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Study on evacuation in subway transfer station fire by STEPS

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Abstract
In this paper, the highly effective three dimensional evacuation software STEPS (simulation of Transient Evacuation and Pedestrian movements) is used to calculate the required safe evacuation time (RSET) under different conditions in a subway transfer station. Several scenarios has been designed where fire happen at a certain location and smoke propagation condition has been simulated in advance. Then the processes of evacuation is analyzed and that whether they are safe evacuations or not is determined. It has been found that the stairs toward the lobby floor on both sides of the platform are bottlenecks of evacuation. Some advices about evacuation are given finally for reduce the evacuation period.

1. Introduction
In recent years, the fire situation is fairly severe in our country and a number of serious fires have occurred. It is an important issue to take effective measures to reduce fire loss [1]. Many experts and scholars have done a great deal of researches on occupant evacuation since 1950s. A number of network evacuation models and grid evacuation models have been developed in recent years [2]. Occupant evacuation models could be basically divided into two major categories, namely, models only considering human movement and models considering human movement and behavioral relations comprehensively. Models of the first category only consider the evacuation capacity of various parts of the building, with the escaping direction and speed merely determined by the physical factors of the building, e.g., crowd density and evacuation capacity of the exits, etc. However, these models ignore human interaction or just consider all evacuees as an integer with common characteristics, e.g., EVACNET4 [3], Takahashi’s model [4], among other models. Models of the second category not only consider the physical characteristics of the building, but also treat each individual as an active factor, considering his/her impact on the fire signal as well as individual behavior, such as individuals’ response time, how to choose exit etc.

As for the design of subway personnel evacuation, China mainly adopts Code for design of metro currently [5]. Gong Wei summarized safety situation of Chinese urban subway system and put forward the fire is major emergency incidents on urban subway system [6]. XIE Zhenguang etc analyzed the fire cases of subway system, analyzed the influence factors-vehicles, rail, power supply system, signal system. For these reasons, they put forward several countermeasures to prevent the accident, these measures would reduce the subway accident and its accident casualties and property losses [7-8].

Performance-based fire protection design method is based on the fire engineering. Scientific solution is found to solve the actual problem and the fire protection design program is determined for the engineering practice. Through analysis of...
performance-based design of the actual example of subway transfer station, the method to calculate the evacuation time can be gained.

2. Design method of evacuation simulation model

Occupant evacuation in the subway is often manifested in group behavior [9]. The design idea for the evacuation simulation model is: before the evacuation begins, occupants are distributed in the train compartments, subway platform, lobby floor, stairs, and etc, with some persons standing still and some outbound; evacuation begins at a particular time, evacuees leave their space and transfer to a safe place outside the subway exit through evacuation routes of railway platform, escalators, stairs, lobby floor and subway exit. In order to facilitate the simulation, the simplified condition is as follows:

(1). Occupants in various positions of the subway station are assumed as a whole. Under normal circumstances, every person can evacuate out of the station independently and each type of occupants has the same characteristic parameters.

(2). Before the start of the evacuation, it is assumed that all occupants are scattered around in accordance with the density distribution in each area. The density distributions of occupants in escalators, stairs and subway entrances are very low that can be ignored. At this time no one stops, all persons are kept at the status of leaving station.

According to the above design ideas, the evacuation process in case of fire on the platform can be modeled through the following steps:

(1). Before the start of evacuation, occupants are distributed in the train compartments, subway platforms and the lobby floor with different types and density values.

(2). At certain time, the fire detection system issues a fire signal or an alarm, and then all occupants begin to evacuate at the same time after the staff reaction time.

(3). The walking speed of each occupant through the passage, platform, lobby floor and other horizontal corridors depends on the density of their location.

(4). The evacuees are assumed to evenly distribute according to the width of all stairs and escalators. The distance of the person who is farthest away from the stairs is the straight line between his location and the stairs.

(5). The person who leaves the station first always chooses the shortest way to evacuate to a safe exit. The doors and stairs are not blocked. The time through the doors can be ignored. The time through the stairs is the time that a single person walks up along the stairs.

(6). The time of all persons evacuating to the subway station exit is the time that the last person leaves the subway exit to reach a safe place.

3. Geometry of the transfer station

The model of a transfer station is established by STEPS, in which some accessory structures are ignored, such as the station house, the track zone, the platform screen door and the ticket office on the lobby floor. The impact of the pillars on the platform, the automatic ticket barriers and metal fences on the lobby floor are considered in the model.

The subway station chosen for this study is assumed to represent a typical subway transfer station with three storey below the ground level, 150 m long × 148 m wide × 11.5 m high as shown in Fig 1. There are five exits leading to the open ground in first basement floor, the cross sectional area of which is 5 m wide × 3 m high. Subway turnstiles are installed in the second basement floor, which are mechanical barriers and have metal arms that passengers should push round as passengers go through them to evacuate to safe region.

Fig. 1. The geometry of the transfer station.
4. Initial conditions for simulation

4.1. Occupant features

1. The characteristic parameters and walking speed of occupants

Table 1. The characteristic parameters of occupants set in STEPS

| Occupant Type   | Shoulder Width/m | Body Thickness/m | Height/m |
|-----------------|------------------|------------------|----------|
| Adult males     | 0.5              | 0.26             | 1.75     |
| Adult females   | 0.44             | 0.27             | 1.65     |
| Aged persons    | 0.45             | 0.3              | 1.6      |
| Children        | 0.35             | 0.22             | 1.2      |

The walking characteristics of the crowd have been studied by researchers from both domestic and abroad and some standard population parameters have been formed. The brisk walking speed of the crowd is about 0.80-1.5m/s, and the normal walking speed is 0.72 to 1.35m/s [10]. Specific parameters are shown in Table 2.

