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The parameter calibration and optimization of social force model for the real-life 2013 Ya'an earthquake evacuation in China

Meifang Li [a], Yongxiang Zhao [a,b,*], Lerong He [a], Wenxiao Chen [a], Xianfeng Xu [a]

[a] School of Economics and Management, Fuzhou University, Fuzhou 350108, China
[b] Department of Civil and Environmental Engineering, University of California, Davis, CA 95616, USA

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ABSTRACT

Due to the fact that escape panics are unexpected and dangerous, which excludes real-life experiments because of technical difficulties and ethical reasons, the evacuation simulations in real-life disasters are still rare. In this paper, the escape panics of classroom evacuation in real-life 2013 Ya'an earthquake in China are simulated and reproduced using the social force model. Firstly, a robust differential evolution (DE) is employed to calibrate and optimize the parameters of social force model to achieve a desired non-linear evacuation speed which is consistent with real-life video data. It is demonstrated the DE-calibrated social force model can reproduce the characteristics of pedestrian flow in the real-life earthquake evacuation including the nonlinear evacuation speed curve and the pedestrian position distributions at different time. Moreover, the trained evacuation leader has remarkable impact on the evacuation process which can be beneficial to maintain the calm and order of crowd, decrease the desired velocity of crowd, and thus avoid fatal accident to the most degree. Finally, different layouts of classroom have similar evacuation efficiency because different internal layouts can only change partial flow of pedestrians in the left and right corridors, and total flow aggregating in the exit of classroom is still unchanged. However, total evacuation time can be sharply reduced to 17 s from above 36 s, and evacuation efficiency has almost doubled when the back door is open, which means we should try to keep all the emergency exits open in order to provide the crowd with more chances to escape when disasters occur.

1. Introduction

Modeling escape panics behaviors has attracted considerate attention in emergency evacuation studies in recent years. Pedestrian behaviors have been successfully reproduced by statistical physics models including social force model (Helbing et al., 2000a,b; Helbing and Molnar, 1995) proposed by Helbing, cellular automation models (Burstedde et al., 2001; Kirchner and Schadschneider, 2002; Kirchner et al., 2003), lattice gas models (Muramatsu and Nagatani, 2000; Tajima and Nagatani, 2002; Maniccam, 2003; Helbing et al., 2003), and so on. These theoretical models provide important design guidelines for transportation and building environment (Pelechano and Malkawi, 2008; Zhao et al., 2008; Chow and Ng, 2008; Seyfried et al., 2009; Xu and Song, 2009), as well as offering strategies for emergency evacuation in all kinds of natural or man-made disasters such as fires, tsunamis, and earthquakes (Weckman et al., 1999; Rassia and Siettos, 2010; Lämmel et al., 2010). Moreover, with the development of video tracking technology, video-based studies of pedestrian evacuation have also been investigated by different groups (Isobe et al., 2004; Nagai et al., 2006; Antonini et al., 2006; Helbing et al., 2007; Johansson et al., 2008; Zhang et al., 2008; Fang et al., 2010).

However, due to the fact that escape panics are unexpected and dangerous, which excludes real-life experiments because of technical difficulties and ethical reasons, majority of these researches mainly focused on mimic exercises in simulated situations (Yeo and He, 2009; Kady and Davis, 2009; Liu et al., 2009; Kobes et al., 2010) or animal experiments (Saloma et al., 2003; Altshuler et al., 2005; Shiwakoti et al., 2009), and the emergency evacuation simulations in real-life disasters are still rare.

With the rapid development of Chinese economy, an increasing number of video data recording special scenes of real-life earthquakes or other disasters are deployed through internet or TV programs for public security purposes. After the Ya'an earthquake occurred at 08:02 Beijing Time on April 20, 2013 in China, the Chinese Government broadcasted a real-life video recording of classroom evacuation of Mingshan high school in the earthquake by CCTV News (http://news.cntv.cn/2013/04/23/

* Corresponding author at: School of Economics and Management, Fuzhou University, Fuzhou 350108, China.
E-mail address: zhaosanhe@263.net (Y. Zhao).

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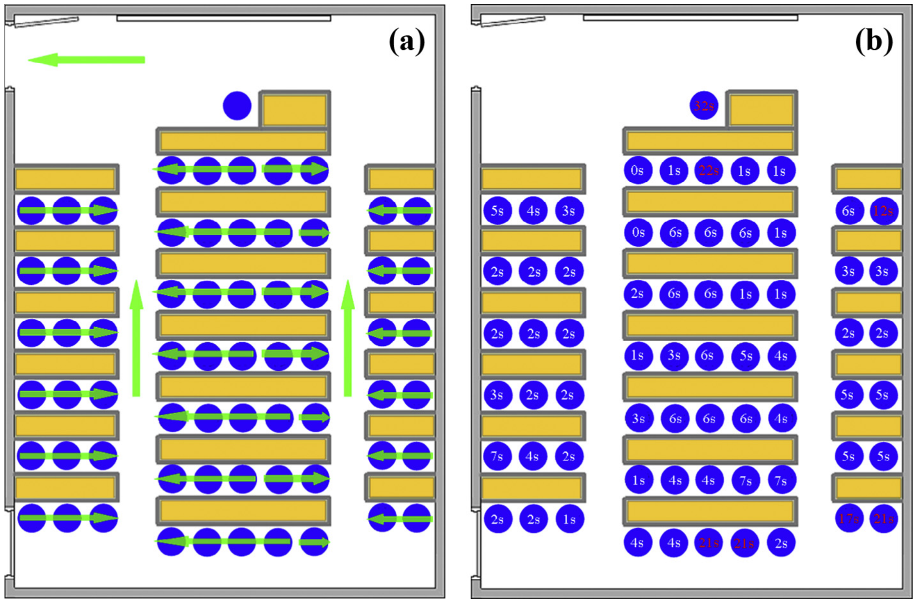

