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Research Article

Study on Stranded Crowd Number Quantitative Model during Evacuation for University's Multifunctional Gymnasium

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Abstract: This study, beginning with crowding situation caused by staff stranding in gymnasium, introduces theoretic basis of relative accidents, definite basic parameters including crowd flow rate, group flow and marginal sizes of evacuation channel, walking velocity of groups with different densities and predictive velocities of evacuation in different regions. Deduce and build stranded crow number quantitative model. By analyzing cases, calculate specific route and time of a Chinese university's multifunctional gymnasium in travel time method. Find evacuation bottle neck probably exist. Calculate specific stranding situation according to such model, find potential safety hazard and provides advice for improving stands exits. It can provide evaluation standards and references for designing, managing and transformation. It can also choose evacuation routes and make emergency plan.

Keywords: Evacuation, gymnasium, model, university

INTRODUCTION

With the development of Chinese society and economy and the extreme abundant of social resources, the development of university's education is also paid much attention to. The nation's investment on infrastructures is also increasing rapidly. Chinese college's sports hardware is improved greatly. Various gymnasiums are functioned. In order to avoid waste of resources and idling, besides to get some management and maintaining funds, their functions are changed greatly, developing diversified. Meanwhile, due to the development of architecture science and more and more multifunctional acquirements, current gymnasiums become complex and integrating (Gong, 2001). Research has proved, as crowded place, once emergency happens, if the education on safety hazard and group evacuation is wrong, the stamp will result in great financial loss. Analyze various accidents, we convict that the casualties with direct cause of accidents like explosion, fire and ineffective building structure are few. But its stamping accident is the final source (Huang, 2010). Numbers of foreign scholars deduce and calculate this model, according to evacuation in great gymnasiums, in different theoretic directions, from simple to complex models, which have a lot of performances. According to Togawa (1955) building evacuation time formula, Wen Limin proposes fire crowding flow model. Zhang *et al*. (2006) have deep researches on their studying area. This study, beginning with crowding situation caused by staff stranding in gymnasium, introduces theoretic basis of relative accidents. It builds stranded crowd quantitative model in staff evacuation for university's multifunctional gymnasiums. It can provide evaluation standards and references for designing, managing and transformation. It can also choose evacuation routes and make emergency plan.

SET BASIC PARAMETERS

The stranded crowd quantitative model includes several parameters like crowd flow coefficient (number of people through unit channel width in unit time), group flow and marginal sizes of evacuation channel, walking velocity of groups with different densities and predictive velocities of evacuation in different regions.

Set crowd flow coefficient: Crowd flow coefficient (people/m/s) is a measurement of channel utility efficiency. In reality, set it as an experience constant (Table 1) (Huang, 1997).

Specific formula is show as:

Flow rate = number of flowing/
(time×width) (people/m/s) (1)

According to liuyu's model for relation between flow coefficient and crowd density (Liu *et al*., 2002), the f calculation formula can be deduced:

$$f = 2.27\rho^{0.5} - 0.374\rho^{1.5} \quad (2)$$

ρ = Crowd density on exit. Its specific calculation formula is shown as formula 5.

Table 1: Acrowd flow coefficient

Entrance and exit name	Flow coefficient (people /m/s)
Aisle	1.5
Entrance of stair room	1.3

Table 2: Marginal sizes

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

Table 3: Relation between walking velocity and density

Crowd density (people/m2)	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 4: Predictive velocity

Classification	Evacuation direction	Walking velocity
	Up	0.45
Stair	Down	0.60
Seat	—	0.50
Others	—	1.00

Crowd flow is closely relevant to flow passing rate, which can be indicated in following formula:

$$F = fW \tag{3}$$

or

$$F = v\rho W \tag{4}$$

where,

F = Crowd flow through exit in certain time, whose unit is people/s
f = Flow coefficient, whose unit is people/m/s
v = Crowd flow velocity
ρ = Crowd density, whose unit is people/m^2
W = Width of exit, whose unit is m

Marginal size: During evacuation, the distance exists in margins of passenger and building. Therefore, in real calculation, the marginal sizes have to be subtracted. Then the width is effective (Table 2) (Li, 2011).

