Simulation on the Influence of Type-S Current-limiting Railing on the Passenger Flow at the Entrance

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Abstract. The type-S current-limiting railing is usually set in front of the entrance of stations to relieve the backlog of passengers and the congestion at the entrance. The influences of type-S current-limiting railing on the passenger flow at entrance were investigated through numerical simulation. Results showed that the type-S current-limiting railing increased the walking distance of passengers to the entrance. Therefore, it resulted in the decrease of the passenger flow rate and pedestrian density in front of the entrance, as well as the increase of the interval time between passengers went through the entrance. The passenger flow rate at the entrance increased with the total number of passengers. When the number of passengers that queueing up at the entrance was large, the congestion would be formed even the type-S current-limiting railing was set, while the passengers inside the railings were well-organized under the effects of current-limiting railing. The influence of railing number on the passenger flow rate at entrance was not significant, while the pedestrian density in the railings decreased with the railing number. When the railing width was large, the pedestrians might walk abreast and speed up to surpass the passengers ahead of them in the railings. The passenger flow rate at the entrance increased linearly, and the interval time between passengers decreased linearly with the railing width. Therefore, limiting the railing width could decrease the passenger flow rate at the entrance and relief the operation pressure of stations.

1. Introduction
The safety evacuation of passengers at stations is always the hotspot in the research on public security [1-3]. The operation pressure and the safe evacuation capability in the station are related to the passenger flow conditions at the entrances and exits. Therefore, the influences of entrance or exit conditions on the walking behavior and evacuation process of the passengers have received attentions [4-5]. If the passenger flow rate is too large, the passengers would stagnate in the station. So, the current-limiting railing is usually arranged in front of the entrance in the station with massive passenger flow.

There are some studies focused on the influence of current-limiting railing on the passenger flow in stations. Zhang et al. [6] explored the influence of current-limiting railing on the pedestrian flow in the railway station. The results showed that current-limiting railing would weaken the opposing and side pedestrian flow collisions. Mu et al. [7] investigated the influence of current-limiting railing that arranged at the floor escalator in platform on the personnel evacuation. They indicated that the fixed current-limiting railing went against the evacuation of passengers, and the mobile current-limiting
railing was conducive to the evacuation of passengers. Li [8] explored the influence of current-limiting railing that arranged at the platform, the station hall and the entrance and exit on the passenger movement in the station. The results showed that the type-S current-limiting railing showed the best effects on reduce the local pedestrian density among all kinds of the current-limiting railings. However, the type-S current-limiting railing also led to the increase of the passing time of passengers in the station.

The type-S current-limiting railing is a typical type of current-limiting railing, and the influences of type-S current-limiting railing on the passenger flow in station deserve further study. The influence of type-S current-limiting railing on the passenger flow at entrance was conducted in the present study through numerical simulation. The appropriate arrangement parameters of the type-S current-limiting railing was discussed.

2. Numerical Method and Simulation Scenarios

Simulations on the influence of type-S current-limiting railing on the passenger flow at the entrance were conducted by using the FDS+evac, which has been widely used in the studies on walking and evacuation process of pedestrians [9-11]. In the simulations, the pedestrians are arranged in a specific area randomly. The walking speed of the pedestrian is related to their inhere walking speed, as well as the forces exerted on them. The motion equation of the pedestrian is [12],

\[ m_i \frac{d^2 x_i(t)}{dt^2} = f_i(t) + \xi_i(t) \]  

where the walking speed of pedestrian is represented by \( \frac{dx_i}{dt} \), \( m_i \) is the mass of pedestrian, \( x_i(t) \) is the location of pedestrian, and \( \xi_i(t) \) represents the random fluctuation, \( f_i(t) \) is the forces exerted on the pedestrian, which comprises four items,

\[ f_i = \frac{m_i}{\tau_i} (v_i^0 - v_i) + \sum_{j \neq i} (f_{ij}^{soc} + f_{ij}^{w} + f_{ij}^{\tau}) + \sum_w (f_{iw}^{soc} + f_w) + \sum_k f_{ik}^{w} \]  

On the right side of Equation (2), the first item represents the motive force of the pedestrian in evacuation, the second item describes the interactions among pedestrians, the second item describes the interactions between pedestrians and walls, and the last item is used for describing other environment influences on pedestrian, like the fires.

