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Experimental study on pedestrian flow through wide bottleneck

Weichen Liao [a,b,*], Armin Seyfried [b], Jun Zhang [b], Maik Boltes [b], Xiaoping Zheng [c], Ying Zhao [d]

[a] *College of Information Science and Technology, Beijing University of Chemical Technology, Beijing 100029, China*
[b] *Jülich Supercomputing Centre, Forschungszentrum Jülich GmbH, Jülich 52425, Germany*
[c] *Department of Automation, Tsinghua University, Beijing 100084, China*
[d] *Centre for Information Technology, Beijing University of Chemical Technology, Beijing 100029, China*

Abstract

A series of well-controlled laboratory experiments with up to 350 test persons were performed to investigate the pedestrian flow through wide bottlenecks. The density and velocity inside the bottleneck do not depend on the bottleneck width, while those in front of the bottleneck change with the width. A linear dependency is found between the flow and bottleneck width (up to 5 m) by comparing our results with the data from literature. However, differences appear only if the data from steady states are used. These differences indicate the effects of other factors like bottleneck length et al. on the flow.

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Delft University of Technology
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1. Introduction

In the last few decades, problems related to bottleneck and its effects on pedestrian flow have gained increasing attention. To have a deep understanding on pedestrian flow through bottlenecks, several experiments have been performed. Most of them were conducted under well-controlled laboratory condition in which the participants were asked to move normally (Daamen and Hoogendoorn (2003); Kretz et al. (2006); Nagai et al. (2006); Rupprecht et al. (2007); Liddle et al. (2009); Seyfried et al. (2009); Liddle et al. (2011); Rupprecht et al. (2011)), while others studied the influence of alarming (Müller (1981); Daamen and Hoogendoorn (2010)), pushing (Helbing et al. (2003, 2005); Daamen and Hoogendoorn (2010)) or queuing (Yanagisawa et al. (2009)). Nagai et al. (2006) investigated the initial density ranging from 0.4 m^{-2} to 5.0 m^{-2}, and found that pedestrian flow increases with increasing initial density in which the rate of the increase decreases. Rupprecht et al. (2007), Seyfried et al. (2009) and Rupprecht et al. (2011)) changed the number of the participants in the experiments to study the steady state. Daamen and Hoogendoorn (2003) and Daamen and Hoogendoorn (2010) varied the composition of the participants, and found that the population with 5% disabled pedestrians leads to a lower flow and that with mainly children leads to the highest flow. Some researchers

* Corresponding author. Tel.: +49-246-161-8665; fax: +49-246-161-6656.
E-mail address: w.liao@fz-juelich.de

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focused on the influence of geometry factors. Rupprecht et al. (2011) studied the distance between bottleneck and holding area, and found that the pedestrian flow increases with increasing distance. However, we should notice that the distance actually changes the density of the inflow to the bottleneck, so the effect of distance is similar with that of initial density. Rupprecht et al. (2011) and Müller (1981) found that the pedestrian flow increases with increasing width of holding area. Since the bottleneck width is a part of the width of holding area, the ration of these two widths should be studied together. The influence of the bottleneck width on the flow was widely investigated (Liddle et al. (2009); Seyfried et al. (2009); Daamen and Hoogendoorn (2010); Liddle et al. (2011); Rupprecht et al. (2011)). The specific flow through bottleneck is approximately 1.9 $(\mathrm{m}\cdot\mathrm{s})^{-1}$ in normal situation, and is independent on its widths ranging from 0.6 m to 2.5 m (Seyfried et al. (2009), Rupprecht et al. (2011)). However, it is still unknown whether this value also holds for very wide bottlenecks. Besides bottleneck width, short bottlenecks allows higher pedestrian flow than long ones (Liddle et al. (2009, 2011); Rupprecht et al. (2011)). All the studies above used all data from the beginning to the end of the experiments to calculate the flow, and whether the flow using the data from steady states is different from that using all data still needs to be checked.

For this study, a series of well-controlled laboratory experiments were performed to investigate the pedestrian movement through wide bottlenecks. The structure of the paper is as follows. In section 2 the experimental setup is described. The measurement method and the analysis of experiments are documented in section 3. In section 4 we compare our results with data from literatures. Finally, the conclusions are made in section 5.

2. Experimental setup

The experiments were performed in Hall 2 of the Fairground Düsseldorf (Germany) in May 2009. They are part of the Hermes Project (2009) in which the data resulting from the experiments were used to calibrate and test pedestrian movement models. Up to 350 test persons (mostly students) participated. The mean age and height of the participants was 25 ± 5.7 years and 1.76 ± 0.09 m, respectively. The free velocity $v_o = 1.55 \pm 0.18$ $\mathrm{m}\cdot\mathrm{s}^{-1}$ was obtained by measuring the free movement of 42 participants.

Since the aim of the study was to investigate the influence of the width of wide bottleneck on pedestrian flow, only the bottleneck width b = 2.4 m, 3.0 m, 3.6 m, 4.4 m and 5.0 m was changed in the setup (as shown in Fig.1). The geometry was built with boards higher than 2 m to prevent that parts of the bodies (arms and shoulders) exceed the boundaries of the bottleneck. The length of the bottleneck was l = 1.0 m. The holding area had the shape of a semi-circle with radius r = 8.618 m. It was positioned directly in front of the bottleneck to ensure the same initial density ($\rho = 3\ m^{-2}$).

The participants were asked to move in normal velocity after an acoustic signal. The whole process of each experiment was recorded by two synchronized stereo cameras of type Bumblebee XB3 (manufactured by Point Grey). One situated above the entrance to the bottleneck, and the other situated above the exit of the bottleneck (marked by the solid points in Fig. 1). They were mounted on the rack of the ceiling 7.84 m above the floor with the viewing direction perpendicular to the floor. The cameras have a resolution of 1280 × 960 pixel and a frame rate of 16 fps.

3. Data analysis

3.1. Trajectories

Pedestrian trajectories were automatically extracted from the video recordings using the software *PeTrack* (Boltes et al. (2010)). Then they were checked by visual inspection whether all pedestrians are tracked. Finally the trajectories from the two cameras were automatically combined. The procedure led to an upper bound of 5 cm in the uncertainty of the trajectories, which covered wrong calculated disparity and slightly shifted optical axis. The pedestrian characteristics including density, velocity and specific flow at any time and position in the analysis are determined from these trajectories. Fig. 2 shows the cumulated trajectories for bottleneck width b = 3.0 m.

3.2. Density and velocity

The Voronoi method is used in this work to extract pedestrian characteristics for its high precision (Zhang et al. (2011)). Fig. 3 and Fig. 4 show the time series of density and velocity in the selected measurement areas, respectively.