Comparison of turbulent pedestrian behaviors between Mina and Love parade

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Abstract

Study on the characteristics of turbulent pedestrian behaviors has enormous practical significance for activity organization, capacity estimation, facility design, pedestrian model’s verification and congestion detection. In this paper, the turbulent pedestrian flows of the Mina and the Love Parade crowd disaster are analyzed. The differences are compared in many aspects, such as time averaged velocity field, space averaged velocity, instantaneous velocity field, scales of eddies, speed distribution and velocity direction distribution. The results can be used to indicate dangerous regions and unreasonable designs of facilities.

Keywords: turbulent pedestrian flows; crowd behaviors

1. Introduction

Mass events, such as sports events, festivals, cultural and religious events or concerts, are frequently held all over the world. This arouses serious safety issues and tough tasks for organization of mass events and emergency management. Nowadays, much effort has been made and some interesting phenomena have been found, such as jamming, lane formation, oscillations, “panic”, “fast-is-slower” and density waves.

Schadschneider et al. [1] described the main qualitative and quantitative empirical results, focusing on collective phenomena and the fundamental diagram, discussed practical issues and gave a few examples for applications to safety analysis. Based on the video recordings of the Mina crowd disaster, Helbing et al. [2] found three moving states as the increasing of crowd density, which are laminar flows, stop-and-go flows and “turbulent” flows. Helbing et al. [3] also reviewed the situation before and during the Love Parade disaster, and analyzed various factors

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contributing to the disaster and the causal interdependencies and interaction effects. Krausz et al. [4] presented an automatic, video-based analysis of the events in Duisburg and developed methods to automatically detect situations of dangerous congestion and crowd turbulence. Typical turbulent features of the Love Parade disaster were analyzed, including individual movement characteristics and flow field features [5]. The laminar flow and stop-and-go waves during a real mass event in China were investigated. The fundamental relationship was compared with others and re-verified [6−7]. However, the empirical researches are insufficient and the crowd behavior in the state of “turbulent” flows has not been investigated in much detail.

In this paper, the turbulent pedestrian flows of the Mina and the Love Parade crowd disaster are described. In Section 2, the two crowd disasters, respectively in Mina during the Hajj and in Duisburg during the Love Parade, are reviewed. Instantaneous velocity field extraction algorithm are introduced. Then in Section 3, the discrepancies of crowd behavior in the state of turbulent flows between Mina and Love parade are analyzed in detail, followed by the conclusion section.

2. Materials and methods

2.1. The crowd disaster

Hajj is the largest annual Islamic religious activities. Muslims are required to make a pilgrimage to Mina during their lifetimes, if physically or financially possible. During the pilgrimage, they gather together to pray, eat and learn. Many pilgrims carry personal luggage, such as tents, clothes and food. In 1426H on 12 January 2006, the last day of the Hajj, millions of pilgrims swarmed into the bridge of Jamarat from the entrance and were in a hurry to hold the stone-throwing ritual. In front of one of the entrances to the bridge, pieces of luggage spilled from moving buses, causing pilgrims to trip. The subsequent crowd did not know what had happened in the front and continued moving. Those who were tripped were then crushed by the wave of pilgrims behind them. The stampede happened and led to over 345 deaths. Fig. 1(a) shows the images from video recordings of the Mina crowd disaster (the video recordings are accessible from http://www.trafficforum.org/crowdturbulence). The video was covered by a color layer to represent the crowd “pressure” [2]. But the instantaneous velocity fields extracted from these video recordings are not affected in this paper because the extraction method is based on the statistical properties of images.

