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Discussion on Tunnel Fire Test Research

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ABSTRACT: With rapid development of tunnel construction in China, tunnel disaster prevention, especially fire protection, becomes more and more important. In this paper, research on tunnel fire test is briefly discussed, including comparison between the state of research in China and other countries, test research aim, test environment and facility, definition of simulating fire source as well as test results. It points out the limitation on tunnel fire test in China. Meanwhile, in order to improve the level of tunnel fire protection, the suggestion for constructing comprehensive disaster prevention test center of tunnel in China is also given out.

1 INTRODUCTION

Road and city tunnels have been rapidly built in recent ten years, which is the challenge to tunnel disaster prevention and safe operation. R&D of tunnel fire test has important practical significance through the analysis of tunnel fires, for example, Mont Blanc tunnel and Frejus tunnel and so on.

Characteristics of road tunnel fire are closely related to tunnel parameters, including the ratio of length to width, narrow space and poor ventilation. Tunnel fire is mainly involved in class A fire and class B fire. Traffic density and velocity are higher. The possibility is high, which goods and vehicles are ignited by oil fire because of crash or leakage. Tunnel fire is easily spread, and high temperature and smoke are dangerous to survive. It is very difficult for emergency evacuation and fire protection. In total, tunnel fires bring significant casualties, property loss and structure destroy.

According to actual fire size, HRR (heat release rate, the rate at which heat energy is generated by burning. The heat release rate is ordinarily expressed as megawatts (MW)) is higher than fire size expectant. Structure destroy and casualties are brought by heavy goods fire, which do not traditionally belong to dangerous goods. For example, margarine and flour of Mont Blanc tunnel fire, paint of St.Gothard tunnel fire, tyres of Frejus tunnel fire.

In a number of catastrophic tunnel fire incidents, the fires have often spread between vehicles over large distances, occasionally hundreds of meters. In the St. Gotthard fire incident, the nearest HGV to the initial fire, which involved two crashed HGVs (Heavy Goods Vehicle), was stopped 30 m north of the fire, yet the fire quickly spread across this distance. The fire then spread across a distance of 48m from this HGV to the next HGV stopped in the tunnel. From there it spread along the queue of vehicles stopped in the tunnel until the action of the fire brigade halted its progress at the seventh HGV[1].

2 RESEARCH DEVELOPMENT OF TUNNEL FIRE TEST

More and more research institutes and organizations pay attention to tunnel fire due to catastrophe. Many full-scale tunnel fire tests have been already done in other countries. Their research objects included the influence of heat and smoke spreading on emergency evacuation, influence of ventilation on HRR, fire spread and tenability conditions, influence of fire protection system on fire spread, smoke spread, gas temperature and cooling vehicles near fire, detection time and measuring precision of fire detector, visibility of evacuation, accuracy of CFD(Computational Fluid Dynamics), fire development in different situations and so on.

Considering tunnel test facilities, Chinese tunnel fire tests are mainly tested in scale model tunnel, and fire size is small. Test results, in scale model tunnel, are different from actual full-scale tunnel fire tests. Southwest Jiaotong University studied the disaster prevention and rescue of road tunnel in Qinlin Zhongnan Mountain. It built the scale modeltest tunnel, with two round cross-section tubes tunnel models which are 100m long. Transversal linear scale is 1:6 with 1% longitudinal slope. It pointed outprovided phases of fire development, tunnel fire prevention and rescue plan through the research on gas temperature in tunnel fire test[2]. Chongqing Communications Research & Design Institute did researched oin fire alarm system of tunnel, including thermo-sensitive alloy wire, fiber and dual channel flame photometric detector[3]. Especially, full-scale fire tests in the actual operating tunnel, Yangzong tunnel in Yunnan province, have been done many times recently.

Foreign test tunnels are mainly scrapped tunnel, operating tunnel and tunnel test center, for example, Runehamar tunnel in Norway, the second Benelux tunnel in Netherlands and test center of tunnel disaster prevention in Spain.

