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Research Article

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Characteristics and Control of Flame Spread in Tunnel Fires

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Abstract: With the rapid development of traffic, there are more and more road tunnels in China and all over the world, and tunnel accidents are more and more frequent. Due to the unique tunnel exit and dense vehicles in the tunnel, tunnel accidents are often more serious than other fire accidents, especially the disaster caused by the accident of dangerous chemical vehicles. Taking the tunnel fire flame diffusion as the starting point, this paper analyzes the fire diffusion and spread, summarizes the characteristics of tunnel fire flame spread, and puts forward countermeasures to reduce disaster losses.

Keywords: tunnel fire; Flame diffusion; Turbulent fire

1. Introduction

At about 3:00 a.m. on 8 April 2011, a tanker truck exploded in the Qidao Liang Tunnel on the Lanlin Expressway from Lanzhou City to Linxia Hui Autonomous Prefecture in Gansu Province, causing serious damage to the facilities in the tunnel, and resulting in the deaths of four people and minor injuries to one.

This paper studies the causes of the disaster in terms of flame spreading, explains the principle of flame spreading, and proposes emergency measures to avoid similar incidents.

2. Accident analysis

Tunnel fires have a variety of causes, and the impact of fires from different causes varies. For tunnel fires, most incidents are related to car accidents, but there are also other cases of fire starting. For example, the 1999 Mont Blanc Tunnel fire was caused by a driver's cigarette butt; the 2017 tunnel fire in Weihai, Shandong Province, China was caused by arson. To sum up, the main causes of tunnel fires are as follows: 1) sparks from vehicle collisions. 2) spontaneous combustion caused by aging or disrepair of the vehicle. 3) sparks from friction between the wheels and the road surface. 4) arson by humans. 5) human error leading to contact of cigarette butts and other sources of ignition with combustibles.

As tunnels are generally denser, and the formation of wind tunnels will accelerate the spread of flames, the slope of the tunnel also has an impact on the spread of tunnel flames7［1,2]. In addition, due to the relative closure of the tunnel, the tunnel tanker trucks and other large amounts of burning material carried can not be transferred within a short period of time, the fire situation is generally more serious. Therefore, tunnel fires generally have:

(A) The diversity of disasters

Tunnel fire and its laws due to transport, vehicle cargo, tunnel type and fire when the traffic conditions and other factors and complex and variable. From the tunnel fire statistics at home and abroad, tunnel fires in the A class of fires occur more frequently, the B class of fires, mixed goods fires caused by the frequency of serious tunnel fires［3].

(B) The mobility of the fire point

Tunnel fire, drivers and passengers due to visual limitations and special visual sensors, can not make a rapid response to the fire, fire vehicles will continue to run normally in the tunnel［4,5], even if drivers and passengers found the fire, in order to facilitate the alarm, disposal of road tunnels in the motor vehicle will

usually run to the emergency stopping zone to stop, the train will try to keep the traction | power to drive away from the tunnel to reach the open space after the disposal. The mobility of transport, the decision of the tunnel fire point will be running with the vehicle to change the location of the fire［6].

(C) The burning form of diversity

Tunnel fire combustibles are mainly transport vehicles and their on-board cargo to provide, there may be gas-phase, liquid-phase, solid-phase combustibles combustion, combustible gases, vapours, premixed concentration reaches the explosion limit, there will be an explosion, which is the performance of the tunnel fire combustion form of diversification. The shorter the tunnel, the larger the cross-section size, the closer the fire to the ground building fires; the longer the tunnel, the fire is more similar to the underground building fires［7]. In the absence of forced ventilation, the duration of fuel-controlled combustion is shorter, the entire combustion process is mainly controlled by the ventilation conditions of the combustion, combustion products - carbon oxides in the generation of more, belonging to the typical anoxic combustion［8,9].

(D) Fire spread jumping

Tunnel fire expansion and spread by ventilation conditions, traffic conditions and other factors, forced ventilation can improve the combustion conditions in the tunnel, traffic congestion for the tunnel fire provides more types, the number of combustible materials. The type, quantity and distribution of combustibles in the tunnel depend on the traffic vehicles and their cargoes involved in the disaster［10]. Traffic accidents, train upheaval or vehicles parked in the tunnel, the heat of the fire is mainly transmitted by thermal radiation and thermal convection, when the heat is enough to ignite the neighbouring vehicle or vehicle combustible goods, even if there is a distance between the vehicles, the fire is still able to jump spread［11]. In addition, tanker trucks or other flammable goods transport vehicle fire, explosion may occur, the extreme form of tunnel fire jump spread［12].

(E) The severity of the hazard

Tunnel fire combustibles are diverse, such as hazardous chemicals, flammable and explosive substances and other types of combustibles, these will produce a large number of toxic and harmful gases, including smoke is extremely serious, which has a high temperature and toxicity, in the ventilated tunnel smoke spreads very fast, in the tunnel is extremely difficult for people to escape, most of them die in the high temperature smoke asphyxiation, and rescue personnel are also affected by the severe Impact［13,14].

