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研究課題名（和文）Study on the influencing mechanism of the obstacle layout to improve the pedestrian egress

研究課題名（英文）Study on the influencing mechanism of the obstacle layout to improve the pedestrian egress

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研究成果の概要（和文）：歩行施設の設計において障害物を配置することは避けられず、歩行者の退室効率に与える影響を理解することが重要である。しかし、障害物が歩行者の退室に与える影響のメカニズムは不明確であり、その設計に関する科学的根拠や基準も不十分である。本研究では、この問題を解明するために現地実験とシミュレーションを併用した。一方、現地実験の結果、障害物が退室効率に与える影響は歩行者の自己組織化行動に依存することが明らかになった。さらに、数値シミュレーションにより、障害物が退室効率に及ぼす影響について、向上、均衡、低下の三つの相転移が一般化された結果が示された。

研究成果の学術的意義や社会的意義
This research shifts the research trend from the prioritized positive to a thorough analysis of the obstacle’s influencing mechanism. It also contributes to actual pedestrian management by providing scientific evidence for obstacle layout design and pedestrian guidance to eliminate congestion.

研究成果の概要（英文）：Due to the inevitability of placing obstacles when designing walking facilities, it is important to understand the influence of the obstacle on pedestrian egress, i.e. the process for the pedestrians to leave from a certain area. However, the influencing mechanism of the obstacle on the pedestrian egress was unclear, making the scientific evidence and standards for the design of the obstacle insufficient. In this proposal, I elucidate this problem by both field experiments and simulation. On one hand, field experiments showed the influence of the obstacle on egress efficiency relies on the self-organization behavior of pedestrians. On the other hand, numerical simulation results gave a generalized result on the phase transition of the three possible influences, i.e., improved, balanced, decreased, of the obstacle on the egress efficiency.

研究分野：安全工学

キーワード：pedestrian management　crowd dynamics　pedestrian flow

１．研究開始当初の背景

Along with the surging population in the metropolis, management of the crowd for more efficient and safer public areas has been a significant research topic. As a solution, the placement of obstacles was reported to improve egress efficiency (D. Helbing et al., *Nature*, 2000; A. Kirchner et al., *Phys. Rev. E*, 2003), which is counterintuitive because obstacles are usually believed to obstruct pedestrian movement rather than improve it. However, these positive results were derived from agent-based simulation, where pedestrians have been typically regarded as physical particles (electric charge or grains) interacting with others, while are a lack of cognition that identifies pedestrians from physical particles. Therefore, to provide evidence to improve the simulation models, it is indispensable to conduct experimental research with pedestrians as subjects to explore the essence of pedestrian behavior.

As a reference, in previous animal experiments on ants, mice, and sheep (N. Shiwakoti et al., *Safety Science*, 2018), the efficiency-improvement effect has been widely observed. In contrast, in previous experiments on pedestrians, I have found controversy about the effect of the obstacle on pedestrian evacuation efficiency. To be specific, the obstacle has been reported to improve (D. Yanagisawa et al., *Physical Review E*, 2009), have no influence (A. Garcimartín et al. *New Journal of Physics*, 2018) and decrease (X. Shi et al., *Physica A*, 2019) the evacuation efficiency in different scenarios. Furthermore, the reason for this controversy is still dubious. Therefore, to apply obstacles to actual usage for efficiency improvement, it is essential to explore a generalized conclusion on the influencing mechanism of the obstacle to evacuation efficiency.

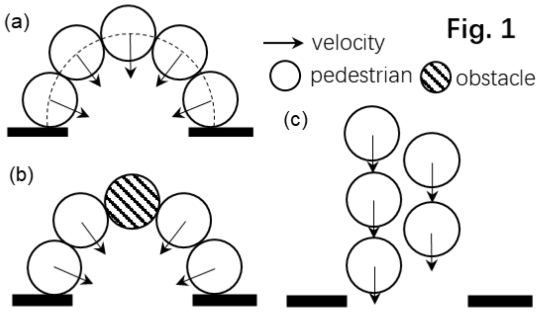

Fig. 1

Previous studies tend to attribute the improvement of egress efficiency to the function of the obstacle in absorbing physical pressure, which I found is not generalized enough. To explain the proposed mechanism, it was presumed that actual pedestrians can be compressed to some extent, after which the physical force will emerge. Under the situation in Fig. 1(a) where pedestrians are rushing to the exit, the mutual physical forces among pedestrians are large, making pedestrians stuck before the exit in an arching shape (D. Helbing et al., *Nature*, 2000). By placing a static obstacle shown in Fig. 1(b), the arching can be eliminated because the pushing force among the rushing pedestrians can be absorbed.

However, I believe that arching is easier to happen among physical particles or animals without or with limited cognition, while scarce to happen among rational pedestrians. As particles with cognition, pedestrians can avoid conflicts in advance by nature through the self-organization phenomena (D. Helbing et al., *Transportation Science*, 2005). As shown in Fig. 1(c), other than forming an arch, pedestrians tend to form lanes in a zigzag way before the exit, thus minimizing the conflicts and maintaining a high egress efficiency. As a result, a more thorough and generalized mechanism suitable to actual pedestrians should be developed.