Fig.1 TST test center of disaster prevention

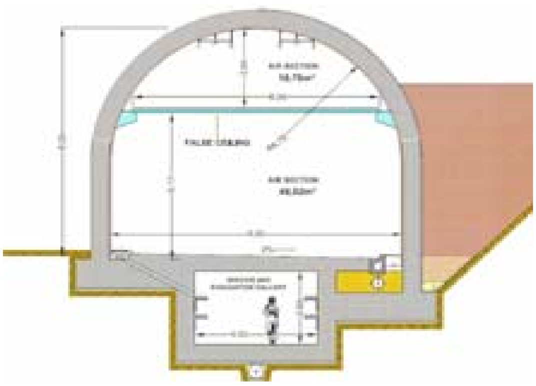

Fig.2 Cross-section of TST tunnel

Fig.3 TST fire test in tunnel

2.1 Test Center of Tunnel Disaster Prevention in Spain

The Test Center basically includes the following facilities: the ventilation and fire test tunnel, a high temperature fan testing station, auxiliary buildings and services. Many tests were done in the test center, which include testing of tunnel ventilation systems and equipment under realistic fire conditions, testing and validation of fire detection and extinguishing systems for tunnels, fire resistance tests for tunnel construction materials and functional equipment, and practical training for fire protection brigades and other emergency intervention teams.

The test tunnel was made of concrete, with dimensions equivalent to a two lane road tunnel. Test tunnel is 600m long, 9.50m wide and 8.12m high, with 400m minimum radius, 1%

longitudinal slope and 2% transverse slope. It has two ventilation stations and emergency gallery. Emergency gallery is 4m wide and 2.5m high, which has three emergency exits whose space is 150m. The tunnel ventilation has been designed with a maximum flexibility, including removable false ceiling in order that virtually any ventilation system can be tested: Longitudinal, Semitransversal, mixed systems and Saccardo. A series of tests about tunnel fire, ventilation and fire protection system were done in the test tunnel.

2.2 Runehamar Tunnel Fire Tests in Norway[5][6]

The tunnel is a two-way-asphalted road tunnel. It is 1600m long, 6m high and 9m wide, with a slope varying between 0.5% uphill and 1% downhill. The Norwegian Road Administration owns the tunnel. Tests of tunnel disaster prevention are carried every year.

Table 1 Data of fire test in Runehamar tunnel

Test	Description	Total mass	Total energy content	Mass ratio of plastic
		(kg)	(GJ)	(%)
1	Wood pallets and plastic (PE)	10160	247	18
2	Wood pallets and mattresses (PUR)	6390	135	18
3	Furniture and fixture+rubber tyres	8330	179	18(tyres not included)
4	Plastic cups (PS) in cardboard boxes on wood pallets	2850	62	19