The dimensions of simulation area were 10 m × 20 m, and the initial location of the pedestrians was set in the right side of the simulation area with the dimensions of 10 m × 10 m, as shown in Figure 1. In the simulations, the pedestrians walking towards the entrance through the type-S current limiting railing. The movement parameters of pedestrian at the entrance with different structure of the type-S current limiting railing were investigated, and the simulation scenario without current limiting railing was also conducted for contrast. The passenger flow rate and the interval time between passengers that went through the entrance were mainly discussed. There were 56 simulations conducted, and the influences of the total number of passengers, the railing number, the railing width and the entrance width on the passenger flow at the entrance were discussed. The parameters in simulations were listed in Table 1. The passengers consisted of 60% adult, 20 % elderly and 20% child in the simulations.

![Figure 1. Example of the simulation model (five railings; railing width: 1 m; entrance width: 1 m).](image-url)
Table 1. Parameters in the simulations

| Parameters                  | Values                  |
|-----------------------------|-------------------------|
| Total of the passengers /p  | 25; 50; 75; 100; 125; 150; 175; 200; 225 |
| Number of the railing       | 2; 3; 4; 5; 6; 7; 8; 9  |
| Width of the railing /m     | 0.8; 1.0; 1.2; 1.4; 1.6; 1.8; 2.0 |
| Width of the entrance /m    | 1.0; 2.0                |
| Dimensions of the simulation area | 20 m × 10 m            |

3. Simulation Results and Discussion

3.1. Function of type-S current-limiting railing

The influence of type-S current-limiting railing on the passenger flow at the entrance were firstly analyzed, and the scenarios with no current-limiting railing were also exhibited for contrast. The movement process of the passengers in front of the entrance in the scenarios with and without type-S current-limiting railing are compared in Figure 2. When the total number of passengers was 200, and the width of the entrance was 1 m, the required times for all of the passengers getting through the entrance were 408 s and 176 s for the scenarios with and without the type-S current-limiting railing (railing number: 9; railing width: 1 m), respectively. It means that the type-S current-limiting railing is able to reduce the passenger flow rate at the entrance, and relief the operating pressure of station. Compared Figure 2 (a) with (b), there was a fan-shaped congestion area of passengers in the scenario with no current-limiting railing. In the scenario with type-S current-limiting railing, the walking speed of pedestrians at the turning section was obvious lower than straight section in the type-S current-limiting railing. Therefore, there was a space between the passengers that went into the type-S current-limiting railing successively at the straight section. Moreover, most of the passengers apt to walked in the middle of two railings. Therefore, the distribution of passengers in the type-S current-limiting railing was even. Although the congestion of passengers was also existed in the condition with type-S current-limiting railing when there was larger amount of passenger in front of the entrance, while the movement of passenger became well-organized obviously. Compared with the scenario with no current-limiting railing, the passenger density as well as the risk of crowd-related accident in front of the entrance was lower when the type-S current-limiting railing was set.

![Figure 2](image1.png)  
(a) without type-S current-limiting railing  
(b) 9 railings, width of railing: 1 m

**Figure 2.** Effects of the type-S current-limiting railing on the movement process of passengers.

The passenger flow rates at the entrance with different total number of passengers in the scenario with and without type-S current-limiting railing are shown in Figure 3. According to the simulation results, the passenger flow rate at the entrance firstly increased with the total number of passengers and then became stable. In the conditions with and without type-S current-limiting railing, the stable stage appeared when the total number of passengers was larger than 175 and 125, respectively. The passenger movement processes in front of the entrance at these critical conditions were also illustrated in Figure 3. It can be found that there was a congestion of passengers in front of the entrance in these two scenarios, which might be the reason that the passenger flow rate was no longer increase with the total number of passengers. In this condition, the entrance width might be the key factor that affected the passenger flow.
rate at the entrance instead of the total number of passengers. Taking the congestion in front of the entrance as the critical condition to control the total number of passengers, the critical value of total number of passengers in the condition with type-S current-limiting railing was higher than the no current-limiting railing condition.