Relation between walking velocity and density: In emergencies like fire and staff disturbance, when evacuation is needed, aside from their real threaten, panic should also be considered. When crowd is under no control, some key sections will do not work to result in stranding and crowding situations, increasing the probability of danger.

Crowd density is a parameter for density degree in a space, which is often demonstrated by crowd number in unit area:

$$\text{Crowd density } (\rho) = \text{total number/area (people/m}^2) \tag{5}$$

Togawa (1955) and Ando *et al*. (1994) propose the density-velocity function, which is shown as:

$$u = u_0 .\, \rho^{-0.S} \tag{6}$$

ρ is crowd density. u_0 is a constant, which is 1.34 m/s. According to function above, when ρ = 1.0 people/m^2, crowd is flowing freely. Mobile velocity u = 1.3 m/s. When ρ = 2.0 people/m^2, crowd begins stranding. Mobile velocity u = 0.7 m/s. When ρ = 5.38 people/m^2, crowd is totally stranding. Mobile velocity u = 0 m/s. Their relation is shown as Table 3 (Liu and Liu, 2004).

Predictive velocity: In emergency, walking velocity has related to many factors. Chinese scholars have proposed main reference values after practices Table 4 (Li, 2005).
The specific formula is shown as:

$$\text{Mobile velocity} = \text{mobile velocity/ time (m/s)} \tag{7}$$

Mobile velocity reflects crowd's flowing velocity, which is a key to specific evacuation time and also the main factor of whether stranding crowd happens and the time for evacuation.

MODEL SET

Theoretic basis: Crowd flow theory about stranding situation in evacuation is described as: set a basic cutting area P in evacuation direction, then the crowd flowing into P is called as inflow crowd. Otherwise, it is called as outflow crowd. if some situations like channel becomes narrow and qualities of door, stair and floor changes, it is easy to cause stranding and disturbances on basic cutting plane P. The stranding crowd on P plane is called as stranding crowd, which equals the difference between inflow crowd and outflow crowd. The specific formula is shown as formula 7-11 (Zhang, 2004).

- **Aggregation clustering number:** From evacuation time (t = 0) to T, the aggregation clustering number on P:

$$y_1 = \sum_{i=1}^{n} \int_0^T N(t) B_i(t) dt \tag{8}$$

where,

$N(t)$ = Clustering flow coefficient on entrance
$B_i(t)$ = Width of i th entrance
n = Number of entrances

