

Study on theater evacuation based on building EXODUS

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Abstract. In assembly occupancies with serried seats distribution, such as cinemas and theaters, the evacuation bottleneck is not only limited to the exit but also in the narrow corridors formed by a large number of seats. These narrow corridors are also an important factor that why people cannot evacuate quickly. This paper observes the evacuation situation of a college theater at the end of movies, and uses Building EXODUS to study the influence of seat jumping and corridors' width altering on evacuation. Studies shows that when the number reaches 20%-60% of the capacity, seat jumping situation during evacuation can improve evacuation efficiency. While the number exceeds 60% or less than 20% of the capacity, the total evacuation time will not change significantly. If the total width of the hallway remains unchanged and the width of each hallway is changed, the exit may reach the state of congestion in advance, which aggravates the congestion at the exit and also has a certain impact on the seat jumping to escape.

1 Foreword

In crowded places with dense seats, such as cinemas and theatres, exit is not the only obstacle that restricts evacuation, and the narrow passageway formed by a large number of seats in the room also has a serious impact on evacuation.

When there is a fire in the cinema, the main factors affecting the safety of personnel evacuation to include: large fire load, ignition sources, Dense personnel, Lack of independent external access, Crossing of evacuation paths and Lack of transition space [1-5]. Tian, et al. took into account the behavior decision-making characteristics such as seat jumping of evacuees in the evacuation of passenger cars, and introduced a kind of multi-valued function to expand cell state set so that the scaling characteristics of obstacles could be quantified. The results showed that the simulation results combined with the impact of scaling obstacles were credible. It is found that the evacuation animation of the $N^k_{O-t^k_{evac}}$ curve has a certain spatio-temporal correlation under the condition of seat jumping. With the increase of the perception domain of evacuees, the more reasonable the evacuation path is, but at the same time, the more conflict points caused by seat jumping increase [6-7]. Imanishi, et al. conducted an evacuation drill for 400-540 people aged 6-90 in a multifunctional theater in Japan for the first time, and found that people in the central area chose the aisle closest to their seats, and people on both sides chose to walk along the wall [8]. Instead of forming queues in the aisles between the seating areas, people tend to walk along the seats rather than crowding in the aisles because the narrow space between the rows is closer to the target exit. Wu, et

al. proposed the concept of "sub-safe area" for the first time by taking a theater as an example [9]. Helbing, et al. obtained through simulation that the corridor between seats in the gymnasium was designed as a zigzag shape, which could effectively avoid moving along a straight line during evacuation, thus reducing the crowding among passengers and improving evacuation efficiency [10-11].

Due to the rapid development of college cinemas [12], this paper will take a college cinema as an example and conduct a series of comparative analysis and research by observing the evacuation situation of people after the movie and simulating the impact of seat jumping behavior on evacuation.

2 The viewing scene after the cinema

This article conducted on-site observation of the evacuation of people in a movie theater in a university, and found that people prefer to evacuate through corridors 2 and 3, and corridors 1 and 4 are almost unused; people are accustomed to evacuating through gate 2 when entering the venue. Even if door 1 is in a state of concealment, few people will try to evacuate through door 1. In a non-emergency state, when people find that there is a long queue in the aisle, they tend to wait at the original seat instead of joining the line. The team, Figure 1 shows the actual evacuation after the theater is gone.

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Fig.1 Cinema scattered observation

3 Evacuation model

3.1 Model construction and dimension

According to the 1:1 modeling of the actual movie theater, the length and width are 28.5m and 20.5m respectively. There are exits on both sides of the screen. The width of the two inner exits is 1.9m, and the width of the two outer exits is 2.0m. In the theater, the same position and number of seats are arranged according to the actual situation. Each seat occupies a grid point of 0.5 m*0.5 m. There are 112 seats in the seating area on both sides and 266 seats in the middle area. A total of 490 seats. There is an interval of 0.5m between each row of seats as a corridor for people to walk during evacuation. The widths of the four longitudinal evacuation corridors 1, 2, 3 and 4 are respectively 1.5m, 2m, 2m and 1.5m, as shown in Figure 2.