![Figure 3. Average passenger flow rates under different overall number of passengers.](image)

The interval time between passengers that went through the entrance in the scenarios with different total number of passengers is listed in Table 1. It was obvious that the interval time between passengers in the condition with type-S current-limiting railing was much longer compared with the no current-limiting railing condition, especially in the scenarios with less passengers. It means that the effect of type-S current-limiting railing on reducing the passengers through the entrance per unit time is significant. Overall, the interval time between passengers decreased with the total number of passengers, and the decrease effect was more obvious in the condition with type-S current-limiting railing.

| Total number of passengers | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 |
|---------------------------|----|----|----|-----|-----|-----|-----|-----|-----|
| Interval time between passengers (with no current-limiting railing) /s | 1.00 | 0.98 | 0.86 | 0.88 | 0.85 | 0.84 | 0.82 | 0.81 | 0.80 |
| Interval time between passengers (with type-S current-limiting railing) /s | 4.29 | 2.85 | 2.03 | 1.84 | 1.72 | 1.66 | 1.55 | 1.62 | 1.54 |

3.2. Study on the arrangement parameters of type-S current-limiting railing
(a) Railing number of type-S current-limiting railing
In the condition with type-S current-limiting railing, the passenger flow at the entrance would be affected by the arrangement parameters of the type-S current-limiting railing. The arrangement parameters included the current-limiting railing number and current-limiting railing width in this study.

In the studies on current-limiting railing number, 24 simulation scenarios were conducted. The average passenger flow rate of the entrance in the conditions with different railing numbers is illustrated in Figure 4. It shows that the increase of both the total number of passengers and the width of entrance would result in the increase of passenger flow rate of the entrance. According to the simulation results, the average passenger flow rate decreased with the railing number basically when the railing number
was smaller than five. When the railing number was larger than five, the decrease of average passenger flow rate was no longer continued, but showed a fluctuation. At the condition with less railing number, the space between passenger in the current-limiting railing was small, as shown in Figure 5(a). Therefore, the passenger flow rate at the entrance was relatively high. With the increase of the railing number, the space between passenger in the current-limiting railing became larger, and the passenger flow rate at the entrance decrease gradually. The passenger movement in the type-S current-limiting railing of the simulation scenario with five railings is shown in Figure 5(b). When the railing number increased to nine, the space between passenger in the current-limiting railing was almost the same with the condition of five railings, as shown in Figure 5(c). Therefore, the decrease of average passenger flow rate was no longer continued when the railing number was larger than five. There were many turnings in the railings when large railing number conditions, which has significant influence on the walking speed of passengers. So, the average passenger flow rate showed a fluctuation in these scenarios. Compared with the influence of railing width on the flow rate at the entrance, which would be discussed below, the influence of railing number on the flow rate at the entrance was not significant.

![Passenger flow rate in conditions with different railing numbers](image)

**Figure 4.** Passenger flow rate in conditions with different railing numbers.

![Movement process of passengers in the conditions with different railing numbers](image)

**Figure 5.** Movement process of passengers in the conditions with different railing numbers (100 passengers, width of the entrance: 1 m, remained passengers: 70p).