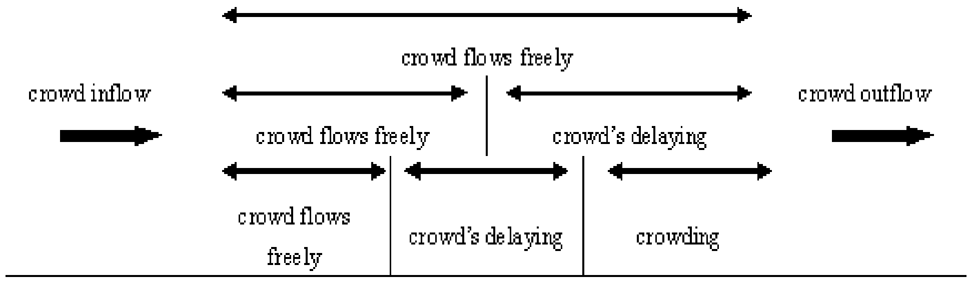

Fig. 1: Procedure of waiting stage

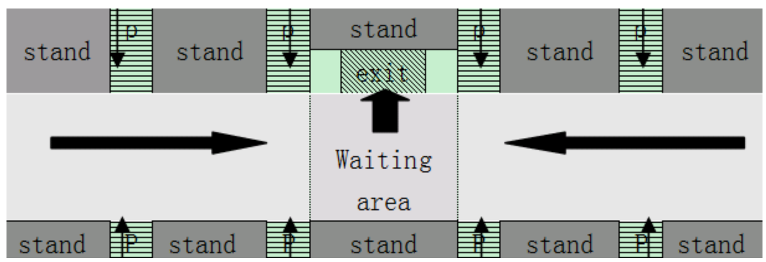

Fig. 2: Evacuation on stands

- **Outflow clustering number:** Until T, outflow clustering number through P, including number in first stage of evacuation and that after T_0:

$$y2 = \sum_{i=1}^{n} \int_0^{T_0} N(t) B_i(t) dt + (T - T_0) N' B' \tag{9}$$

$N(t)$ = Clustering outflow coefficient on exit
$B_i(t)$ = Width of exit
T_0 = Time for certain flowing happening

- **Stranding clustering number:** Until T, the stranding clustering number on P is:

$$\varphi = y1 - y2 = \sum_{i=1}^{n} \int_{T_0}^{T} N(t) B_i(t) dt - (T - T_0) N' B' \tag{10}$$

Solve its difference and set is as 0, the time for maximum stranding clustering number can be solved:

$$\frac{d\varphi}{dT} = \sum_{i=1}^{n} N(T) B_i(T) - N' B' \tag{11}$$

- **The end time of evacuation:**

$$T_e = \frac{1}{N' B'} \left[Q - \sum_{i=1}^{n} \int_0^{T_0} N(T) B_i(t) dt \right] + T_0 \tag{12}$$

According to track-cross theory of accident-causing theory, the risk of stamping is caused by energetic functions from certain time and space contacts of unsafe behavior and states. Once a gymnasium done, its potential hazard will be still. Then the key to avoid the timing and spatial contacts between unsafe behaviors and unsafe states is to control humans' behaviors.

According to current theories, whether an accident happens is demonstrated as two procedures: flow freely→waiting for evacuation→evacuation; flow freely→waiting for evacuation→accident. Research has already proved, accident is caused by too long time for group waiting for evacuation and internal or marginal disturbances. The time stage focuses on stage waiting for evacuation. The specific procedure is s hown as Fig. 1 (Huang, 2010).

Model hypothesis: Chinese gymnasium's evacuation on exits always bases on aggregating branches of stands to exit. The specific situation is shown as Fig. 2.

According to Togawa (1955) building evacuation time formula and fire clustering flow model proposed by Chinese scholars, branch entrance of multi stands, single exit. The flow in the channel is linear. At t ($t_0 \le t \le t_1$), the model for stranding number is (Zhang *et al.*, 2006):

$$N = \sum_{i=0}^{k} \int_0^t F_i(t) dt - \int_{t_0}^{t} F(t) dt \tag{13}$$

where,

- $F_i(t)$ = i th crowd flow at t
- $F(t)$ = Crowd flow on exit at t
- k = Branch entrance number
- t_0 = Delaying time from evacuation to cutting plane P
- t_1 = The time when density reaches 5.38人/m^2, which is the blocking time; the model conforms to clustering flow theory.

EXAMPLE ANALYSIS

Engineering situation: This gymnasium is multifunctional, including main gymnasium and exercise gymnasium. The main one is double-layer. The mobile stand on first layer can contain 1520 audiences. The fix stand on second layer can contain 2000 people. There are 6 exits. The widths of stair between first and second layer is 2.30-2.50 m. The widths of fire-resistant door closed on the first layer *8 are 1.5 m. The widths of fire-resistant door closed on the second layer×4 are 2.6 m-2.9 m. Their levels are one. The gymnasium mainly takes on tasks like teaching, competition, commercial performances and rally; Engineering diagrams are shown in Fig. 3.

