacuation model and they propose two ways to calculate. They are formula calculation and computer simulation and both of them have succeeded. This study introduces two international ways to calculate group evacuation, by analyzing plans and provides references for real applications.

MODELING METHODS

The key to design safety evacuation is evacuation time. Engineering calculation is simple, fast and convenient. There are many ways to calculate evacuation times. This study stresses two ways.

Key nodes method:

$$\text{Evacuation time } (T) = N/AB \quad (1)$$

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

Table 1: Crowd flow coefficient

Name	Flow coefficient (people/m/s)	Remarks
Channel	1.5	Emergency
Entrance for stairwell	1.3	Evacuation

Table 2: Marginal sizes of evacuation channels

Channel type	The width index has to be subtract (cm)
Stair	15
Channel	20
Door	15

Travel time method:

$$T = N_a / fB_{\min} + l_{\max} / v \quad (2)$$

T = Evacuation time
N_a = The total number of people waiting to evacuate
f = The crowd flow coefficient in evacuation channel (people/m/s)
B_{min} = The minimal effective width of evacuation channel
l_{max} = The maximum distance between various evacuation area and safety area
v = Crowd's moving velocity

Evacuation channel crowd flow coefficient (people/m/s), in practice, often is set as experienced coefficient, shown as Table 1 (Huang, 1997).

In the course of evacuation, certain distance must exist between passengers and channel margins. So in reality, the sizes of margins have to be subtracted so as to get the effective width, shown as Table 2 (Li, 1997).

Application range and limits: In the macro perspective, set all the channels as a total channel. Under the ideal state, all staff evacuate to exits through total channel. This method can certain the proportional relation between capacity and exits, but not the only standard. Such doesn't consider the distribution of crowds in different regions, or real differences among different routes. In reality, the evacuation depends on the most crowding evacuation time. Besides, it also does not consider the times for walking in the stadium.

Travel time method is easy to calculate, especially for complicating stadium. It fully considers crowd's evacuation time and travel time, but without considering delaying and crowding situations. In this study's following study, the effects of delaying and crowding situation on walking speed will be discussed, besides, the practical example will be discussed to analyze the bad effects and countermeasures.

MODEL SET

Relations between crowd density and crowd speed and analysis of crowd density dangerous level: Once the emergencies like fire and disturbance happen, besides the real threaten from fire and disturbance, the fear of crowd should also be considered to some degree. When crowd lose control under the fear state, the density will become too large, then delaying and crowding will happen, so that adding the probability of danger, related experience constants are shown in Table 3 to 4 (Liu and Liu, 2004).

Risk forming mechanism of crowd stampede accidents: According to trajectory intersection theory, people's unsafe behavior and thing's unsafe state contacts in certain time and space in their own development, whose energy affects body to trigger stampede accidents. Because the existing risk keeps constant once the building is accomplished. So the key to avoid the timing and spatial contact of people's unsafe behavior and thing's unsafe state is to control human's behaviors.

According to theories existed, whether an accident happens mainly features as two procedures: free moving->waiting for evacuating->evacuate; free moving->waiting for evacuating->accident. Research has proved, the accident is caused of too long time for waiting for evacuating and the marginal and internal disturbance. The time mainly focuses on waiting stage, the evacuation process is shown in Fig. 1 (Huang, 2010).

Table 3: Relation between walking speed and density

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

Table 4: Crowd density dangerous level

Level	Density (people/m^2)
Dangerous density	3.59
Clogging density	2.15
Maximum density accepted	1.08

Table 5: Evacuation predicting speed of crowd in different region

Function of building	Classification of sections	Evacuation direction	Speed
Theater or	Stair	Up	0.45
buildings		Down	0.60
With same	Seat section	-	0.50
Functions	Other section	-	1.00

Table 6: Minimal evacuation net width for each 100 people in theatre, cinema and hall

The number of seats in audience hall			≤2500	≤1200
Fire-resistant level			One, two	Three
Evacuation place	Door and channel	Flat ground	0.65	0.85
		Stair ground	0.75	1.00
	Stair		0.75	1.00

Crowd evacuation speed: On the condition of emergency, the walking speed depends on many factors. Chinese scholars proposed main values for references, shown as Table 5 (Li, 2005).