Table 2. The walking speed of occupants of different types at different places [11]

| Occupant Type     | Transfer passage/m/s | Stairs up /m/s | Stairs down /m/s | Platform/m/s | Lobby /floor/m/s |
|-------------------|-----------------------|----------------|------------------|--------------|------------------|
| Adult males       | 1.39                  | 0.75           | 0.95             | 1.56         | 1.58             |
| Adult females     | 1.22                  | 0.66           | 0.83             | 1.41         | 1.43             |
| Aged person & Children | 1.06               | 0.52           | 0.4              | 1.15         | 1.17             |

The evacuation capability of the stairs and exits is determined based on the NFPA130. The capacity of the escalator is 2.67p/s/m under normal circumstances and 2.4p/s/m in case of fire according to the Code for Design of Subway. In case of fire, all escalators are out of service and used as a pedestrian staircase in order to be conservative.

2. The occupant load

The passenger flow is calculated in accordance with the morning peak. Depending on the distribution of morning peak passenger flow, the occupant load at each place is set as follows:

1. The number of passengers on the train during the morning peak: 1860/person;
2. The number of waiting passengers and staff on the platform (including passengers boarding the train in the peak hour): 200 (person) on the platform alongside a stopped train, 500 /person on the platform without a train;
3. Passengers and staff on the lobby floor, stairs and passages: 500 /person;
   The total number of occupants in the subway station: 1860+700+500=3060 /person.

4.2. Evacuation scenario

The evacuation route available is different with varied positions where unexpected incidents break out. Some stairs, escalators and evacuation passages would be blocked, which causes congestion at other stairs, escalators, evacuation passages and exits in service. Thus the evacuation route is changed and the evacuation time extended. According to the different fire scenarios, two evacuation scenarios are designed as the following:

1. The fire occurs on the platform of Basement 2: the fire occurs immediately after a train stops besides the platform of Basement 2. Assume that passengers on the train will be evacuated to the platform at 10s. Passengers on the platform will be evacuated to the lobby floor through stairs and escalators at both sides of the platform. Some occupants may be evacuated to the platform of Basement 3 through the cross stairs, then evacuated towards the lobby floor through three stairs and escalators. Finally all occupants will be evacuated to the ground through the exits of the lobby floor.
2. The fire occurs at the transfer platform of the cross stairs: the cross stairs will not be used for evacuation in this case, the occupants on the platforms of Basement 2 and Basement 3 will be evacuated through the stairs and escalators. All occupants will be evacuated to the lobby floor, and then evacuated to the ground through the exits of the lobby floor.
4.3. Requirements on safe occupant evacuation in fire engineering

In fire engineering, requirements on safe occupant evacuation are that all occupants should be evacuated to safe venues (or places) before the fire develops into hazard to human bodies. Its mathematic description is as follows: $\text{ASET} > \text{RSET}$, where ASET is the available safety egress time; RSET the required safety egress time [11].

5. Results and discussions

5.1. Fire occurring on the platform of Basement 2

In this scenario, each stairs or escalator has been fully utilized. Passengers on the train were all evacuated to the platform at 10s. The number of people to be evacuated at this time was 3060, and 2060 passengers gathered on the platform of Basement 2. However, only two stairs and escalators toward the lobby floor were available, then some occupants are evacuated to the Basement 3 through the cross stairs. Although this increased the evacuation distance of some occupants, the passenger flows on the platform of Basement 2 were dispersed effectively, reducing the evacuation time on the whole. All occupants on the platform of Basement 2 were evacuated completely at 240s and evacuated to the lobby floor at 300s. All occupants are evacuated out of the station at 344s.

This model was simulated with FDS when fire occurs. The heat release rate (HRR) for steady simulation is assumed to be 3 MW in this study. For dynamic simulation, HRR is varied with time. The transient HRR from the fire source is modeled by an analytical $t^2$-type curve. FDS simulation shows that fire smoke did not spread into the lobby floor at 360s [12]. Therefore, occupants were able to be evacuated completely in time through this evacuation route under the effective smoke control.

![Image](image_url)

**Fig. 2. The egress process in Evacuation Scenario 1.**

5.2. Fire occurs on the transfer platform of the cross stairs

The egress process would become extremely slow in Scenario 3 due to the location of the fire source, which made the cross stairs not available as part of the evacuation route any more. Thus the evacuation efficiency of occupants on the platform of Basement 2 was affected. There were only two stairs and escalators toward the lobby floor, which caused...
congestion at the stairs and reduced the walking speed of evacuees. Occupants on the platform of Basement 2 would be evacuated to the lobby floor completely at 385s. So when fire breaks out under this condition, evacuation of passengers on the train will become very difficult.

6. Conclusions

Simulation results of evacuation in a subway cross transfer station are analyzed and evacuation strategies are evaluated. The main conclusions are as follows:

(1). Evacuation could be completed within the specified time in general case of emergency; safe evacuation is difficult to achieve in special case of emergency. Occupants could not be evacuated completely in 360s which the specification stipulates. The stairs toward the lobby floor on both sides of the platform are the bottlenecks of evacuation.

(2). Opening or closing of an evacuation route is just depending on where the fire occurs in simulation. But in the actual fire scenario, the choices of occupants for exits are affected greatly by smoke. Though the parameters of occupants are made in some special sets, a simple evacuation simulation is still difficult to represent the evacuation process in a real fire scenario.

Fig. 3. The egress process in Evacuation Scenario 2.

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