Furthermore, previous studies have focused too much on egress efficiency, while neglecting the influence of the obstacle on the congestion level. Particularly, despite previous studies that have proposed that the congestion level reflects the crowdedness that pedestrians actually experience (D. C. Duives et al. *Physica A*, 2015), none of them have quantitatively proved the consistency between the measured congestion level and the perceptive congestion level. Therefore, to improve pedestrian egress environments, it is essential to explore the influencing mechanism of obstacles on both egress efficiency and perceived congestion.

２．研究の目的

The purpose of this research is to figure out the influencing mechanism of the obstacle on pedestrian egress by conducting experiments on egress efficiency and congestion level Accordingly, the obtained mechanism will be introduced into the simulation model to help with the actual obstacle design under what-if situations.

３．研究の方法

The influence of the obstacle under various situations is supposed to be explored by both experiments and simulation. Fig. 2 shows the experimental scenarios and the corresponding pedestrian trajectories. The experiments were conducted under a room egress scenario with an obstacle placed in the middle. A camera was installed above the horizontal axis of the corridor and fixed about 20 m above the ground, thus enabling extracting pedestrian trajectories from recognizing the colors of pedestrians. Based on the experimental results, numerical simulation was also performed, with the details introduced in Section 4-(3).

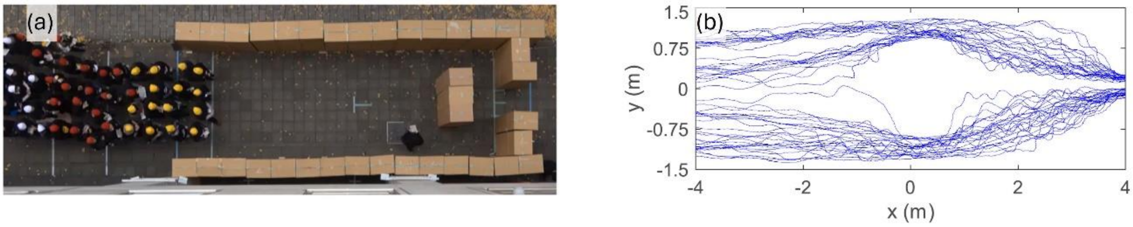

Fig. 2 Example of crowd experiments and the corresponding pedestrian trajectories.

４．研究成果

Based on the controversy in previous research, there are three phases of the obstacle influence: obstructing, balancing, and guiding phase which correspond to the decrease, constant, and increased egress efficiency, respectively. This research reproduced the obstructing and balancing phase in field experiments and further reproduced the guiding phase in numerical simulation. Besides, the gap between physical and perceived congestion was also found.

(1) Correlation between pedestrian self-organization and obstacle influence

Through experiments on pedestrian flow under the influence of obstacles, the obstructing phase and balanced phase within the three phases have been identified. Analysis of experimental data, including clustering techniques, confirms that the existence of these phases depends on the pedestrian self-organization behavior. The experimental setup involved placing the obstacles in front of exit bottlenecks, with variables including obstacle width and distance from the bottleneck. Results indicate that when the obstacle is close to the exit (as shown in Fig 3(a)), pedestrian flow trajectories exhibit linear shapes resembling lanes like vehicle lanes, which indicates pedestrian self-organization behavior. However, when obstacles are farther from the exit (as shown in Fig 3(b)), pedestrian flow trajectories become more chaotic, indicating disruption of self-organization behavior by the obstacles.

To quantify pedestrian self-organization behavior, the applicant proposes an enhanced k-means clustering algorithm (as shown in Fig 3(c)) to identify pedestrian flow "lanes" and local "lane-changing" behaviors. Subsequently, using the distance between individual pedestrian trajectories and corresponding "lanes" as a parameter for self-organization behavior, it is found that this parameter strongly correlates with pedestrian flow evacuation efficiency. As depicted in Fig 4(a), evacuation efficiency exhibits two distinct trends with changes in obstacle size depending on the distance between the obstacles and the exit: when obstacles are close to the exit, obstacle size is unrelated to evacuation time; when obstacles are far from the exit, evacuation time increases with increasing obstacle size, leading to a gradual decrease in evacuation efficiency. Further analysis reveals that despite varying trends in evacuation efficiency, self-organization parameters consistently exhibit a strong correlation with evacuation efficiency. This further elucidates that pedestrian flow evacuation efficiency is contingent upon the strength of pedestrian self-organization ability.

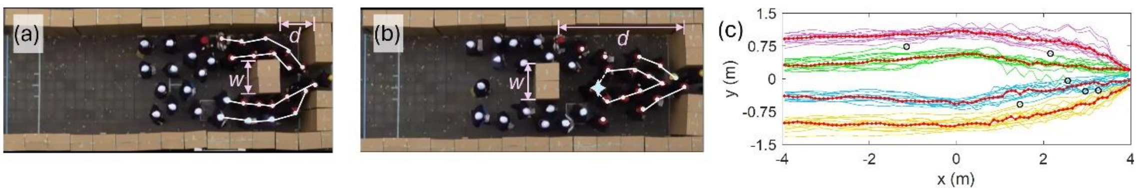

Fig. 3 Pedestrian lane formation during pedestrian egress with obstacle.