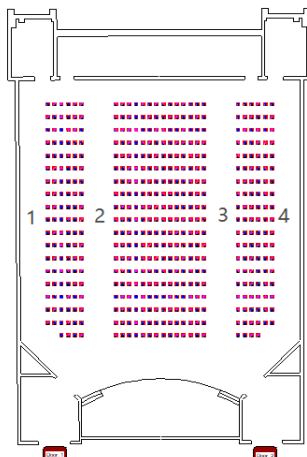


Fig.2 Theater floor plan

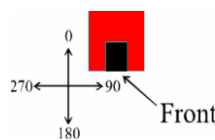


Fig.3 Seat orientation diagram

In building EXODUS, it is necessary to change the property of the seat lattice point required to be set in the modeling module, and change the property of the seat lattice point from the free space to the seat, as shown in Figure 4. The direction of the seat is shown in Figure 3, and the front of each seat is represented by a black rectangle.

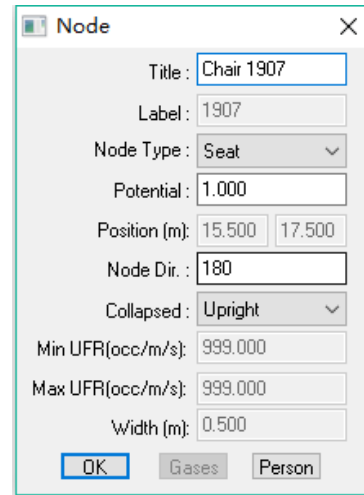


Fig.4 Node attribute modification

3.2 Personnel parameters

At present, China has not issued relevant standards and regulations to regulate the walking speed of personnel in evacuation assessment, although domestic scholars. Some related problems have been studied and some data have been obtained, but there are still some deficiencies at present.

Therefore, referring to foreign standards and combining SFPE's escape index values for different individuals, the horizontal movement speed of personnel was set as 1.2m/s-1.5m/s, and the walking speed on the theater steps was set as 1.01m/s. In the simulation process, the distribution of personnel was randomly distributed, while the characteristics and attributes of other personnel remained uniform.

4 Simulation analysis of theater personnel evacuation

4.1 The impact of overturning seats on evacuation

In the process of evacuation of people from a college theater, it was found that the evacuation bottleneck not only occurred at the two exits, but the longitudinal aisle between the seating areas was often the worst-hit area of crowds. In the event of a fire and other accidents that require emergency evacuation, accidents such as trampling may occur in the aisle, causing more serious impacts. Therefore, this paper simulates the behavior of jumping over the seat during the evacuation process to analyze whether the evacuation of the over seat can relieve the evacuation pressure in the aisle and improve the evacuation efficiency.

This simulation uses random distribution of people on the seats. The number of simulated people starts from 50 and increases upward, from 50 people to 450 people. Finally, the simulated seats are fully seated, that is, the capacity is saturated, 490 people. Each simulation takes three sets of data and averages them.

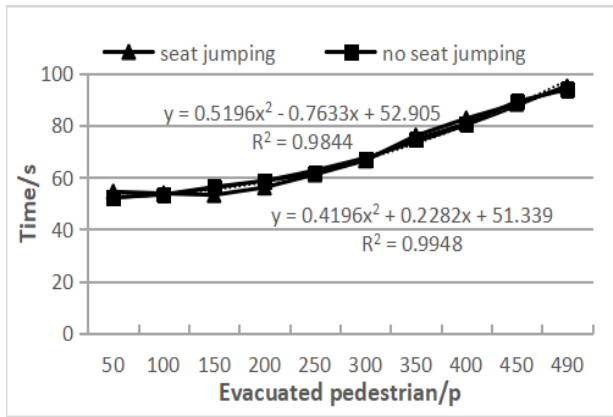


Fig.5 Average evacuation time

The average evacuation time of overturned and non-overturned seats is shown in Figure 5. It can be seen from Figure 5 that when the number of people is less than 100, that is, when the number of people is less than 20% of the capacity, the evacuation time is shorter without jumping over the seat. The main reason is that due to the small number of people, there is no congestion in the corridor and the exit. At this time, jumping over the seat will increase the difficulty of evacuation and reduce the efficiency of evacuation. When the number of people is between 100-300, that is, when the number of people reaches 20%-60% of the capacity, evacuation by jumping over the seats can significantly increase the evacuation efficiency and shorten the evacuation time. The main reason is that there is no serious congestion at the exit at this time. Escape by jumping over the seat can shorten the waiting time of personnel in the corridor. When the number of people exceeds 300, that is, the number of people is greater than 60% of the capacity, whether or not to jump over the seat has almost no effect on the evacuation time. The main reason is that the exit has become the most important evacuation bottleneck. Jumping over the seat can only change the time for individual personnel to arrive at the evacuation exit, and cannot alleviate the congestion at the exit, but may cause the congestion at the exit to appear early. The fitting functions of the evacuation time and the number of people when jumping seats and not jumping seats are $y = 0.5197x^2 - 0.7634x + 52.907$ ($R^2 = 0.9844$), $y = 0.4197x^2 + 0.2266x + 51.347$ ($R^2 = 0.9948$).