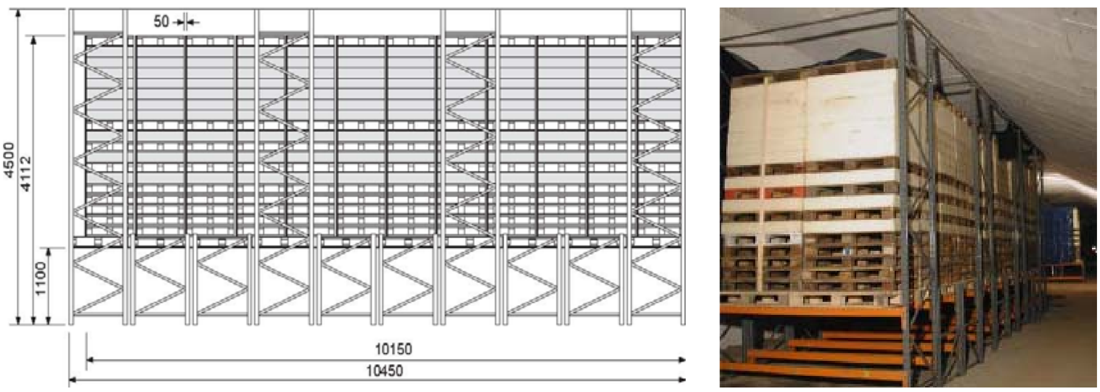

Fig.4 Test 2 fire source

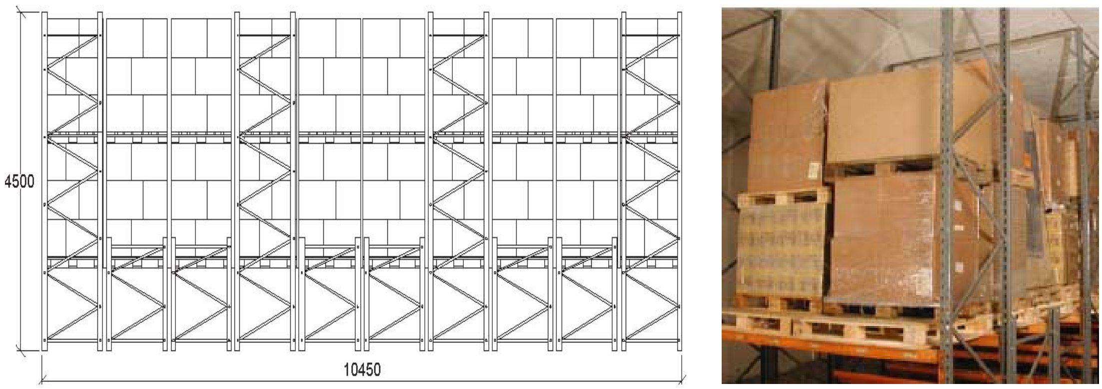

Fig.5 Test 4 fire source

Full-scale tunnel tests were done in the Runehamar tunnel in September 2003. research objects included fire development, peak HRR, fire spread rate, toxic smoke of different goods, fire spread between vehicles, possibility of fire protection and rescue, temperature in the ceiling of tunnel about heavy goods vehicle. Temperatures were measured at several positions along the tunnel, from 100m upstream of the fire to a measurement station 458m downstream of the fire. The majority of the temperatures were measured using unsheathed thermocouples, 0.25mm type K. Near the fire, sheathed thermocouples with a diameter of 1mm were used. Most of the gas temperatures were measured 0.3m below the tunnel ceiling. The HRR (heat release rate), gas velocity and composition, smoke, and radiation were also measured. Test data acquisition uses a wireless Radio-LAN network. Design fire is based on different variations or mixtures of material in actual vehicles. Further, the configuration of the commodity is based on Swedish statistics (see Table 1).

The results from the Runehamar tunnel tests show that not only oil tank vehicle but also non-hazardous, solid commodities, can give a very fast increase in temperatures, which are significantly higher temperatures than have been measured in connection with solid material in tunnel fire tests previously. The temperatures measured downstream of the fire were very high, and the measurements indicated that the flaming zone could expand up to a length of 70–100 m. The high temperatures affected the entire tunnel ceiling downstream of the fire, which caused considerable spalling of the unprotected tunnel ceiling after the first test, resulting in considerable rock debris completely covering the road.

Fire test of PVC membrane and diesel pool were done in Runehamar tunnel, 2005. The highest gas temperature is 1100℃. Fire prevent test, 20m complete lining PE foam protected with 80mm sprayed concrete with PP-fibre, was done through diesel pool fire. The peak HRR is 50MW, and the highest gas temperature is approximately 1250℃[7].

2.3 The Second Benelux Tunnel Fire Test in Netherlands[8]

The tests were carried out in a recently built traffic tube of the Second Benelux tunnel. The tunnel consists of six tubes in total: three tubes for road traffic, one tube for slow traffic and two tubes for a metro. The objectives of the fire tests focused on the following issues: the influence of longitudinal ventilation on the development of the fire, smoke front velocities and stratification, critical velocity, the influence of ventilation on the HRR and the tenability conditions in tunnel, the influence of open deluge sprinkler on the fire protection, the spread of smoke and steam, the influence of delayed activation of the sprinkler system and so on.

The test tunnel has two traffic lanes, which is 840m long, 9.8m wide and 5.1m high. The tunnel has a maximum slope of 4.4%, with the lowest point of the tunnel located in the middle of the tunnel. The test site was located at 265m from the downstream portal, which is rectangular cross-section. The tunnel ceiling and part of the walls were sprayed with insulation in order to enhance the fire resistance of the tunnel structure. In preparation for the tests, the walls, ceiling and floor of the tunnel were covered with additional fire protection cladding over lengths of 35m upstream and 35m downstream of the fire. The area in which the measurements were performed ranged from 50m upstream to 200m downstream of the fire. The radiation heat flux sensors were located at eye-level at distances of approximately 5m, 10m and 20m from the fire centre. The smoke layer radiation was measured at 10m downstream from the fire. Smoke/air temperatures were measured at five different heights in the middle of the tunnel with thermocouple trees located at upstream distances of 10m, 20m and 50m and downstream distances of 10m, 20m, 50m, 100m and 200m with respect to the fire centre. Type K-thermocouples were used with a diameter of 0.5mm. The surface temperatures of the tunnel walls, the ceiling were also measured. The passage of the smoke front was determined by measuring the attenuation of a laser beam crossing the tunnel transversely at 0.6m below the ceiling. The same type of laser equipment was used to measure smoke optical densities at a height of 1.5m in the middle of the tunnel. Ventilation velocities were measured at upstream and downstream of the fire. All of the tests were recorded on video using cameras.

Fire tests were performed by pool pan, car or truck model. This mixture of n-heptane and toluene was chosen as fuel in the pool pan. The mock-up of a small truck included 800kg of wooden pallets (36 wooden pallets, 4 piles with 9 pallets each), with four tyres placed on top and a tarpaulin. The length, width and height of the mock-up were 4.5m, 2.4m and 2.5m.