The Love parade on 24 July 2010 was held in the area of a previous freight station in Duisburg. Visitors could enter or exit from the festival area via the inverse T-section composed of the tunnel and the ramp, where the crowd flows were bidirectional. The flow capacity was significantly reduced due to many risk factors, such as the counter flow, the 90 degree turn, fences, food stand, vehicles and so on. With regard to these risk factors, an additional exit ramp and police cordons were adopted to ensure the public safety. However, the number of visitors evacuated from the additional exit ramp was small. Police cordons were formed to reduce the visitor flows in both sides of the tunnel and in the middle of the ramp. At first, there were just a few visitors between the three police cordons. With the increasing of visitors, police cordons were under large pressure from both sides. The two police cordons in the west and east were open. The visitors previously waiting there moved towards the ramp and encountered those waiting around the police cordon in the middle of the ramp, where the pressure became much larger. Under such large pressure, the police cordon was dissolved. Later, a fourth police cordon was formed in the upper area of the ramp (The overview of the festival area and locations of the four police cordons were illustrated in Fig. 1 of the Ref. [3]). The visitors in the inverse T-section were crowded and lost their control. The crowd disaster happened. 21 people died and more than 500 people injured. Fig. 1(b) shows the images from video recordings of the Love parade crowd disaster (the video recordings are accessible from http://www.youtube.com/watch?v=8y73-7IFBNE&feature=youtu.be).

2.2. Velocity field extraction algorithm

The scenarios analyzed here include a large crowd of people. We can hardly identify individuals. The video recordings of the Mina crowd disaster are not the original surveillance videos. As a result, the conventional measurement methodologies, e.g. tracking of individuals, hardly meet our needs. The velocity field extraction method adopted in this paper is based on the cross-correlation algorithm [6–8]. In the cross-correlation algorithm
method, the image quality requirements for analyzing, e.g. resolution and contrast, are not strict as that in the method which tracks the individual object in the image, because the cross-correlation algorithm investigates and measures the crowd behaviors rather than the individuals. The displacement between blocks from consecutive frames can be obtained by locating the peak in the cross-correlation surface. The velocity at each interrogation window is equal to displacement divided by the time between sequential frames. Perspective transform is necessary because of the deformation of images. The details of the algorithm are illustrated in Ref. [6].

![Fig. 1. The images from video recordings of the crowd disaster (a) Mina (b) Love parade.](image)

### 3. Results and discussions

The pedestrians are in turbulent state, when the crowd density becomes extremely high. During the Mina and Love parade crowd disaster, turbulent pedestrian flows happened due to the high density. But the appearance and development processes of turbulent pedestrian flows in these two different scenarios are distinguished. During Mina crowd disaster, the turbulent flows are converted from the stop-and-go waves. But turbulent flows burst out from the static pedestrians in jammed crowds during the Love parade [5]. The characteristics of the different turbulent flows, respectively in Mina and Love parade crowd disaster, have considerable discrepancies.

Fig. 2 shows the time averaged velocity field of the crowd in Mina and Love parade. The arrows represent the velocity vectors. The lengths and orientations of the arrows represent the velocity vectors’ size and directions based on the perspective transform in the physical space. In Fig. 2(a), the velocity vectors are almost homogeneous and parallel to each other and to the horizontal. The dominant crowd flows are moving right. But the velocity vectors in Fig. 2(b) are multi-directional and irregular. This is because the crowd in Mina can move slowly along the dominant direction, but visitors joining the Love parade are jammed by the forth police cordon and creep in the neighborhoods of themselves.

As Fig. 3 shows, people’s averaged velocities over space vary with time. In Fig. 3(a), the mean speed is about 0.033m/s. Speeds have small fluctuations around the mean speed at a time interval of 2 to 28 s. In Fig. 3(b), the mean speed is about 0.104m/s. The fluctuations around the mean speed are large and the maximum fluctuation is 0.18 m/s. The peaks and troughs of the velocity curve are due to the shock waves’ appearance and disappearance. Unlike the crowd in Mina having a dominant direction, the visitors in Love parade are squeezed completely in the T-section by the police cordons, where the population is almost saturated and the pressure is extremely high. Under this circumstances, a few visitors’ shifting can arouse large shake and shock waves.

Fig. 4 shows the instantaneous velocity field of the crowd in Mina and Love parade, respectively. The lines are the streamlines. Obviously, there are three large-scale eddies in Fig. 4(a). But in Fig. 4(b) many small-scale eddies are showed. The velocity field is much more irregular than that in Fig. 4(a). The differences in eddy scale are caused by the eddy generation mechanism. In Mina, the eddies occur due to the crowd self-organized avoidance of the congestion. But in Love parade the visitors are squeezed completely and the interactions among them are intense. As a result, viscous forces among visitors are large and the scales of the eddies are small.
The curls of velocity field are influenced by the velocity vectors’ size and directions. To recognize eddies, the effect of velocity vectors’ size must be eliminated by conducting normalization method as followed.

\[
    u' = u / \sqrt{u^2 + v^2}
\]

\[
    v' = v / \sqrt{u^2 + v^2}
\]

where \( u \) and \( v \) respectively represent the horizontal and vertical components of velocity vectors. \( u' \) and \( v' \) respectively represent the normalized horizontal and vertical components of velocity vectors.

