Study on Smoke Control of Wuhan CBD Urban Traffic Link Tunnel

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Abstract

An Urban Traffic Link Tunnel (UTLT) is a novel type of underground transportation system consisting of a main tunnel in a loop shape and several linked tunnels. It has a higher level of fire risk compared to other common road tunnels. In this study, numerical and experimental study has been conducted to investigate the smoke control of Wuhan Central Business District (CBD) UTLT. The transient distributions of the smoke spread have been analyzed, and the optimal smoke control strategy for the Wuhan CBD UTLT has been put forward.

Keywords: urban traffic link tunnel; fire; smoke control; numerical simulation; experiments;

1. Introduction

The traffic jam occurring in the downtown has become the priority in traffic problems to be solved along the development of urban traffic. UTLT (Urban Traffic Link Tunnel) can alleviate ground traffic effectively, thus building UTLT has become the inevitable trend of urban modernization and sustainable development [1]. UTLT located in important or prosperous urban district consists of looped main tunnel connecting with underground parking garage and linking tunnels to the outside, the traffic flow is huge in main tunnels whose cross-section is rectangle with a low height [2,3]. These features of UTLT bring more probabilities of fire so the smoke control needs to be more effective in order to protect people in the tunnel when a fire takes place.

2. Introduction of Wuhan CBD UTLT

Wuhan CBD UTLT locates under ShangWu East Road, ZhuJiang Road, ShangWu West Road and FanHai Road, which mainly serves cars to travel to and from the underground parking garage of Wuhan CBD. The function of the UTLT would be improving travel efficiency, easing the conflict of human-vehicle flow, enhancing the environment of CBD and realizing the idea of low carbon traffic. The total length of UTLT is about 1.9km including the main tunnel and the linking tunnels, and it crosses by number 3 subway, number 7 subway and HuangHai Road tunnel. The general layout of UTLT is shown in Fig.1.

The UTLT main tunnel contains three lanes with each lane 3m wide, and it is 11.2m in width and 3.9m in height, above the main tunnel there are both a ventilation duct and a multifunctional duct for all kinds of pipes. The linking tunnels contain two lanes with one lane travelling outside the tunnel and one lane travelling inside the tunnel. Besides the main tunnel section under ZhulJiang Road, other three main tunnel sections have a natural ventilation shaft. Therefore the main tunnel has two types of cross section as shown in Fig.2.
3. Numerical Simulation on Smoke Control of Wuhan CBD UTLT

Wuhan CBD UTLT has two kinds of ventilation system, which are natural ventilation with air shafts at the top of tunnel and semi-transverse ventilation with automatic exhaust ventilators along the tunnel. In the normal operation, the natural ventilation is used to keep the air inside the tunnel at a tolerable level, when natural ventilation doesn’t meet the air criterion, axial flow fans will be started for mechanical ventilation; when a fire takes place in the tunnel, both ventilation systems will be used to exhaust the smoke outside the tunnel. The automatic exhaust ventilators is installed every 40-50m in each section of the tunnel, and five ventilators near the fire will be opened to exhaust the smoke when a fire takes place.

There are four underground ventilation rooms along the ZhuJiang Road and FanHai Road, which are equipped with three axial flow fans each. Among these four rooms, room 1,2,4 are equipped with three axial flow fans DTF-1500-716-4 which has a flow rate of 72085m$^3$/h each; room 3 is equipped with three axial flow fans DTF-10-4P which has a flow rate
of 43140 m³/h each. In this study, the Fire Dynamics Simulator (FDS) [4, 5] will be used to simulate the smoke control system in Wuhan CBD UTLT.

3.1 Fire Size

Based on the statistics offered by World Road Association PIARC, the maximum fire size caused by a car is 5MW [6]. As only small cars are allowed to travel in Wuhan CBD UTLT, the fire size is set to be 5MW in this study.

3.2 Fire Scenarios

As there are two kinds of ventilation system, three fire positions have been chosen to study the smoke control of Wuhan CBD UTLT. One position is located in ZhuJiang road tunnel section which has only semi-transverse ventilation system, and the other two positions are located in ShangWu East Road tunnel section which has both natural and semi-transverse ventilation system, as shown in Fig.3. Two fire scenarios have been simulated for the fire in the ZhuJiang Road tunnel section, with one or two axial flow fan activated respectively. Two other fire scenarios have been simulated for the fire in the ShangWu East Road tunnel section, with only natural exhaust system activated. Two different tunnel models have been built using FDS, both of which are 456m in length, as shown in the Fig.4. The details of each fire scenario are shown in table 1 and the total simulation time of each fire scenario is set to be 900s.