The interval time between passengers that went through the entrance in the scenarios with different railing numbers are listed in Table 2. According to the simulation results, the interval time between passengers firstly increased with the railing numbers. When the railing number was larger than five, the increase of interval time between passengers was no longer continued, and a fluctuation of the interval time between passengers was found. The influence of railing number on the interval time between passengers was coincident with that on the passenger flow rate.
### Table 3. Average interval time between passengers in conditions with different railing numbers.

| Average interval time/s | Two railings | Three railings | Four railings | Five railings | Six railings | Seven railings | Eight railings | Nine railings |
|-------------------------|-------------|----------------|--------------|--------------|-------------|---------------|---------------|--------------|
| 100p, entrance width: 1m | 1.58        | 1.60           | 1.69         | 1.69         | 1.75        | 1.77          | 1.88          | 1.80         |
| 200p, entrance width: 1m | 1.58        | 1.46           | 1.48         | 1.51         | 1.59        | 1.51          | 1.47          | 1.62         |
| 200p, entrance width: 2m | 1.16        | 1.25           | 1.42         | 1.46         | 1.37        | 1.65          | 1.53          | 1.49         |

(b) Railing Width of type-S current-limiting railing

In the studies on current-limiting railing width, 14 simulation scenarios were conducted. The railing width ranged from 0.8 m to 2.0 m. The railing number was five and the entrance width was 1.0 m or 2.0 m. The curves of passenger flow rate at the entrance with different railing widths and the data fitting results are shown in Figure 6. It is found that the passenger flow rate at the entrance increased linearly with the railing width approximately. The curves of interval time between passengers that go through the entrance with different railing widths and the data fitting results are shown in Figure 7. From Figure 7, the interval time between passengers that went through the entrance decreased linearly with the railing width approximately. The above analysis proves that the influence of railing width on the passenger flow at the entrance was significant. If the passenger flow rate at the entrance required decrease and the interval time between passengers that went through the entrance required increase, the railing width could reduce appropriately in the arrangement of the type-S current-limiting railing.

![Graph showing passenger flow rate and interval time](image)

Figure 6. Curves of passenger flow rate at the entrance with different railing widths and the results of data fitting.
For further analysing and explaining the influences of the railing width on passenger flow at the entrance, the passenger movement process in the type-S current-limiting railing in the conditions with the railing width of 0.8 m, 1.2 m, 1.6 m and 2.0 m are shown in Figure 8. When the railing width was 0.8 m, all of the passengers in the current-limiting railing walked in a single row due to the restriction of railings. In the condition with the railing width of 1.2 m, some of the passengers walked parallelly, and speeded up to surpass the passengers in front of them in the area that the passenger just entered the current-limiting railing. When the railing width was 1.6 m, there were more passengers walked parallelly and the detour phenomenon was more common in the current-limiting railing. When the railing width increased to 2.0 m, the passengers’ movement in the current-limiting railing were more freedom, and even the phenomenon of three passengers walked parallelly was found in this condition.
In the arrangement of the type-S current-limiting railing, the railing width should be determined according to the number of passengers queueing up outside the entrance and the operation condition inside the station. The passengers might walk parallely in the current-limiting railing and speeded up to surpass the passengers in front of them when the railings width was wide enough. These walking behavior against the uniform distribution of the passengers, and might lead to the crowd accidents in the current-limiting railing. According to the simulation results in the present study, the above undesirable walking behavior of passengers was relatively obvious in the conditions with the railing width that larger than 1.2 m.

4. Conclusion

The influences of type-S current-limiting railing on the movement of pedestrian at the entrance were investigated in the present study by using the FDS+evac. The main conclusions are as follows.

1. The type-S current-limiting railing was able to reduce the passenger flow rate at the entrance, decentralize the passenger queuing up and reduce the local personnel density in front of the entrance.

2. With the increase of total number of passengers, the passenger flow rate at the entrance firstly increased, and then became stable when the congestion was formed at the entrance.

3. The average passenger flow rate firstly decreased with the railing number. When the railing number was larger than five, the decrease of average passenger flow rate was no longer continued, but showed a fluctuation.

4. Compared with the railing number, the influence of railing width on the passenger flow of the entrance was more obvious. The passenger flow rate of the entrance increased linearly and the interval time between passengers that went through the entrance decreased linearly with the railing width approximately. The passengers might walk parallely in the current-limiting railing and speed up to surpass the passengers in front of them when the railing width was wide enough.

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