Minimal effective width of evacuation channel: The total widths of evacuation channel, evacuation stair, evacuation door and evacuation exit in places with crowds such as theater, cinema, hall and stadium should be decided according to the number of people accessed and evacuation width (shown as Table 6 and 7) (Jing, 2006).

Rules for evacuation time in Chinese stadium: According to the researches on some stadiums, to the evacuation times in the stadiums with one and two fire-resistant level, the time should be controlled in 3~4 min according to different scales. Besides, according to the real results, to the audience hall with 2000~5000 seats, the mean evacuation time is 3.17 min; to the audience

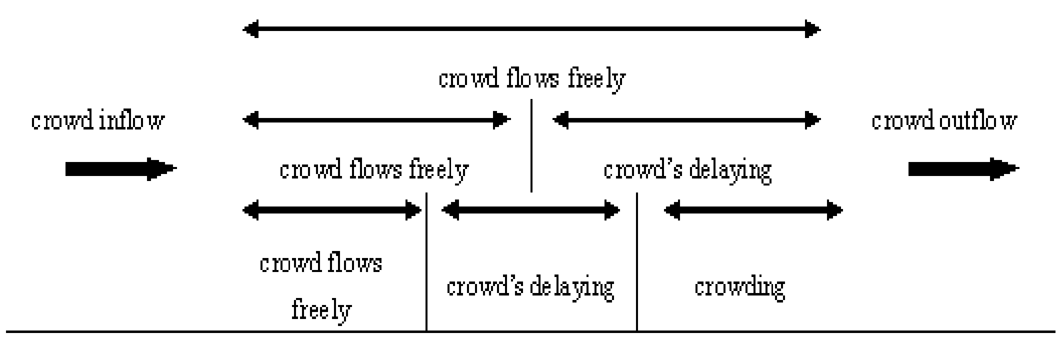

Fig. 1: Waiting stage of crowd evacuation

Table 7: Minimal evacuation net width for each 100 people in stadium

The number of seats in audience hall			3000~5000	5001~10000	10001~20000
Evacuation place	Door and channel	Flat ground	0.43	0.37	0.32
		Stair ground	0.50	0.43	0.37
	Stair		0.50	0.43	0.37

Tip: The total width calculated according to large number of seats should more than that according to neighboring small number of seats