Fig. 1. (a) The evacuation routes of 66 pedestrians in the classroom of Mingshan high school when the Ya'an earthquake occurred. (b) The pre-evacuation delay time of 66 pedestrians in the real-life earthquake disaster.

VIDE1366716241778591.shtml). The epicenter was located in Lushan County, Ya'an, Sichuan, about 116 km from Chengdu along the Longmenshan Fault in the same province heavily impacted by the 2008 Sichuan earthquake. The entire video records of classroom evacuation in the earthquake can also be accessible through the internet (https://www.youtube.com/watch?v=G5H_ylTY0N4). It thus provides us an unprecedented opportunity to investigate the pedestrian evacuation behaviors in the real-life earthquake disaster.

The main objective of the paper then is to explore and understand the evacuation behaviors in real-life disaster by using the social force model to simulate and reproduce escape panics of classroom evacuation in real-life 2013 Ya'an earthquake in China. The paper was organized as follows. Firstly, a robust differential evolution (DE) was employed to calibrate and optimize the parameters of social force model in order to achieve a desired nonlinear evacuation speed which is consistent with real-life video data. Then the maximum crowd pressures under different desired velocities are analyzed, and the trained evacuation leader has remarkable impact on the evacuation process which can be beneficial to maintain the calm and order of crowd, and thus avoid fatal accident to the most degree. Moreover, the effects of classroom layout on evacuation efficiency are further discussed, and different layouts of classroom have similar evacuation efficiency because internal layouts can only change the partial flow of pedestrians in the left and right corridors. Finally, the evacuation efficiency has almost doubled when the back door is open, which means we should try to keep all the emergency exits open in order to provide the crowd with more chances to escape.

2. DE-based calibration and optimization model

2.1. Evacuation scene description

In this paper, in order to extract the appropriate model parameters from real-life video data, the dynamic video recordings were transformed into discrete frames by the Total Video Converter firstly, then the Canny edge detection algorithm was employed to facilitate the parameters estimate and manual measurement (Yang et al., 2011). Because of the shaking of the video camera during the earthquake and the limitation of video quality, absolutely accurate parameters would be hard to extract even with elaborative manual measurement.

Fig. 1(a) demonstrates the evacuation routes of 66 pedestrians in the classroom of Mingshan high school when the Ya'an earthquake occurred at 08:02 Beijing Time on April 20, 2013 in China. In the evacuation scene, the classroom has a dimension of 6.6 m by 9.0 m and includes 65 students and one teacher. Moreover, each single desk has dimensions of 0.55 m by 0.42 m. The front door of the classroom is 1.0 m wide, and the back door is closed when the earthquake occurred.

In the real-life video, the route choices of pedestrians in the classroom during earthquake evacuation can be clearly seen by careful manual measurements which have been shown in Fig. 1(a). In the earthquake, the route-choice behavior of pedestrians is mainly affected by the passing capacity of the frontal route and the route distance from the pedestrians to the exit. That means the pedestrians will tend to give priority to the route with higher traffic capacity and fewer obstacles such as desks and chairs firstly, then consider the distance from themselves to the door, which is consistent with experimental results of extant literature (Chen et al., 2013).

After the May 12, 2008, Wenchuan earthquake, which caused huge loss of life and property (Yang et al., 2011), the schools in Sichuan province, China have reinforced the mimic exercises of earthquake evacuation. In those mimic exercises, students are told to hide themselves under their desks, and not escape from classroom immediately when the earthquake occurred for the first time. However, the behaviors in real-life unexpected earthquake panic are markedly different from that in previous prepared mimic exercises due to socio-psychological reasons, and in the real-life earthquake disaster, people need a responding time or pre-evacuation delay time to notice the onset of the disaster.

Fig. 1(b) clearly depicts the approximate pre-evacuation delay time of 66 pedestrians in the real-life earthquake disaster. From the video recordings, we can find that two students close to the exit and corridor started evacuating immediately when the earthquake occurred, and other students all had a pre-evacuation delay from 1 s to 32 s. In Fig. 1(b), the average pre-evacuation delay time is approximate 5.24 s. The delay time is marked in red when