Specific flow rate at openings for pedestrians including slow walkers

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Using laboratory walking experiments, this paper investigates the effect of the ratio of slow walkers, such as elderly people, on pedestrian flow behavior. Specifically, we quantify the specific flow rates at a bottleneck opening by parametrically varying both the ratio of slow walkers to normal walkers and the width of the opening. The results show that the measured specific flow rates at the opening exceeded the rate of 1.5 persons/m/s, which is commonly used in building fire safety design in Japan, even with high percentages of slow walkers. This finding, given the opening width and the ratio of slow walkers, enables more accurate assessments of the fire evacuation time.

Keywords Elderly person, Evacuation experiment, Specific flow rate

1. Introduction

Currently, the global aging population is approximately 10%; this percentage is expected to exceed 16% by 2050. In particular, Japan exhibits the highest aging rate in the world, with elderly individuals comprising approximately 29% of its total population. This increasing aging population presents new challenges for building fire safety design. Evacuation time assessments typically assume uniform walking capabilities and neglect mobility-impaired evacuees. To deal with the demographic shifts in aging societies, improving evacuation time assessments is essential. A critical parameter in evacuation time assessments is the specific flow rate through bottlenecks, which is defined as the number of people passing through an opening with a unit width per unit time. In Japan, a value of 1.5 persons/m/s, derived from station platform observations by Togawa [1], is commonly used; however, experimental studies [e.g., 2, 3, 4] have demonstrated specific flow rates higher than 1.5 persons/m/s [1].

Kretz et al. [2] conducted full-scale experiments to investigate the flow capacity through a 40-cm-thick wall opening under normal conditions, with opening widths ranging from 40 cm to 160 cm. The flow capacity showed a linear decrease from 2.2 persons/m/s to 1.8 persons/m/s as the bottleneck width increased from 40 cm to 70 cm, while maintaining a constant capacity of approximately 1.8 persons/m/s for wider openings between 70 cm and 120 cm. In large-scale evacuation experiments, Daamen and Hoogendoorn [3] studied emergency door capacity while examining diverse population compositions and various opening widths. Their results demonstrated specific flow rates greater than 2.25 persons/m/s in most cases. Jo et al. [4] examined the relationship between the spatial conditions and the pedestrian flow behavior via walking experiments and demonstrated that both the pedestrian trajectories and the specific flow rates were significantly influenced by the spatial configuration of the passageways and openings. However, the influence of higher proportions of slow walkers on pedestrian flow characteristics has not been sufficiently investigated in the context of aging populations. Accordingly, this study investigates the flow behavior at openings with a special focus on pedestrians including unassisted slow walkers as a preliminary investigation into aging population effects. Experiments with participants were performed to quantify the specific flow rates under controlled laboratory conditions.

2. Experimental setup

The experiments were conducted on December 15, 2019, using an opening with a variable width installed in a room with a size of 14 m × 7 m, where 24 participants started walking simultaneously from designated starting positions through the opening to a specified destination area (Figs. 1 and 2). The flow behavior of the participants was recorded using three video cameras to count the number of participants passing through the opening as a function of time and to evaluate the specific flow rates.

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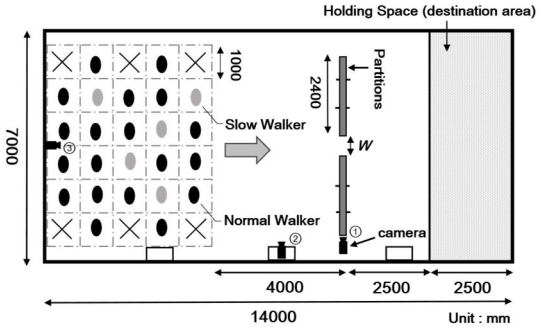

Figure 1. Plan of the experimental setup.

Figure 2. Images taken during the experiment (blue caps for typical walkers and red for slow walkers).

The 24 able-bodied participants comprised 21 males and 3 females (22 in their 20s, 1 in their 30s, and 1 in their 40s) initially positioned at 1-m intervals as shown in Fig. 1. The participants were assigned two types of roles: typical walkers and slow walkers. The walking speed of each role was controlled using metronomes with different beats per min (BPM); participants were instructed to synchronize their steps with the metronome beats via portable audio players. The metronomes were set at 102 BPM for typical walkers and 63 BPM for slow walkers. These BPMs were calibrated via preliminary trials such that the free walking speeds of each role were on average close to 1.0 m/s (standard deviation = 0.09 m/s) and 0.6 m/s (standard deviation = 0.06 m/s), respectively. That is, possible variabilities in walking capability were simplified into two categories focusing on the free walking speed from a practical viewpoint. The participants were visually distinguished by colored caps corresponding to their assigned roles (blue for normal walkers and red for slow walkers).

The experimental conditions comprised 18 cases with two varying parameters: the opening width W (0.9 m, 1.2 m, and 1.5 m) and the slow walker percentage Φ (0%, 10%, 20%, 30%, 40%, and 100%), with slow walkers distributed uniformly except in the last row in the direction of movement. Each trial was initiated by a simulated fire evacuation announcement and ended when all participants reached the designated destination area, with participants instructed to keep walking to the destination area without stopping even after passing through the opening.

3. Results and discussion

Figure 3 shows the relationships between the specific flow rate at the opening, calculated by dividing the total participant count by the product of the opening width and total passage duration, and the slow walker percentage. The results show that the specific flow rate at the opening decreases with increasing slow walker percentage. Approximately all of the measured specific flow rates exceeded Togawa's value of 1.5 persons/m/s [1], while those for $\Phi = 0\%$ were consistent with previous experimental observations [2, 3, 4]. For $W = 0.9$ m, an increase in the slow walker percentage had a relatively small effect on the specific flow rate at the opening compared with the other opening-width conditions. An opening width of 0.9 m is not sufficient for persons to pass through in two rows; therefore, many participants leaned their bodies when passing through the opening; this efficient behavior resulted in higher specific flow rates relative to the other opening-width conditions.

4. Conclusions

The specific flow rates through openings were quantified depending on two parameters: the slow walker ratio and the opening width. Although further investigation is necessary, the results enable more accurate assessments of the fire evacuation time, given the opening width and the slow walker ratio.

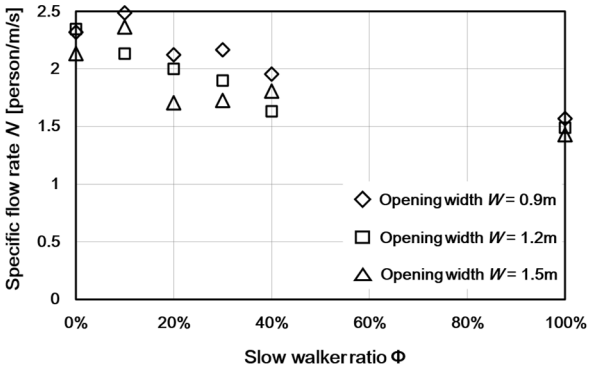

Figure 3. Relationships between the specific flow rate N and the slow walker ratio Φ.

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