Using Agent-based Simulation for Safety: Fact-finding about a crowd accident to improve public space design

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Abstract – With the growing city density and large gatherings happening all over the world, crowd safety has become a new topic. This research discusses how to diagnosis and improve crowd safety in urban public space by analysing a real crowd accident that happened in Shanghai in 2014 using an agent-based simulator. Fact-finding analysis shows that insufficient capacity of the whole area, density difference in bottleneck stairs and lack of separation measurements in front of bottleneck stairs are the main causes of the accident. According to the media query towards the original space plan, we made two alternative plans in the bottleneck area and tested their performances.

***Keywords*:** crowd accident, agent-based simulation, city design, disaster prevention, crowd management

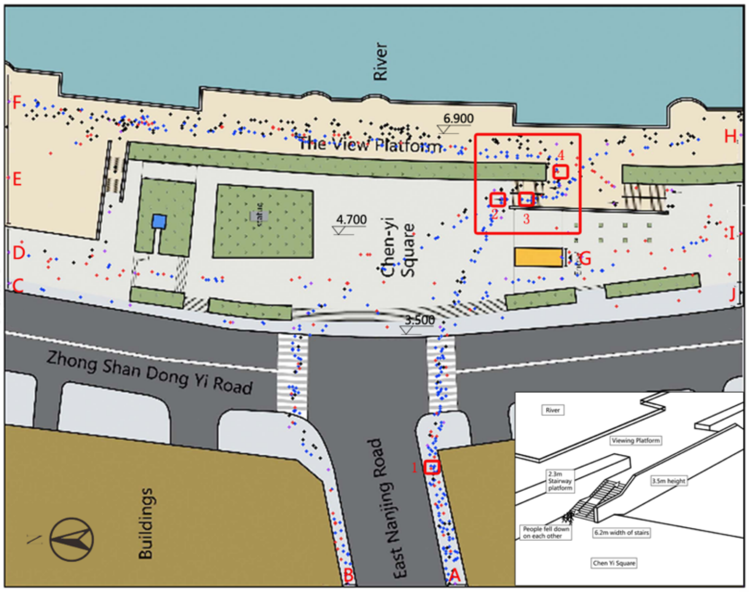
1. Introduction

Traditional architectural design follows various codes and regulations, and in terms of crowd safety capacity and evacuation speed are mainly taken into consideration. The analysis of various crowd accidents indicated that even in a public space that fully meets the design criteria an accident can occur because of the avoidance or competitive behaviour of pedestrians. However, in urban public space, even such criteria are scarce. Since the 1990s, experimental and quantitative analysis about pedestrian counter flows were occasionally conducted. This paper focuses on characterizing a real case with a multi-direction flow at a stair bottleneck and its potential solution and addresses the pressure inside crowds.

2. Diagnosis space for fact finding — 2014 Shanghai Bund Stampede

2.1. Overview of the situation

The Shanghai Bund Waterfront is a linear area along the Huangpu River that occupies an area of 3.1 km^2 (Fig. 1, left). This area has 3 different elevations of 3.5m, 4.7m and 6.9m corresponding to the pedestrian street, Chen Yi Square and the viewing platform. The viewing platform is built on top of a flood defense wall and is considered to be the best viewing location. Chen Yi Square has its highest density from East Nanjing Road where visitors come from subway. The crowd accident happened on 31 December, 2014 at 23:35pm, on the stairs on the north-east corner connecting the square to the viewing platform, when people gathered for the New Year countdown. The stairs have 17 steps, 6.2m in width, with no separation in the middle, thus tightening the crowds from the square and forming a bottleneck. The tragedy caused 36 deaths and 49 injuries. The following January, the investigation report was released [1], and the accident details became clear (Table. 2). It is noteworthy that a few minutes before the accident happened, people moving upwards and downwards constantly collided and stalemated in the middle of the stairs, and then formed a liquid-like 'wave' [1] [4].



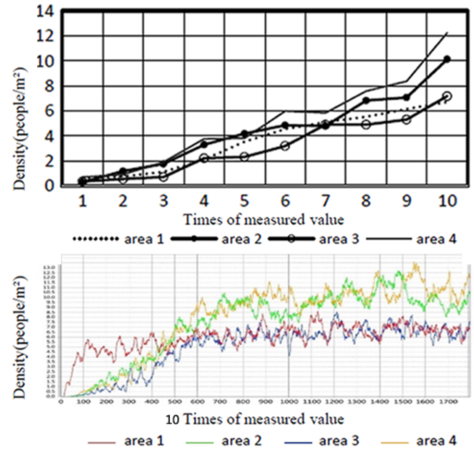


Table. 2 Event Time Line and Corresponding Density

Time	Event	Density
20:00	More people came in than came out. Visitors gradually gathered on viewing platform.	Density of the Bund area: 20:00 - 21:00: 3.9 people/ m². 21:00 – 22:00: 5.2 people/ m². 22:00 – 23:00: 7.7 people/ m². 23:00 – 23:35: 10 people/ m².
20:27	Set one-way belt on stairs.	
22:44	Set intercept line in East Nanjing Road.	
22:37	One-way belt on stairs was broken.	
23:23-23:33	People moving upwards and downwards constantly collided and stalemated in the middle of the stairs, and then formed a “wave”.	
23:35	The downwards pressure of the stalemate suddenly increased, causing someone at the bottom to fall down. After the first person fell, people started to fall down on each other. Then a stampede happened.	

Table. 1 Survey of flow (people/minute)

Entry: A	Entry: B	Entry: C	Entry: D	Entry: E	Entry: F	Entry: G	Entry: H	Entry: I	Entry: J
119	44	2	13	5	51	14	38	48	10

Fig. 1: Density analysis for fact finding.