According to basic parameters, calculate different evacuation time in travel time method to find key points, where delaying situation may happen.

The formula is:

$$T = N_a / fW_{\min} + l_{\max} / v \tag{14}$$

- T = Evacuation time
- N_a = Total number of people waiting for evacuating
- f = Flow coefficient (people/m/s)
- W_{min} = Minimal effective width of evacuation channel
- l_{max} = Maximum distance from evacuation point to safe field
- v = Crowd mobile velocity

After calculating 8 exits on the first layer to 5 exits, the total evacuation time is 99s~265s. The total evacuation time on east of 2-layer stands is 113s~202s. Then the delaying will happen in an extremely low probability. The west of 2-layer stand, due to large number of evacuation group and the exits in the middle of stands, the total evacuation time is nearly 300s. Considering the probability of arching phenomenon (Liu *et al*., 2004), the stranding will enhance density

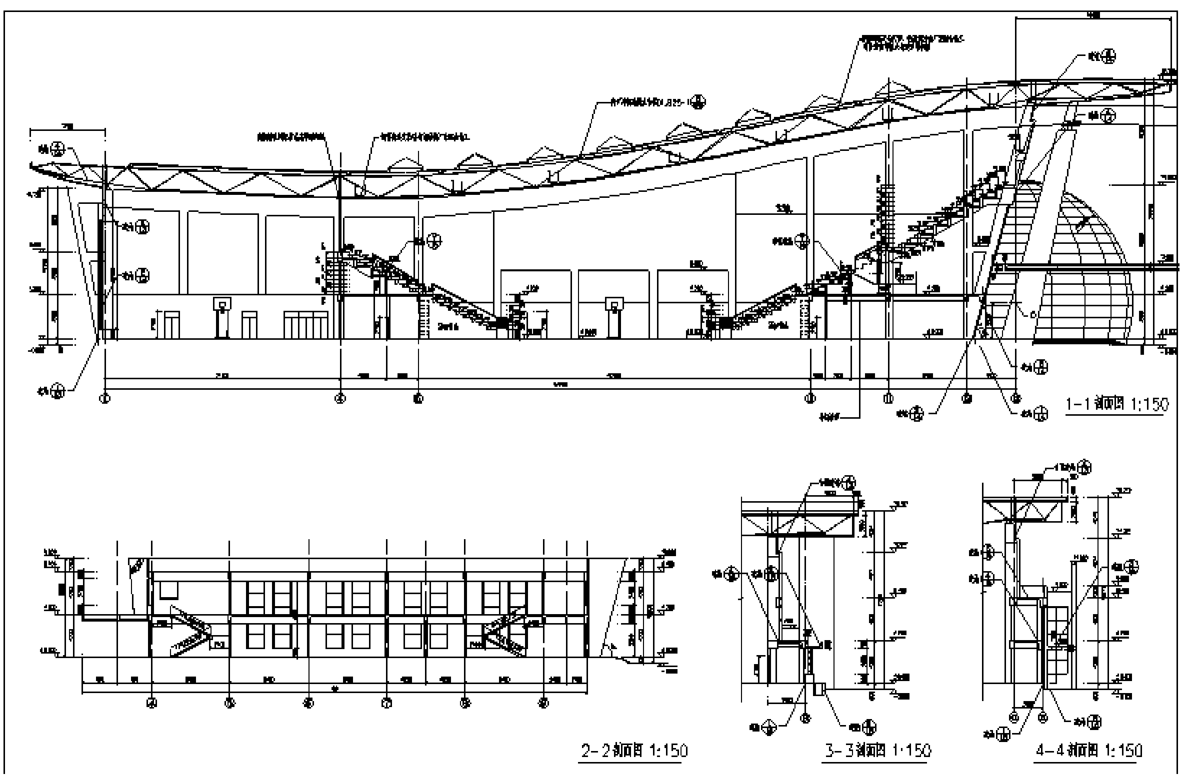

Fig. 3: Sectional view

Table 5: Density danger level

Level	Density (people/m2)
Danger	3.59
Block	2.15
Maximum satisfying density	1.08

(the density danger level is shown as Table 5. The widths of stand exits and structures don't reach the deduced results. Besides, the probability of stamping is high. Therefore, this study deduces and calculates stranding crowd number quantitative model on evacuation on the west of 2-layer stand.