![Fig.3](image-url) the fire positions in UTLT

![Fig.4](image-url) (a) without natural ventilation shaft (b) with natural ventilation shaft
Table 1 fire scenario settings

<table>
<thead>
<tr>
<th>scenario</th>
<th>Fire position</th>
<th>Smoke control mode</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Right under the natural shaft of ShangWu East Road tunnel</td>
<td>Smoke is extracted outside by the natural shaft right above the fire, and the semi-transverse system is supposed to be out of function.</td>
</tr>
<tr>
<td>2</td>
<td>Between two natural shafts of ShangWu East Road tunnel</td>
<td>Smoke is extracted outside by the natural shaft upstream and downstream of the fire, and the semi-transverse system is supposed to be out of function.</td>
</tr>
<tr>
<td>3</td>
<td>In the middle of ZhuJiang Road tunnel</td>
<td>240s after the occurrence of fire, two smoke ventilators upstream and three smoke ventilators downstream the fire are opened and one axial flow fan is activated.</td>
</tr>
<tr>
<td>4</td>
<td>In the middle of ZhuJiang Road tunnel</td>
<td>240s after the occurrence of fire, two smoke ventilators upstream and three smoke ventilators downstream the fire are opened and two axial flow fans are activated. Smoke is extracted outside through the ventilation duct at the top of tunnel.</td>
</tr>
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</table>

3.3 Simulation Results Analysis

The transient distributions of the smoke spread in the end of the simulation of the four different scenarios are shown in Fig.5. As shown in the Fig.5 (a) and (b), all of the smoke has been exhausted outside of the tunnel through the natural shaft in both the fire scenario one and two, no matter the fire is right under the shaft or between two shafts. In both scenarios the smoke only spreads no more than 200m near the fire in the end of simulation (900s) , and the smoke layer stratification is apparent and keeps at a relatively high level. As shown in the Fig.5 (c), with only one axial flow fan activated which has a flow rate of 17m³/s, the fire smoke spreads to the whole ZhuJiang Road tunnel section in the end of simulation, and the smoke layer descends to a level which will be harmful for people to evacuate from the tunnel. In this scenario only a part of smoke has been extracted outside through the ventilation duct, and the other part has been spread outside via the tunnel exits and entrances. As shown in the Fig.5 (d), with two axial flow fan activated which has a total flow rate of 30m³/s, the fire smoke only spreads within 430m in the end of simulation, and the smoke layer keeps at a relatively high level which is more helpful for people to evacuate from the tunnel. In this scenario most smoke has been extracted outside the tunnel through the ventilation duct.
4. Experimental Study on Smoke Control of Wuhan CBD UTLT

A 1:10th scale model of Wuhan CBD UTLT has also been built to validate the effectiveness of its smoke control system. The tunnel section chosen to build the model is shown as Fig.6, and Fig.7 shows the set-up of the 1:10th tunnel scale model with a total length of 45m. The tunnel model was made of fire-resistant glass, so experiments with real fire could be carried out in this model. The ethanol has been chosen as the fire source because it doesn’t produce any black smoke, which won’t pollute the tunnel model. In order to observe the effectiveness of the smoke control system, trace gas has been produced by a special gas biscuit, as shown in Fig.8.
Two fire tests have been carried out in the scale model. Test one is in the tunnel section with natural ventilation shaft, which demonstrates that the natural ventilation system is very effective for the fire smoke control, as shown in Fig.8 and Fig.9. Test two is in the tunnel section with only mechanical extraction system which has a total flow rate of 30m³/s. As shown in Fig.10 and Fig.11, the smoke layer keeps at a relatively high level and most smoke has been exhausted outside the tunnel by the axial fan connected to the mechanical ventilation duct.

5. Conclusions

In this study the fire dynamic simulator (FDS) has been used to simulate the fire smoke control in the Wuhan CBD UTLT, and two different tunnel models have been built using FDS to simulate the two different ventilation systems. In order to validate the effectiveness of the smoke control system, a 1:10th scale model of Wuhan CBD UTLT has also been built, and two fire tests have been carried out in different tunnel sections. Based on the analysis of the simulation and experiment results, it can be concluded that:

1. When a fire takes place in tunnel sections with natural ventilation system, all of the fire smoke will be exhausted outside of the tunnel through the natural shaft above the tunnel, no matter the fire is right under the shaft or between two shafts. It is demonstrated that the natural ventilation system of Wuhan CBD UTLT is very effective to control the smoke and helps to create a safe evacuation environment for people.

2. When a fire takes place in the ZhuJiang Road tunnel section with only semi-transverse ventilation system, only part of smoke can be exhausted through the ventilation duct when one axial flow fan is activated, which creates a harmful environment for people to evacuate outside the tunnel. With two axial flow fans activated, most of the fire smoke is exhausted through the ventilation duct, and the fire smoke layer keeps at a relatively high level which is more helpful for people to evacuate from the tunnel. Therefore, when a fire takes place in the ZhuJiang Road tunnel section, it is necessary to activate two axial flow fans and five smoke ventilators near the fire as soon as possible.

3. The ventilation system of Wuhan CBD UTLT can effectively exhaust smoke outside the tunnel, which can make references for similar UTLT ventilation design.
Acknowledgements

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References