4.2 The influence of corridor width on evacuation

Through the evacuation of actual observers after the movie, it is found that although corridors 1 and 4 are unobstructed, most people are still used to evacuate corridors 2 and 3. When corridors 2 and 3 are in a congested state, people prefer to choose Continue to wait on the seat instead of choosing channel 1 and 4 to evacuate. Through the simulation in Section 4.1, it is found that the first and fourth channels are always preferred for evacuation. As shown in Figure 7, the footprint distribution value in the middle/ of the seat areas on the 1st and 4th sides of the seat area is large in blue. According to the simulation animation, it can be found that the people in the middle seat area are often

evacuated to the side seat areas first. Then evacuate to the exit. Among them, the footprint distribution value calculation formula is as follows, and the color display is shown in Table 1.

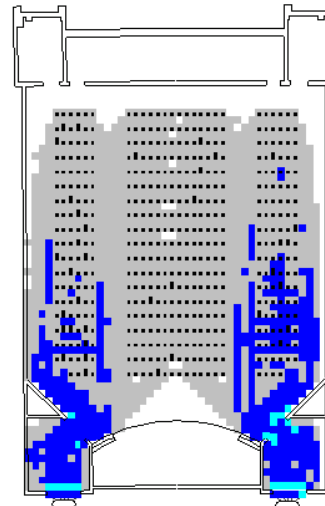


Fig.6 Footprint distribution

Table 1. Footprint color distribution corresponding table

Footprint distribution value	color
<0.0001	white
<0.11	gray
<0.22	blue
<0.33	Light blue
<0.55	green
<0.66	yellow
<0.88	magenta
other	red

4.2.1 Increase the width of 2, 3 channels

According to actual observations, people prefer to use channel 2 and channel 3 for evacuation. Therefore, in this simulation, with the total channel width unchanged, the channel widths 2 and 3 are expanded while the channel widths 1 and 4 are reduced. After the change 1, The widths of 2, 3, and 4 are 0m, 3.5m, 3.5m, and 0m respectively. Under the condition that the escape by jumping over the seat is considered, and other conditions are the same as the simulation in Section 4.1, the influence of the change of the corridor width on the evacuation is studied.

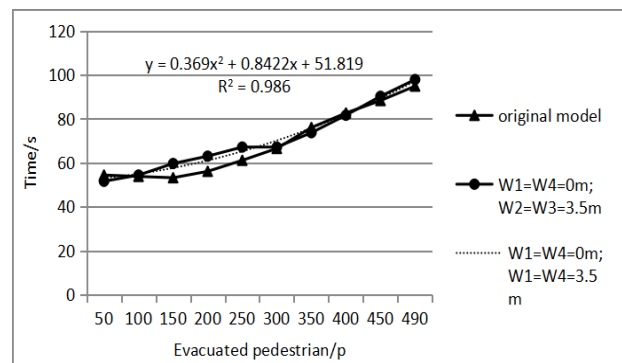


Fig.7 Average evacuation time

Figure 8 shows the average evacuation time after changing the width of the aisle in the case of evacuation over the seat. The fitting function of the evacuation time and the number of people is $y = 0.369x^2 + 0.8422x + 51.819$ ($R^2 = 0.986$). It can be seen from Figure 8 that when the number of people is less than 20% of the capacity, narrowing the channels on both sides and widening the middle channel can improve the evacuation efficiency; when the number of people reaches 20%-60% of the capacity, the evacuation efficiency of the original model is significantly higher than that of the changed channel. The width of the situation: When the number of people is greater than 60% of the capacity, whether to change the width of the corridor has no significant change in the evacuation efficiency. The main reason for this is that although the usual evacuation corridors for people are widened, when corridors 1 and 4 are narrowed, the shortest evacuation route is forced to abandon when evacuation, which increases the evacuation route and evacuation time.

