博士論文（要約）

Study on the influencing mechanism of obstacle layout on pedestrian dynamics aiming at the improvement of pedestrian egress

（歩行環境の改善に向けた障害物配置とその影響メカニズムの解明）

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Pedestrians in real life always have to evade obstacles like walls, pillars and interior furnishings. Therefore, it is essential to understand the influencing mechanism of obstacle on pedestrian dynamics, which could help evaluate or improve the design of obstacles to guarantee the comfortability and efficiency of pedestrian egress. One interesting phenomenon firstly proposed by simulation works is that in emergency scenario where pedestrians are urgent to get out the exit, placing an obstacle in front of the exit could help improve the outflow efficiency. Nevertheless, when it comes to experimental results, the results are controversial and non-emergency cases that are more common in our daily life are rarely focused. Furthermore, there is still lack of generalized influencing mechanism of the obstacle on pedestrian egress efficiency and comfortability. Therefore, in this thesis, we have conducted an in-depth analysis on the influence of obstacle by controlled experiments and macroscopic modeling, which could help guide the obstacle design in real life. Chapter 1 has introduced the backgrounds of pedestrian dynamics including its significance, main methodologies and research topics. Later, present research on the influence of obstacle on the pedestrian outflow under different situations has been introduced. At the end, the motivation and objective of this thesis are presented and explained.

In Chapter 2, we started our exploration on the obstacle with the simplest one-pedestrian condition. Experiments on individual pedestrians have been conducted to make deep analysis on the obstacle evading behavior of single pedestrians. With the variation of obstacle size, both the walking direction and gait features has been examined. The evading trajectories have been found to fit the Gaussian function, based on which the critical evading points, the position where a pedestrian begins to evade the obstacle, have been estimated. Results showed that pedestrians tend to evade earlier if the obstacle size becomes larger, which shows that the geometrical layout of obstacle could affect pedestrian behavior. In contrast, the gait features of pedestrians especially the periodic body sway appears steady despite the variation of with individual pedestrians as participants, which indicates the capacity to adjust their movement to some extent.

In Chapter 3, we began to focus on the crowd pedestrian cases based on controlled experiments. Through concluding the experimental results of present studies, we believe that both the different geometrical layouts and 'pushing' degree among pedestrians have contributed to the controversial influence of the obstacle. To explore the sole influence of geometrical layouts, we have conducted experiments under normal egress condition with 'no pushing'. Results have shown that with the increase of obstacle size, the egress time has kept constant when the obstacle is near to the exit while showed an increasing trend when the obstacle is distant from the exit. Furthermore, we have found that the contributing factor to the egress time is the variation of pedestrian time-headway at the exit. In addition, we have observed that the lane-formation status of pedestrians before the exit has also changed with the obstacle layout, based on which we presume that the variation of egress efficiency relies on the lane-formation status of pedestrians before the exit.

In Chapter 4, the causal correlation between egress efficiency and pedestrian lane-formation has been numerically validated. Firstly, due to the deficiencies of present studies on recognizing nearly parallel pedestrian lanes, we have proposed a customized two-layer k-means clustering method that enables the recognition of lane trajectories and the temporal lane ID of pedestrians. Accordingly, the parameter named deviation degree, i.e. the deviation of pedestrians from his lane ID at the obstacle bottleneck, has been developed to measure the lane-formation status of pedestrians before the exit. Strong correlation between the lane-formation status and egress efficiency has been found, which helps validate our presumption. Furthermore, we have found the variation of lane-formation status is mainly caused by the lane-changing behavior of pedestrians, which is motivated by the desire of pedestrians to obtain better egress conditions through changing from outer to inner lanes before the exit.

In Chapter 5, we have extended our research object to the local congestion level of pedestrians. To accurately measure the local congestion of pedestrians under non-convex situations caused by the obstacle, a modified Voronoi method has been developed with the parameter carefully calibrated by the experimental data. Results show that obstacle could adjust the distribution of local congestion over the walking facility. It is interesting that the optimal obstacle size is obtained under a moderate value, which reminds us the significance of reasonable obstacle design. Furthermore, during the experiments, questionnaires recording the cognitive congestion level that pedestrians have felt have also been taken. Comparison results showed that our estimated local congestion level is in accordance with the actual cognitive value, which indicates the reliability of numerical estimation in reflecting actual pedestrian mentality.

In Chapter 6, based on the experimental data, a macroscopic model has been applied to estimate the egress efficiency under unexamined situations to reflect the influencing mechanism of the obstacle. On the one hand, the reliability of the model in reproducing experimental results have been validated. Besides, it has shown that under 'no pushing' condition, the egress efficiency has shown a decreasing trend with the increase of obstacle size and obstacle-exit distance. On the other hand, the influence of 'pushing' degree has also been estimated through our model. Results show that with the increase of 'pushing' degree, the decreasing trend of egress efficiency under 'no pushing' condition could gradually turn to increasing trend. This is because when the 'pushing' degree is high enough to decrease the egress efficiency, the existence of the obstacle could relieve the pressure before the exit through causing bottlenecks. We believe this result explains the controversy of present experimental results and reminds the significance to consider pedestrian features when placing the obstacle.

To conclude, this thesis has given a thorough analysis on the influencing mechanism of obstacle on pedestrian egress through detailed experimental analysis and macroscopic modeling. Results on the individual evading behavior (Chapter 2) from experiments are expected to enhance the database that can be used to explore pedestrian behavior as well as modeling validation and calibration. Meanwhile, results obtained from the analysis on experiments of crowd egress (Chapter 3-5) are expected to give hints to the obstacle design and pedestrian management from the perspective of both egress efficiency and pedestrian comfortability. Furthermore, the modeling results (Chapter 6) could enable the estimation of egress time and remind the significance to design obstacle layout based on the characteristics of the pedestrians. As a long-term objective, this study can support the composition of the guideline specific to obstacle design in walking spaces oriented to engineering designers and managers.