Due to radiation from the flames, lethal conditions of small truck fires can be expected within a distance of 10m. Without water sprinkler fire spread from a small truck might occur between an adjacent vehicle standing within a radius of 10m from the fire. At a downstream distance of 100m to 200m, for both the ventilated and non-ventilated tests, it is likely that escaping people will be engulfed by smoke within a few minutes and that visibility will be reduced to such a level that escape routes will become obscured.

Fig.6 Fire test in Benelux 2 tunnel

2.4 Yangzong Tunnel Fire Test in Yunnan Province[4][9]

Full-scale fire tests were carried out in Yangzong tunnel (one-way three lanes), Dafengyakou tunnel (one-way two lanes) and yuanjiang tunnel (one-way two lanes). Gasoline and diesel were chosen as fuel in the pool pan. The calculation of HRR was based on mass loss measurements. The peak HRR was 3.4MW. Temperatures were measured by thermocouples, which were positioned under the tunnel ceiling every 20m. Thermocouple trees were settled in the cross-section of 820m long. Ventilation velocity was measured by digital hot-wire anemometer. Smoke front and height was measured according to temperatures and eyes.

From analysis of test result, smoke stratification was obvious in the beginning of fire when jet fans didn't work, which was helpful to emergency evacuation.

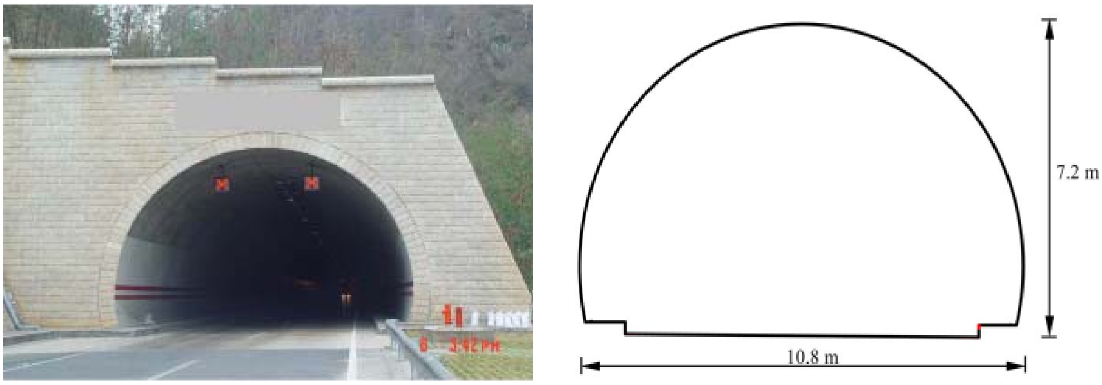

Fig.7 Cross-section of Yuanjiang 1 tunnel

3 CONCLUSIONS

According to analysis, plenty of research had been done in tunnel fire, we compare the Chinese situation with that of other countries about test numbers, test scale and test facilities. Foreign tunnel fire tests are mainly full-scale, and Chinese tests are still mainly scale model. And fire test is limited in operating tunnel because of tunnel structure and safety operation, and large scale fire test seldom carried. We also lack professional and comprehensive tunnel test center. In our tunnel fire tests, the peak HRR and the highest temperature are low, and the fire duration is short. Considering the rapid rate of fire spread in tunnel, we lack fire spread test data applied in our country in traffic jam. Material and form of fire model are single, and we might do tunnel fire test which is based on actual vehicles fire and data. In addition, we need improve the capability of measure equipment and integrating system. We need check and correct between tunnel fire test and CFD.

Table 2 Data of fire test in typical tunnel[4][10]

Tunnel	length	height	cross-section	HRR	temperature	type of fire
	(m)	(m)	(m^2)	(MW)	(℃)	
Norway Repparfjord tunnel EUREKA1990-92	2300	4.8-5.5	25-35	6-128	200-1100	Wood cribs, cars, metro car, rail cars,heptane, HGV
America Memorial tunnel 1993-95	853	4.4, 7.9	36、60	20-100	1360	Fuel oil (4.5-45 m^2)
Japan Shimiz3 tunnel 2001	1120	8.5	115			Petrol (1, 4, 9 m^2), cars, bus
Netherlands Benelux 2 tunnel 2002	872	5.1	50	4.5, 26	600	n-heptane+toluene, car, van, wood pallets(HGV mock-up)
Norway Runehamar,2003	1600	5-6	32-47	66-202	1250-1365	Cellulose,plastic, furniture
China Yangzong tunnel, yunnan	1030 2750 3280	7.2, 8.9		1.5-3.4	130	Gasoline, diesel pool

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