3. Flame Spreading Characteristics

Hazardous materials vehicle fires in tunnel fires are often the most serious fires, and because most hazardous materials tend to be in liquid form, hazardous materials fires generally result in the formation of streaming fires. In addition, the combustion of some of the hazardous chemicals will produce toxic gases, if the personnel in the fire for the characteristics of the hazardous chemicals do not understand, the toxicity will also become an important factor in the injury of personnel. American Hughes Company made experiments in 1990 and got the following empirical results. If the ambient temperature is below Tgo, the spread on the surface of the liquid remains in the liquid phase and is usually slow. If the ambient temperature reaches Tgm, the spread of the liquid surface is purely gas-phase, this time the spread speed can reach 1.6 metres per second or greater, usually people are not able to run through this spread speed (which should also be added to the speed of the liquid flow, which is a kind of gravity flow, can also reach a speed of 1 metre per second). From the experimental data can be seen that the hazards of flowing fire lies in the fast spreading speed, especially in the tunnel in this relatively closed environment, the heat is not easy to dissipate, the ambient temperature is more likely to reach the temperature of the vaporisation of the liquid［15].

In addition, the flame spread characteristics of the tunnel hazardous chemical fire can be referred to the mountain fire model, the fastest downwind spread, the strongest fire, and the extension of the part of the head of the fire; against the wind to spread slowly, the fire intensity of the smallest, and the head of the opposite direction of the fire for the fire part of the tail; between the head of the fire and the tail of the fire between the part of the fire for the fire wing. If the wind direction of the tunnel is in the same direction as the flame spreading direction, the flame spreading speed will be accelerated sharply. People escaping in the direction of

the wind will put themselves in a more dangerous situation. Especially in tunnels with a certain gradient, if the wind direction is downhill, vehicles in the downwind direction are very likely to be caught in the fire ［16,17].

Comprehensively speaking, the main characteristics of hazardous chemical fires are: 1) sufficient combustible materials, high fire temperature; 2) easy to form a stream of fire; 3) by the tunnel gradient and the wind direction of the combined effect; 4) the general presence of toxic gas hazards ［17].

For tunnel fires, if there are no dangerous goods vehicles, the fire hazard will be relatively lower, but still cannot be ignored. For general vehicle fire, due to different time period tunnel vehicle number is not the same, the severity of the fire is not the same. For example, 4.8 Gansu tunnel fire occurred in the morning at 3 o'clock, at this time the tunnel vehicle less, using the accident hazard is smaller, but still caused casualties. General vehicle fire in the vehicle intensive time period flame spread is mainly caused by heat radiation and heat conduction [16]. In this case, due to the presence of a large amount of combustible material in the vehicle itself and the gasoline in the vehicle is the main combustible material, the flame will spread rapidly between vehicles. If it is not detected in time or if other vehicles are not prevented from entering the tunnel where the incident occurred in time, further spreading of the fire can result ［19. In special circumstances, the vehicle fuel tank explosion will cause the flame to jump spread, if a continuous explosion, then the fire will spread to a horrible degree [20]. In the case of fewer vehicles, the flame spread is limited by the condition of the combustible material, and generally will not expand to a more serious range. However, for the fixed facilities inside the tunnel, a general vehicle fire can also cause damage to the road surface, lighting and other systems inside the tunnel ［21]. In general vehicles, there is a special vehicle: large buses. Large buses generally have more people on board, people carrying luggage, as well as clothing worn on the body will become combustible.

4. Fire Control

Tunnel fires are characterised by the severity of the incident and the rapid spread of the incident, so in response to these characteristics, if the fire can be kept small, the fire damage can be minimised. The key to controlling fires is to be able to detect them in time and take measures. Due to factors such as vehicle exhaust from vehicles in tunnels, only by choosing the appropriate detection method can a fire be detected in a timely and accurate manner. The main methods for detecting fire in tunnels are as follows: 1) linear fibre optic temperature sensing detectors; 2) video-based fire detectors; and 3) LiDAR fusion image-based fire detectors. At this stage of the technical environment, the application of the Internet large database for detection and analysis, through the intelligent fire control centre real-time monitoring of detection ［22~24].

Of course, apart from fire detection, fire control is the fundamental means of preventing the further spread of fire. If a fire is detected but no measures are taken, then even the most advanced means of fire detection will not be of the slightest use. For example: Japan's Tokyo Metro fire accident, the conductor has been found in the train a smoking place, but think it is not very dangerous, just a simple treatment, the train is still running at high speed, which ultimately led to the further spread of the fire expanded, so that the train complete fire automatic fire extinguishing system is paralysed, resulting in major casualties. For tunnel fire control, can be divided into the following aspects: 1) For hazardous materials vehicle fire: first of all, we must evacuate people in a timely manner, especially in the vehicle-intensive sections. Secondly, to determine whether there is an explosion risk, for vehicles with explosion risk, to clean up the surrounding combustible material in a timely manner in order to prevent the explosion caused by the spread of jumping fire ［25]. Finally, for the fire can not be extinguished in the early stage of the fire should be as far as possible to minimise the fire hazard ［26]. 2) For general vehicle fires: the most important thing is to ensure the safety of the personnel, in the vehicle-intensive road, to ensure that the fire will not further spread to other vehicles. 3) Regardless of the type of fire, in the discovery of the fire at the first time to ensure that the tunnel of the tunnel is open, and to ensure that the tunnel is no longer entering the tunnel of the new vehicle to the tunnel fire ［27,28]. (4) In general, only a good emergency plan can ensure that the emergency measures can cope with all kinds of emergencies. In addition, the implementation of the emergency plan is the most important. Can not let the emergency measures become a piece of paper ［29,30].

5. Conclusion

This paper takes the 4.8 Gansu high-speed tunnel fire accident as an example, combining the professional knowledge of combustion science and underground engineering fire protection. In view of the flame spread of the tunnel accident, analyse the characteristics of the tunnel flame spread rapidly, the situation is complex, and the reasons for these characteristics, targeted at the proposed tunnel fire response method, to provide a basis for the prevention and rescue of tunnel fires.

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