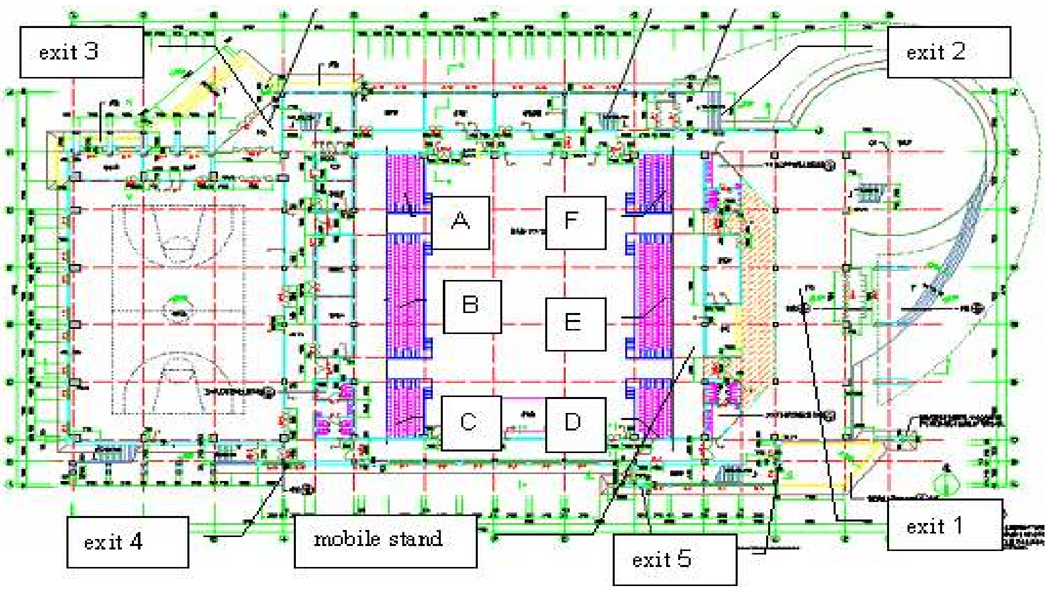

Fig. 2: The first floor

(1.91/0.55) ×37×3 = 385 and (2.75/0.55) ×37×4 = 740, among which 37 is the access ability of hall with 5000~20000 seats, the mean evacuation time is 4 min. So the evacuation time in the stadiums with one and two fire-resistant level is 3~4 min, which is the foundation of designing safe evacuation.

The capacity of audience hall changes hugely, from three or four thousand to ten or twenty thousand. The number in each evacuation door has its scale of changing, but such change has to be related to the width of evacuation door closely. The report shows, the minimal mean width of evacuation door is 1.91 m; the maximum is about 2.75 m. According to such widths and the time for people to evacuate, mean numbers of evacuation people at each door can be calculated, is each group. So the mean number of evacuation people in stadiums with one or two fire-resistant level is 400~700. Designers can make sure the number and widths of evacuation doors, according to the capacities, to meet the acquirements of evacuation times.

CASE STUDY

It is a multi-functional stadium, completed and put into use in 2003, including a main hall and training centers. It has two floors. The fix stand upstairs can hold 2000 audiences and the moving ones can hold 1520 audiences. There are 6 exits. The widths of stairs between first floor and second floor are 2.30-2.50 m. The widths of eight fire-resistant doors closed normally on the first floor are 1.5 m. The widths of four fire-resistant doors closed normally on the second floor are 2.6-2.9 m. The fire-resistant level is the first one. The stadium takes on teaching, competition, commercial performance and rally etc. Engineering diagrams are shown in Fig. 2 and 3.

Different ways to calculate the evacuation times:

Key nodes method: This stadium has 6 exits, except the marginal sizes of evacuation channels. Set each group's as 0.55 m. 3 exits contain 2 groups, 1 exit for 6 groups, 1 exit for 8 groups and 1 exit for 10 groups. The total number of groups in 1 sec is 31. In general, the group flowing at the surface channel is 43 people/min and that at the stair or stair channel is 37 people/min. Ignoring the crowding, the time for walking through the channel and the width of fire-resistant door normally closed, the evacuation time is 3520/ (43*30 ≈ 2.7 minutes. It meets the acquirements which demands that the maximum evacuation time is 6 min.

Travel time method: This method considers the evacuation time at the key nodes and walking time. So it is essential to analyze whether key nodes exist. Set this stadium as an example. It is easy to find that stand exits are key nodes. The evacuation routes are shown as Fig. 4.