Fig. 5 shows the curls of normalized velocity field. Eddies recognized by this method are consistent with those by streamlines in Fig. 4. The peaks of the curls indicate eddy cores. The eddies indicate that, compared to the main direction of the crowd movement, irregular movements happened in the corresponding areas. The crowd in the eddy areas moved against the main stream, which may induce accidents due to the fierce physical contacts. As a result,
the curls extracted from the velocity field of the crowd analyze the potential dangerous area of the crowd, and it also reveals that modifications of the routine or facility design should be made in these areas.

Fig. 5. The curls of instantaneous velocity field (a) Mina (b) Love parade.

Fig. 6 shows the speed distribution containing all the pixels in Fig. 1. Beta distribution \( y = \int_0^x x^{\alpha-1}(1-x)^{\beta-1}dx \) used to fit the distribution of speed. The 99th percentile is adopted to compute the maximum velocity of the turbulent pedestrian flows. In Fig. 6(a), the parameter \( \alpha \) equals to 2.2 and parameter \( \beta \) is 53.6. The 99th percentile is 0.14m/s. In Fig. 6(b), the parameter \( \alpha \) equals to 0.7 and parameter \( \beta \) is 7.0. The 99th percentile is 0.48m/s. We can easily read that there are substantial differences in speed distribution between the two scenarios. In Mina, the eddies in turbulent pedestrian flows are large-scale and the crowd behaviors are harmonious. But in Love parade turbulent pedestrian flows, there are large numbers of small-scale eddies. The interactions among eddies are frequent and fierce. Some pedestrians’ behaviors are influenced by two or more eddies. On this occasion, their speeds are so high, more than 0.5m/s. If there are sufficient empirical data, we may summarize statistical laws and forecast the crowd behaviors.

Fig. 6. The speed distribution (a) Mina (b) Love parade.
Fig. 7 shows the velocity and the fluctuation velocity direction distribution containing all the pixels in Fig. 1. In Fig. 7(a), the main velocity directions are respectively 15° and 345°. But in Fig. 7(b) the main velocity directions are respectively 15°, 345° and 180°. It says that in Mina the dominant flows are moving right and those in Love parade are bidirectional, right and left. In Fig. 7(c), the proportions of different directions of fluctuation velocity are approximate. But in Fig. 7(d) the maximums of the fluctuation velocity directions are respectively 15°, 345° and 180°, which shows the similar characteristics with the velocity distribution in Fig. 7(b). We can read that possibilities of the crowd fluctuation direction in Mina are almost same, but the crowd fluctuations in Love parade have three main directions. These phenomena can be explained from the crowd situation. The crowd in Mina can move slowly and have strong desire to move forward. They have the same purpose and their behaviors are harmonious. They can choose the relatively smooth path coincidently. But in Love parade, there is a police cordon in the upper area of the ramp, which blocks the crowd flows completely. The crowd can only find larger space by moving left or right.

**Fig. 7.** The velocity direction distribution (a) Mina (b) Love parade and the fluctuation velocity direction distribution (c) Mina (d) Love parade.

### 4. Conclusions

Based on the extracted velocity field, the characteristics of turbulent pedestrian behaviors in Mina and Love parade crowd disaster are analyzed. There are many differences between Mina and Love parade. The crowd in Mina have dominant flows. They have the same purpose and their behaviors are harmonious. The pedestrian flows in Love parade are multi-directional and irregular. The crowd can only move right or left to decrease the crowd pressure. The possibilities of the crowd fluctuation direction in Mina are almost same, but the crowd fluctuations in Love parade have three main directions. Unlike large-scale eddies in Mina, there are many small-scale eddies in the crowd in Love parade. The existences of eddies are symbols of congestion due to unreasonable designs of facilities.
Thus the eddy recognition method proposed in this paper can be used to indicate dangerous regions and unreasonable designs.

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References