(2) Difference between physical and perceived congestion

Along with the physical congestion that can be measured from trajectories, the perceived congestion was also collected through a questionnaire survey during the experiments in Fig. 3. Surprisingly, there was a clear difference between the physical and perceived congestion. Comparing Fig 4(b) with Fig 4(c), it can be observed that the trends in physical congestion and perceived congestion differ.

To dissect the mechanisms leading to these differences, the applicant proposed a congestion analysis focusing on individual pedestrians. Indicators of individual congestion include personal density and personal velocity, with personal density commonly calculated as the reciprocal of the Voronoi space area of individuals and personal velocity calculated as the positional difference over unit time. Results indicate that while density serves as an objective indicator of physical congestion, it is not the optimal indicator of perceived congestion. Compared to density, velocity exhibits higher consistency with questionnaire survey results and better represents pedestrians' perceived congestion.

Analysis reveals that the difference between velocity and density stems from pedestrians' varied congestion avoidance strategies. As shown in Fig 4(c), besides the negative linear correlation between velocity and density, indicating a decrease in velocity with increasing density, there is also a horizontal trend where velocity remains unchanged with varying density for some pedestrians. Consequently, some pedestrians, despite encountering low physical congestion, experience high perceived congestion because they are mostly situated behind the crowd and, although adopting a slow walking strategy to avoid physical congestion ahead, they still perceive congestion.

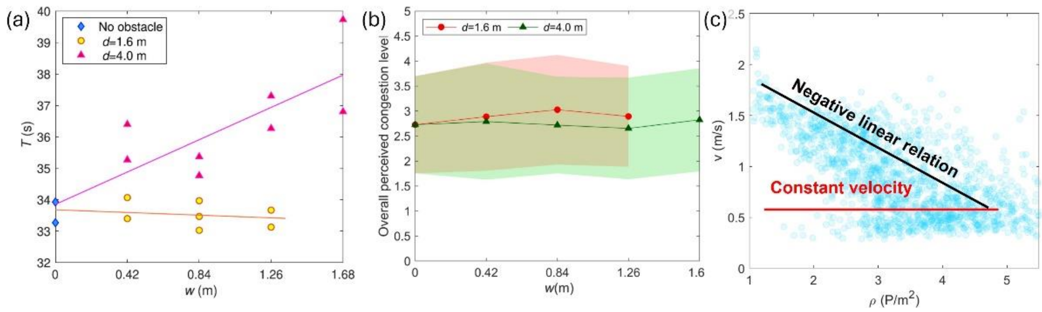

Fig. 4 Difference between physical and perceived congestion.

(3) Numerical simulation on the influence of the obstacle on egress efficiency

To replicate the impact of obstacles, this study established a macroscopic simulation model based on experimental data, with the basic setup outlined in Fig 5(a). The model abstracts narrowed pedestrian pathways as links and the spaces between bottlenecks as nodes. Based on experimental data, the model derives the fitted relationship between link flow and node occupancy. By calculating parameters such as link inflow-outflow and node dwell time over time, the model ultimately predicts pedestrian evacuation time. Results demonstrate that the macroscopic simulation model accurately reproduces evacuation times observed in experiments (as depicted in Fig 5(b)). Furthermore, it can replicate evacuation times corresponding to obstacle layouts not yet validated in experiments, based on the fitted relationship between link flow and node occupancy (as illustrated in Fig 5(c)). Concurrently, consistent with experimental data, the macroscopic simulation results reproduce the obstructing and balancing effects of the obstacle. Further simulations on different pedestrian self-organization behaviors were also performed, which successfully reproduced the guiding phase. Nevertheless, we refrain from introducing it in this report because the content is not published yet.

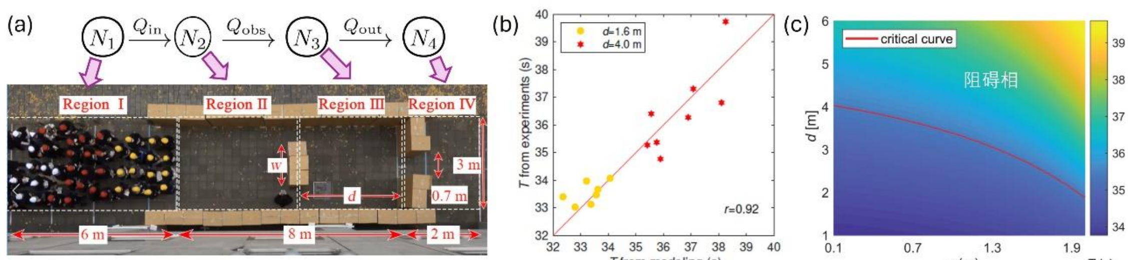

Fig. 5 Results of numerical simulation on the egress efficiency.

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〔図書〕　計0件

〔産業財産権〕

〔その他〕

－

6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関			
ドイツ	Forschungszentrum Julich GmbH			
オーストラリア	UNSW Sydney			
中国	Southwest Jiaotong University			