2.2. Simulation model setting

In our simulation model, space is divided into 40cm cells and one step is set as 0.5 seconds. The simulation area has 10 entries/exits marked as A to J (Fig. 1, left). Agents move following the shortest path rule and 36 pedestrian rules in ASPFver.4.0 (Agent Simulator of Pedestrian Flows, Kaneda et al.), including 6 basic behavior rules, 1 pattern cognition rule, 4 avoidance rules, 3 high density flow rules, 1 pattern cognition rule and 14 wall avoidance rules [3]. Four density measurement areas are shown in red rectangles in Fig. 1. A pedestrian inflow survey was conducted between 15:00 and 16:00 on a September weekend. Survey data is shown in Table 1.

2.3. Experiment 1: Characterising the density growth at the stairs bottleneck

On the accident night, the density was around 4 people/m^2 at 20:00 and gradually increased until the stampede happened. Two groups of stairs in the accident area have a scissor shape and people moving upwards and downwards are on the right. To characterize the density growth in this complex mixed flow area, we timed the surveyed flow-in value from 1 to 10 times. The result (Fig. 1, top right) shows that: (1) The change of density in area 2 follows the density in area 4. This means the pressure on the platform is often higher than the stairs and the square, which leads to a downward pressure. Video observation shows that the accident more likely happened because significant pressure suddenly pushed people down rather than because someone fell, leading to a domino effect [4]. (2) The growth pattern of the platform density (area 4) shows stage character: it goes through a stable period from 4 to 5, then sharply increases to 6. This means that flow control measurements of the bottleneck area should start when the density is 2 or 3.

2.4. Experiment 2: Simulation for fact finding

In experiment 2, we conducted the simulation with 10 times flow-in value, which is closest to the actual accident (Fig. 1, center right). The result shows that the density on the platform (area 4) and in front of the stairs (area 2) is relatively higher than the density on the stairs. A possible reason is that pedestrian flows from five different directions met at the top of the stairs, forming a high-density mixed crowd. On the square in front of the stairs, pedestrian flows from three different directions also formed a high-density mixed crowd, but the density was relatively lower than the platform. Enormous downward pressure caused balance loss and suddenly pushed down the people on the stairs. Adding separation measures in mixed-flow areas will be a solution.

3. Test alternative space plans

3.1. Two alternative space plans

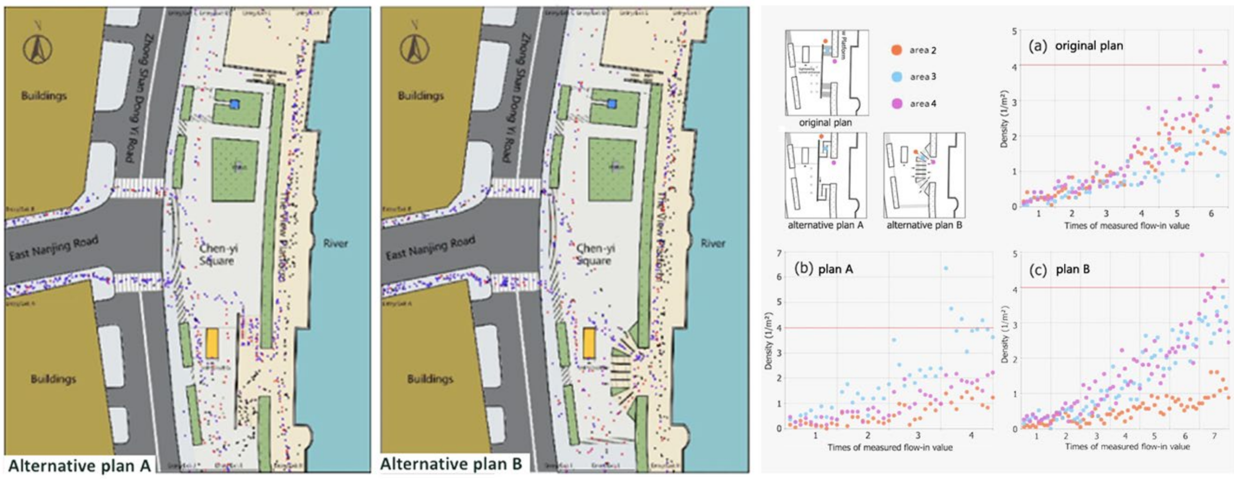


Fig. 2: Density measurement of original plan and alternative space plans.

Shanghai Bund Waterfront underwent landscape transformation in 2010, expanding pedestrian activity space by 40% percent [2]. After the accident, two major questions about the stairs bottleneck were posed: (1) Are the stairs too steep? (2) Would it be better to open the bottleneck area? Regarding these questions, we made two alternative plans and tested their performance (Fig. 2, left). Plan A changed the stairs with two one-direction slopes, and plan B is an open plan without bottleneck.

3.2. Experiment 3: Performance test

In experiment 3, we timed the measured flow-in value in the original space plan and two alternative plans to observe the density change in three measurement areas (Fig. 2, right). The experiments stop when any measurement area reaches 4 people/m^2. The result shows that in unextreme density: (1) The ability to allow more people into the square while maintaining a relatively pleasant density: plan B > original plan > plan A. (2) In plan B and the original plan, the platform reaches risk density first. In plan A, the slope reaches risk density first. When it comes to the preventive measures, the former should be conscious of the pressure difference while the latter should prevent squeeze.

4. Conclusion

In this paper, we quantitatively analysed the bottleneck in a crowd accident and evaluated the possibility of improvement. The pressure caused by the density difference between people is notable, and in current agent-based models, high density scenarios often fail by lacking the ability to present it.

References

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