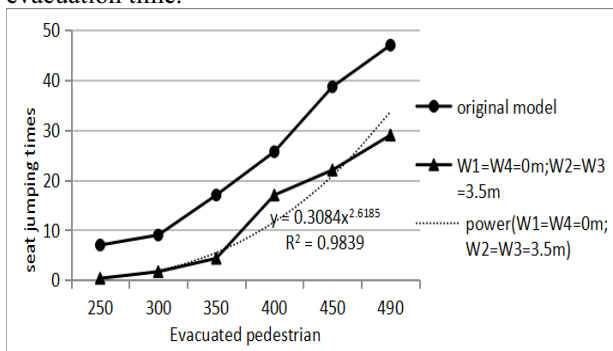


Fig. 8 Average seats overturned

According to Figure 9, the number of overturned seats is significantly less than that of the original model. The main reason is that when the people in the middle seat area of the original model take the shortest route to evacuate, they will evacuate to the seat areas on both sides and on both sides. The seat area performs the behavior of overturning the seat. However, when corridors 2 and 3 are widened, people in the middle area will not pass through the seat areas on both sides for evacuation when evacuating, but will move directly to the evacuation exit. After widening the 2nd and 3rd channels, the function of the average number of people crossing the seat and the number of people also presents the form of a power function, $y = 0.3084x^{2.6185}$ ($R^2 = 0.9839$)

4.2.2 Increase the width of 1, 4 channels

Since it is found in the simulation in Section 4.1 that when people are evacuated, most people take the shortest evacuation route principle and escape through corridors 1 and 4, which is contrary to the actual situation. Therefore, the simulation in this section is to expand the width of 1, 4 channels, while reducing the width of 2, 3 channels, and the widths of 1, 2, 3, and 4 are respectively 2.5m, 1m, 1m, 2.5m after the change .

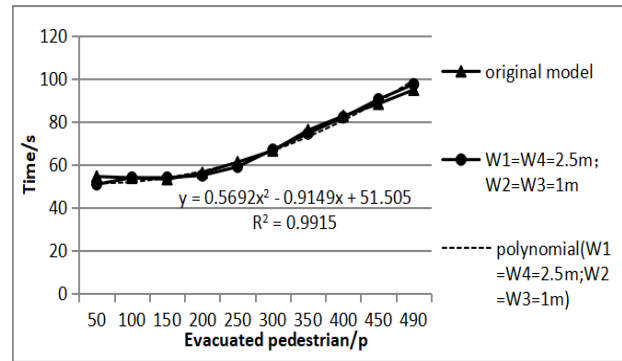
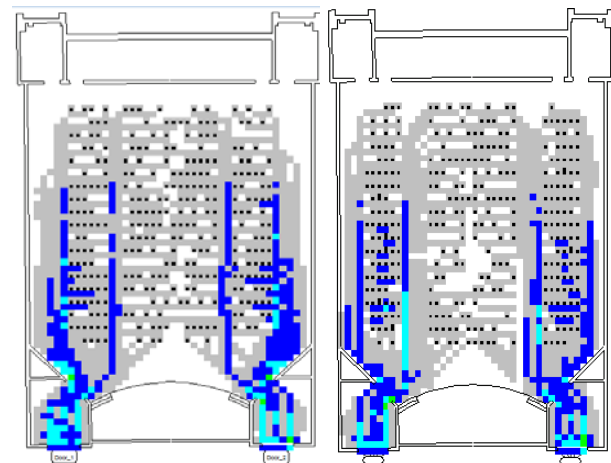


Fig.9 Average evacuation time

As shown in Figure 10, the evacuation time when the width of corridors 1 and 4 is increased is almost the same as the evacuation time of the original size model. The main reason is that the shortest path will be selected when evacuation of people. Increasing the width of corridors 1 and 4 will not affect the personnel. The choice of route will not increase congestion at the channel. The fitting functions of the evacuation time and the number of people are $y = 0.5692x^2 - 0.9149x + 51.505$ ($R^2 = 0.9915$). However, it can be seen from Figure 11 (a) and (b) that although the evacuation time of the two is not very different, when the corridors 1 and 4 are widened, the footprint distribution value at the evacuation exit increases significantly. The main reason is After the widening of corridors 1 and 4, people can reach the evacuation exit more quickly, causing more congestion near the exit.



