Physica A 512 (2018) 1140–1151

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Evacuation experiments in vertical exit passages in an underwater road shield tunnel

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HIGHLIGHTS

- Evacuation experiments were conducted in an actual underwater road tunnel.
- Concurrent descending/ascending experiments were performed on a staircase.
- Foundational experimental evacuation data were obtained in underwater road tunnels.
- Differences in evacuation behavior were explained in different vertical exits.

ARTICLE INFO

Article history:
Received 15 September 2017
Received in revised form 22 March 2018
Available online 16 August 2018

Keywords:
Evacuation experiment
Underwater road tunnel
Vertical exit passages
Evacuation time

ABSTRACT

Evacuation experiments were conducted to examine the movement speed and evacuation capacity in an underwater shield road tunnel where vertical evacuation passages were installed. Behavioral results were collected through several field experiments aimed at investigating vehicle evacuations, the time required to open vertical evacuation passages, slide and stairs descending with and without counter flows. The results show that the individual movement speed in staircase was lower than the speed in slide, but the average Occupant Flow Rate (OFR) in staircase was higher than the OFR in slide. The probable reasons were discussed and analyzed. Females had worse performance when opening the exit door than males. The upstairs movement of firefighters was observed not negatively affect the evacuation performance of occupants down stairs. The replicated experiments showed that appropriate training or drills can help improve the movement speed of occupants. The results of this study will be essential to evaluate evacuation capacity and occupant behavior on stairs and slides of underwater shield tunnels.

1. Introduction

Over 40 underwater road tunnels have been built in China in the past several decades, due to the extraordinary growth of economy and urbanization in the country. An underwater road tunnel plays a key role in transportation hub connecting cities

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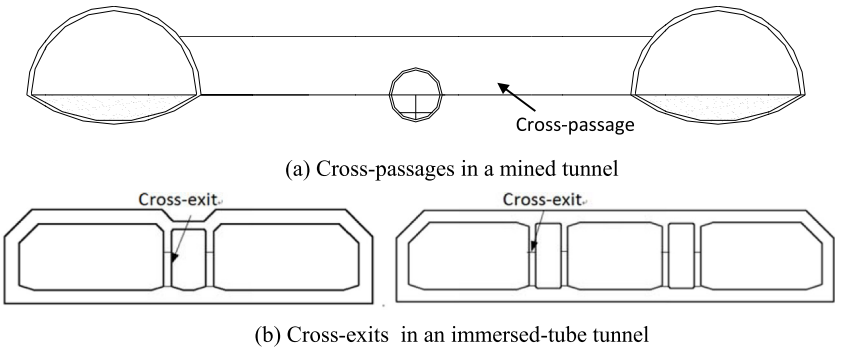
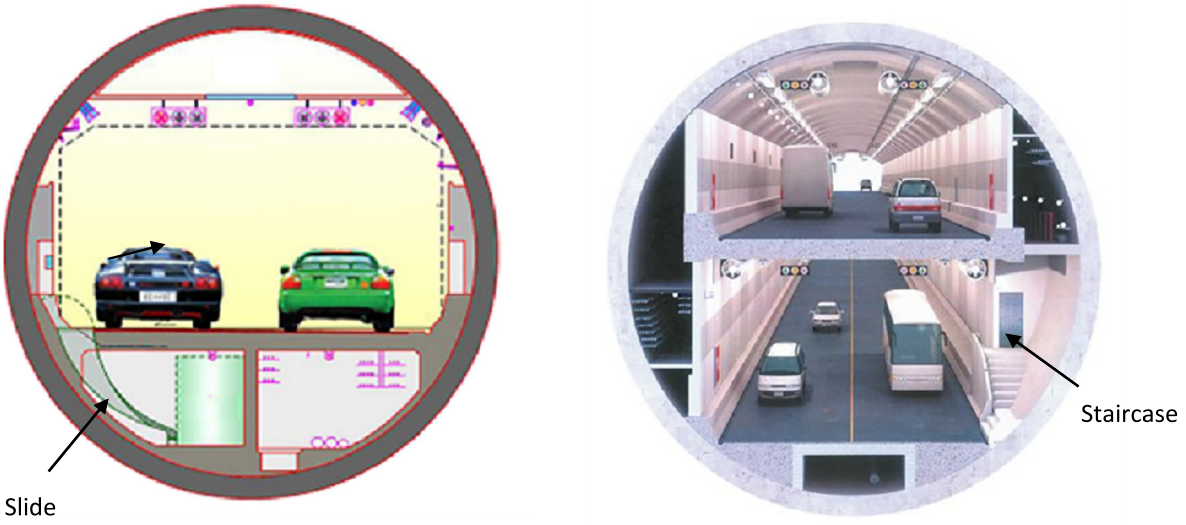
https://doi.org/10.1016/j.physa.2018.08.129
0378-4371/



(a) Cross-passages in a mined tunnel

(b) Cross-exits in an immersed-tube tunnel

Fig. 1. Illustrations of crossover passages in underwater tunnels.



(a) Slide

(b) Staircase

Fig. 2. Typical vertical passages in underwater shield tunnels.

or regions. It should be noted that there are usually large amount of vehicles and passengers in a tunnel. Occupant evacuation in case of fire or other emergencies is therefore a critical concern for underwater road tunnel design and construction.

Both horizontal and vertical passages can be used as evacuation exits in road tunnels. Horizontal crossover passages allow quick evacuation in emergencies, and thus have been used as a major evacuation method for dual-bore mountain road tunnels, as shown in Fig. 1. Shield and boring construction is the main construction method for underwater road tunnels in China [1]. An underwater shield tunnel is usually divided into two zones: an upper zone served as a ventilation and driveway zone, and a lower zone served as a safety/service zone or driveway zone. Connections of these two zones are vertical passages such as slides or staircases. Various styles of evacuation exits are possible in shield underwater road tunnels, including horizontal crossover passages, vertical passages, and their combinations, as shown in Figs. 1 and 2. For example, the crossover passages like Fig. 1(a) were used in the Western Scheldt Tunnel (the Netherlands), and slides like Fig. 2(a) were used in the Trans-Tokyo Bay Highway Tunnel (Japan), the Wuhan Yangtze River Tunnel (China), the Nanjing Yangtze River Tunnel (China), and the Hangzhou Qingchun Road Tunnel (China). Staircases similar to Fig. 2b have been used in the Shanghai Shangzhong Road Tunnel (China).

Researches have been performed to examine occupant evacuation issues in road tunnels. Frantzich [2] studied the passenger's ability to move inside a tunnel in the event of a fire. Boer and van Zanten [3] examined the self-rescue assumption and the adequate use of escape provisions in road tunnels. Ronchi et al. [4] analyzed different evacuation models in road tunnels. Factors influence the evacuation performance were investigated by various studies, including: extinction coefficient, flashing lights, and the responses of occupants to emergency situations [5–10]. Virtual reality technology was applied to evacuation experiments in road tunnels [11–13]. However, most studies were conducted in mountain road tunnels without