Initial setting: The picture of stand exit on the west of second layer is shown as Fig. 4. The schematic diagram is shown as Fig. 5.

- **Flow density:** Traverse width of vertical evacuation stair is 1m. The width is 2 flowing. Each flow's width is 0.5m; the vertical width of traverse evacuation level channel is 1.5 m. The traverse width of exit is 2 m, 4 flowing widths.
- **Area:** the area of waiting area is $A = 4 \times 1.5\ m^2$
- **Number of people on stand:** The stand for "EXAMPLE ANALYSIS" evacuating through this exit contains about 750 people. The audiences on first row of stand 1 and 2 can enter waiting area directly.
- **Flow:** According to sports building design standard (Jing *et al*., 2006) and relative researches, considering factors like exit stair, etc, this study sets crowd flow as the minimum 40人/min of F = 40~42人/min. Because the evacuation can only be positive, set evacuation number 1 people in each 1.5s. The time interval t = 1.5s. Others can be deduced.

Model deduce:

- Each 1.5s, the number evacuated from stand exit is:

$$N_e = 1.5Wf = 1.5W\ 2.27\rho^{0.5} - 0.374\rho^{1.5} \quad (15)$$

- Each 1.5s, the number evacuated to waiting area is:

$$N_i = 1.5akF \quad (16)$$

a = Number of flows
k = Number of stand channels

- if $N_i > N_e$, in each 1.5s, the stranding number at waiting area is:

$$N_d = N_i - N_e \quad (17)$$

- Due to the different number of people on the stand, the number of evacuation people on each channel is different. Therefore, when $N_i = N_e$, the stranding crowd keeps constant. When $N_i > N_e$, the stranding crowd starts decreasing.
- Considering the people on stand 1 and 2 can reach waiting area directly, at the beginning time t_0 when stranding happens, the time for last person on the first row of stand 1 moving to waiting area can be definite. Then the initial stranding number is:

$$N_{t_0} = t_0 akF \quad (18)$$

- According to deduce above, the relation formula for stranding number and time at t ($t_0 \le t \le t_1$)is:

$$N(t) = \sum_{i=0}^{k}\int_{0}^{t} F_i(t)dt - \int_{t_0}^{t} F(t)dt$$
$$= N(t-1) + N_d = N(t-1) + N_i - N_e$$
$$= N(t-1) + 1.5akF - 1.5Wf \quad (19)$$

Fig. 4: Picture of stand exits on the second layer

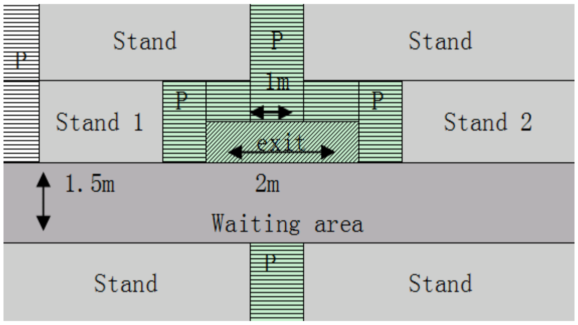

Fig. 5: Schematic diagram of stand exits on the second layer

$N(t)$ = The stranding number in waiting area at t
$N(t\text{-}1)$ = The stranding number in waiting area at t-1
t_0 = The stranding time from the evacuation to cutting plane P happening.
t_1 = The blocking time when the density on stand exit reaches 5.38人/m^2

RESULTS AND DISCUSSION

After calculating, initial crowd density is low and the crowd mobiles freely. The stranding number on exits in each 1.5s is four. With the increasing of density, the stranding number is also increasing. The flow rate f decreases. The stranding number in each 1.5s time interval increases. In this model, when the number of crowd in waiting area reaches $6m^2 \times 5.38 \approx 32$, the density on exit reaches its maximum. The crowd flow will become 0. The flow stops.