(a) (b)

- (a) 1, 4 channel width 2.5m; 2, 3 channel width 1m
- (b) Original model

Fig.10 Footprint distribution

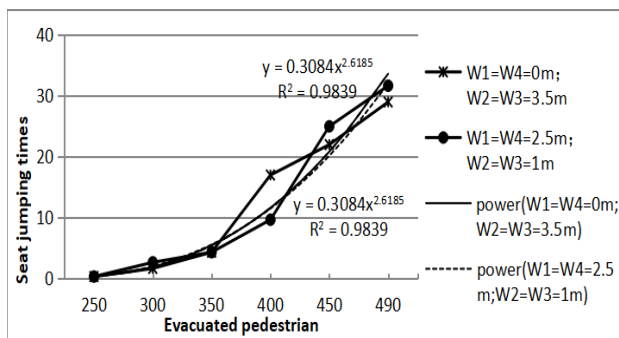


Fig. 11 Average seats overturned

As shown in Figure 12, after widening the 1st and 4th channels, the functional relationship between the average number of people over the seats and the number of people also presents a power function, $y = 0.3524x^{2.5154}$ ($R^2 = 0.9842$). Compared with the widening of the 2nd and 3rd channels, when the number of people is less than 60% of the capacity, the number of times of the two is almost the same; when the number of people reaches 60%-86.7% of the capacity, the number of people who escaped by jumping over the seats is obvious when the 2nd and 3rd channels are widened More; when the number of people is greater than 86.7% of the capacity, more people will escape by jumping over the seats when widening the 1st and 4th channels.

5 Conclusions

(1) Through actual observation of the evacuation situation after the theater's dispersal, it is found that people are often accustomed to returning from the original entrance at the entrance, and hardly try to evacuate from another exit; they are accustomed to evacuation using corridor 2 and 3, and seldom use 1, 4 corridor: When there is a queuing phenomenon at the corridor, people often choose to wait in place.

(2) When the number of people is less than 20% of the capacity, the evacuation efficiency is higher without jumping over the seat; when the number of people reaches 20%-60% of the capacity, the evacuation is faster by jumping over the seat; when the number of people is greater than 60% of the capacity the evacuation efficiency of the two is almost the same.

(3) When the total aisle width remains the same and the number of people reaches 20%-60% of the capacity, the evacuation time is significantly longer than that of the original model when the 2nd and 3rd channels are widened, and the average number of seats overturned is also less than that of the original model.

(4) When the total channel width remains the same, and when channel 1 and 4 are widened, the evacuation time is similar to the original model. But it will cause the exit to enter a congested state in advance, and the congestion will obviously increase.

Acknowledgements

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References

1. Zhang Kai(2017): Study on emergency evacuation path of multi-hall theater based on social force model. Capital University of Economics and Business.
2. Galea E R, Galparsoro J M P.(1994):A computer-based simulation model for the prediction of evacuation from mass-transport vehicles.Fire Safety Journal22(4),pp.341-366.
3. Xie R, Luo X(2013): Building Occupant Evacuation Models Inside Buildings-Approach, Progress and Solutions.2012 International Conference on Information Technology and Management Science Proceedings,pp.255-264.
4. Tian Hao(2015):Fire protection design of theaters in large shopping malls .Fire Science and Technology34(08),pp.1041-1043.
5. Cui LiuYang,Zhang ShuPing(2017):Design of Theater Evacuation Width Based on Cluster Flow Theory.Fire Science and Technology36(05),pp.613-617.
6. Liu Bin, Ma Jian, Mou Ruifang, et al(2015): Passenger evacuation model and analysis for distinguishing obstacle characteristics.Transportation System Engineering and Information15(04),pp.173-180.
7. Liu Bin(2016):Simulation research on the safety evacuation performance of modern tram vehicles .Southwest Jiaotong University.
8. Imanishi M, Sano T(2019):Route Choice and Flow Rate in Theatre Evacuation Drills: Analysis of Walking Trajectory Data-Set . Fire Technology55,pp.569 - 593.
9. Wu Jing(2014). Study on the evacuation problem of a theater in the sub-security zone.Fire Science and Technology33(05),pp.528-530.
10. Jia XiaoLu(2017): Simulation Study of Pedestrian Avoidance and Beyond Behaviors with Obstacles in WalkingFacilities.Beijing Jiaotong University.
11. Helbing D, Farkas I, Vicsek T(2000): Simulating Dynamic Features of Escape Panic.Nature407(6803),pp.487-490.
12. Jiang Chunhua(2015). The development status, marketing strategies and countermeasures of college theaters in the new media era——Taking Bengbu City of Anhui Province as an example.Foreign Trade000(009),pp.62-65.