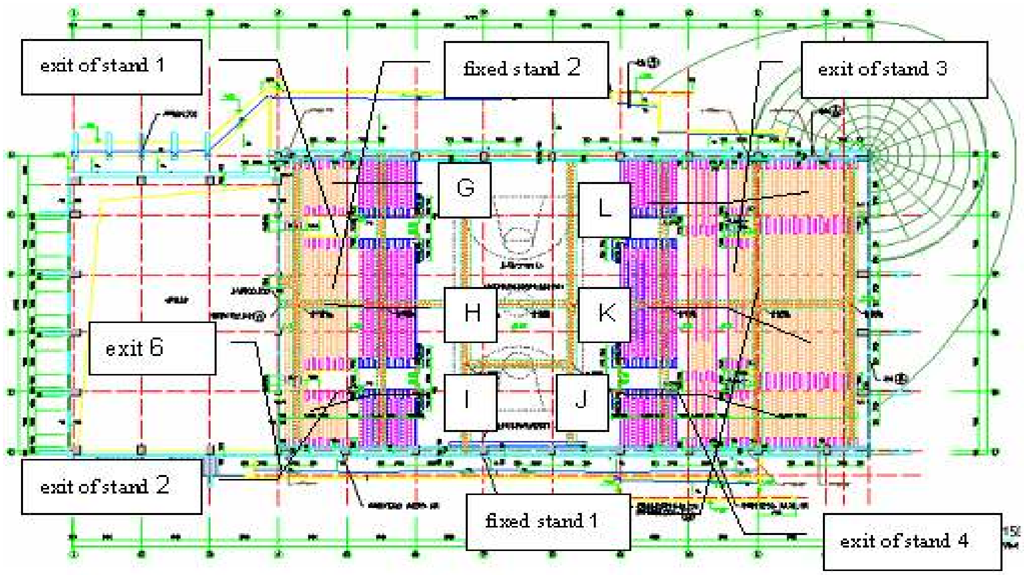

Fig. 3: Plane on the standard height of 15.000 m

floor	stand	evacuation route	exit	route
first floor	A	→ @--@1 → verandah →	3	1
	B	→ @--@2 → verandah →	3	2
		→ @--@3 → verandah →	4	3
	C	→ @--@4 → verandah →	4	4
	D	→ @--@5 → verandah →	5	5
	E	→ @--@6 → square hall →	1	6
		→ @--@7 → square hall →	1	7
	F	→ @--@8 → verandah →	2	8
second floor	G	→ exit 1 → verandah → stair →	3	9
	H	→ exit 1 → verandah → stair →	3	10
		→ exit 2 → verandah →	6	11
	I	→ exit 2 → verandah →	6	12
	J	→ exit 4 → square hall → stair →	5	13
	K	→ exit 3 → square hall → stair → square hall →	1	14
		→ exit 4 → square hall → stair →	5	15
	L	→ exit 3 → square hall → verandah → stair →	2	16

Fig. 4: Different evacuation routes

Table 8: Evacuation times in different routes on the first floor

Route number	1	2	3	4	5	6	7	8
Number of evacuation people	180	200	200	180	180	200	200	180
Evacuation time (s)	105	117	265	265	120	120	120	99

Table 9: Evacuation times in different routes on the second floor

Route number	9	10	11	12	13	14	15	16
Number of evacuation people	100	150	150	100	350	400	400	350
Evacuation time (s)	113	113	202	202	286	276	286	284

Considering the evacuated ability of 4^{th}, 5^{th} exit and that of the stand exits on the second floor, calculate the number of evacuation people and evacuation time in travel time method (shown as Table 8 to 9).

This two tables show that, ignoring the delaying, the maximum evacuation time in the stands area is 4.8 min, higher than that ruled in Chinese stadiums, but meets the basic acquirements that the maximum evacuation time is 6 min. however, we have already given the relation index between crowd density and walking and density dangerous levels, meanwhile, the main reason for final stampede is the block at the exits.

The fixed stands, especially stands 3 and 4, are in the middle, according to indexes shown as Table 7, the effective widths of stands 3 and 4 2.7 m are obviously less than the standard width 3.8 m. At the time of evacuation, crowd from many directions will focus on an exit, where relates to stairs directly. If emergency happens, delaying and crowding will happen at stands 3 and 4, reaching the dangerous density, so that the probability of stampede goes up. Therefore, in reality, training, especially to the staff on the second floor, should be enhanced. Make the evacuation orders to avoid the accidents.

CONCLUSION

Therefore this study introduces two ways for evacuation, which are applied in different areas, lists their parameters, developed evacuation model and provides references for real engineering calculations. Through the case analysis, find out key points that may cause accidents, given corresponding recommendations and solutions.

Multi-functional stadiums result in the common time. If ignoring the evacuation problem, the probabilities of accidents will go up. Once an accident happens, a huge loss may happen. Hazards are proved to exist. So we must take measures to repair and reduce the risks of accidents in a dense crowd evacuation process. Finally, it must be stressed, person is important. People's firefighting knowledge, understanding of evacuation routes, mutual effects of evacuation and mutual psychological hints will make a difference. So we should enhance the introduction of evacuation.

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