According to beginning time for initial stranding is 5 second after evacuation, the number of people in waiting area is 26. The density reaches 4.3. After 1.5s, such number will be more than 30, approaching the most dangerous value. In other word, due to the disadvantages of stand exit 3 on the west of 2nd layer, the stranding in 6.5s will increase rapidly. At that time, the probability of stamping will increase rapidly. Considering the stair structure on exit 3 of 2^{nd} layer, the dangerous probability will go on increasing. According to relative small specific structure of west stand exit 3, after modeling calculation, the stand exit should be controlled more than 3 m, which can meet basic requirements.

CONCLUSION

This study, according to clustering theory and track-crossing theory of accident-causing theory, gets basic instruction thoughts. On the basis of relations among crowd flow coefficient (number of people through unit channel width in unit time), group flow, marginal sizes of evacuation channel, walking velocity of groups with different densities and predictive velocities of evacuation in different regions and data marks, build the stranding crowd quantitative model. This model considers the applicant requirements fully. It can estimate the stranding may happen at bottle neck and the stranding number of people at different time. It can provide references for real designs. It can also be a calculation tool for managing evacuation and avoiding timing and spatial combination of various dangerous factors. At last, it should be noted, human is important. Human's mastering on fire fighting knowledge, understanding of evacuation routes, mutual effects of evacuation, mutual psychological hints, etc, will make a difference. Therefore, in reality, the self-protection education should be enhanced.

REFERENCES

Ando, J., H. Watanabe and S. Sakashita, 1994. Study of gravity anomaly on and around Izu-Oshima volcano. Bull. Earthq. Res. Inst. Univ. Tokyo, 69: 309-350. (In Japanese with English abstract)

Gong, X., 2001. Discussion on college's multifunctional gymnasium. J. Hubei Polytech. Univ., 16(3): 8-10.

Huang, F., 2010. Study of quantitative analysis in safety evacuation in sports stadium. Master Paper from Capital Economy and Trade University.

Huang. H., 1997. The curve of timely characteristics at the outlet of the safe evacuation of personnel' flow and concentration in high-rise buildings from a fire disaster. J. Chongqing Jianzhu Univ., 19(1): 26-34.

Jing, J. *et al*., 2006. Code for fire protection design of buildings GB-50016-2006. The Ministry of Public Security Fire Research Institute of Tianjin, Tianjin.

Li, Y., 2005. Performance-based Design in Building Fire Protection Design. Chemical Industry Press, Beijing.

Li, J., 2011. Study of calculation method on stadium evacuation time. J. Harbin Univ. Comm., 27(2): 252-256.

Liu, Q., L. Yangjie and S. Huapu, 2004. Discussion on gymnasium flow evacuation and its model. China Civil Eng. J., 10: 93-98.

Liu, W. and S. Liu, 2004. Building fire safety evacuation design and evaluation method. Fire Tech. Prod. Inform., 3: 3-6.

Liu, Y., W. Lin and D. Li, 2002. The Quantitative Model of Crowd Evacuation in Olympic Venue. Harbin Institute of Technology, Harbin.

Togawa, K., 1955. Study of fire escapes basing on the observations of multiple currents. Report No. 14. Building Research Institute, Ministry, Tokyo.

Zhang, B., 2004. Application of clustering flow theory in avoiding stamping accidents. J. Safety Health, 4: 42-43.

Zhang, Q., M. Liu and G. Zhao, 2006. Study of stranded crowd number quantitative model of stadium crowd evacuation. J. Safety Environ., 6(3): 21-23.