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Characteristics of Tunnel Explosion Accident and Its Emergency Disposal Process

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Abstract. In this paper, recent typical tunnel explosive accidents in China, such as Bamianshan tunnel explosion accident, No. 5 Futuyu tunnel explosion accident, Yanhou tunnel explosion accident, Qidaoliang tunnel explosion accident and so on, have been collected and reviewed. Particular attention has been paid to these direct and indirect causes of explosive accidents, accident tunnel structure, accident process and loss, and subsequent emergency disposal measures. Based on details and information about these accidents, characteristic of various types of explosive accidents, including non-large tunnel explosion accident and large tunnel explosion accident in tunnel has been analyzed and their basic reason has been proposed. It shows that the leakage of mashgas and improper loading of explosives during construction, inflammable and explosive chemicals and materials transportation, vehicle crash and tire spontaneous combustion during operation could cause of explosion accidents in tunnel, while the combination among these causes could finally lead to a series of explosions, large-scale burning, a large number of casualties and massive economic losses. And emergency disposal process for these explosive accidents has been also summarized here. All of these aim to provide reference for the prevention of explosive accidents in tunnel and the formulation of emergency disposal plans in future, which could finally improve the operational safety of the highway tunnel.

Keywords. Tunnel explosion accident, cause, characteristics, emergency disposal process

1. Introduction

Up to the end of 2020, China's highway tunnel has reached to 21999.3 km and the total mileage of the highway tunnel has increased by 30.2 times compared to that in 2001. And the amount and scale of tunnel accidents increase greatly with the rapid development of highway tunnel. Among these accidents, tunnel explosion accident could be recognized as the most harmful and seriously threaten people's lives and property safety, which has attracted more attentions from administrations and relevant researchers. At present, many explosion accidents in tunnel have been mainly caused by the leakage of mashgas and improper loading of explosives during construction, and chemicals transport mistakes during operation, which could lead to the huge economic

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loss, large scale casualties and even the serious destruction of tunnel construction. In this paper, direct and indirect causes, accident tunnel arrangement and emergency disposal measures have been collected and analyzed through reviewing these explosion accidents in recent years. This aims to avoiding the occurrence of the tunnel explosion accidents, making the emergency disposal plan, improving the fire and explosion safety of tunnels in future.

2. Tunnel Explosion Accidents at Home and Abroad

2.1. Bamianshan Tunnel Explosion Accident

Bamianshan tunnel explosion accident occurred at the tunnel under construction from HunanYanru Expressway without any fire protection facility. As shown in figure 1, the explosion accident was caused during unloading process of 288 kilograms explosives from agricultural vehicles. There were 24 people in tunnel during occurrence of explosion, and the explosion caused 20 deaths, one serious injury and one minor injury. Professional coal mine search and rescue team, fire department and public security department participated in the on-site rescue after the accident. In order to prevent the tunnel collapse during search and rescue, the safety experts about bridge structure were invited to command the rescue. A rescue vehicle and a truck were sent to the accidental tunnel by the fire department for performing the rescue. Search and rescue in combination with smoke exhaust and drainage work were carried out in the accidental tunnel after the warning line was set in the entrance. Because of poor air quality and low visibility in tunnel under construction, the search and rescue team used life detectors and other equipment to operate two searches and rescues. The direct cause of this accident was caused by an explosive explosion during unloading process, while its indirect cause is the ineffective safety management on transport vehicles for explosives and related people in tunnel under construction [1].

Figure 1. Bamianshan tunnel explosion accident from HunanYanru Expressway.

2.2. Large Mashgas Explosion Accident in Dongjiashan Tunnel

In figure 2, the accidental tunnel is the Dongjiashan tunnel under construction, without any fire protection facility, located at the Sichuan Duwen Expressway. The explosion accident was caused by abnormal mashgas emission when the collapse of the Tanzi side, in combination with poor ventilation to accumulate mashgas, and short circuit of three-core plug next to the power distribution box, which resulted in 44 civilian deaths, 11 injuries and direct property loss estimated at 20.35 million. After explosion, more

than 70 rescuers from coal mine search and rescue team of Guangneng group and Leshan City rushed to perform emergency rescue. The direct cause of the accident is the abnormal emission of mashgas. Mashgas contains methane (CH_4) as the main component, also including CO_2, N_2 and trace inert gas, which always accumulates at the top of the tunnel or around the changed section due to its light weight. And the accident could be indirectly attributed to insufficient safety management, such as poor ventilation management, gas inspector supervision, etc., and ignorance of danger from the abnormal mashgass emission in the design, which finally lead to lack of preventive and control measures for mashgas emission during construction [2,3].

Figure 2. Explosion accident in Dongjiashan tunnel from Sichuan Duwen Expressway.

2.3. No. 5 Futuyu Tunnel Explosion Accident

In figure 3, the accidental tunnel is No.5 Futuyu Tunnel, located at Zhangshi Expressway in Hebei Province. It is a double-arch two-lane one-way expressway tunnel with a length of 626 m, a width of 13.25 m, an internal longitudinal slope of-1.75 % downhill, and the design speed of 80 km/h. The explosion accident was caused by the overload of sodium chlorate by vehicle, friction between loaded cargo to generate heat, spontaneous combustion of rubber tire to ignite binding ropes, rags, sealing cloths, and then explosion of sodium chlorate, which resulted in 15 civilian deaths, 19 injuries and direct property loss estimated at 42 million. During the accident, the vehicle exploded with a huge fireball and dazzling white light and the resulting shock wave, high temperature and flame caused casualties and the damage of vehicles. Subsequent chain explosions occurred among fuel tanks, brake tanks, fire extinguishers and tires. The scattered sodium chlorate dust floated out of the tunnel. The vehicle still burned, the tank behind the vehicle disappeared, and several coal trucks were ignited after the explosion. And the accidental tunnel entrance burned black, and the guardrails of dozens of meters were damaged. The ground was covered by black soil slag with a pungent burning smell. Several houses about 100 meters away from the explosion were destroyed with the various degree, and coal blocks were scattered around. After the accident, the public security traffic police and transportation department immediately launched the emergency rescue plan, aggregated more than 300 people from the public security traffic police, fire protection, medical treatment, safety supervision, environmental protection, and arrange the related equipment for the emergency rescue. Fire department dispatched 4 fire trucks to the accidental tunnel, diverted and controlled the vehicles from Zhangjiakou and Shijiazhuang, opened the central guardrails of No.3 and No.4 tunnels, and commanded the rear vehicles to turn around, leave the accidental tunnel and dredge the road. In order to ensure the safety of transportation recovery in the accidental tunnel, experts were organized to examine the structural stability of the tunnel, mountain and geological environment and propose the repair plan. The direct cause of the accident was the explosion of sodium chlorate. Sodium chlorate is a strong oxidant, which is easy to be exploded, and its explosion

occurs when it is subjected to strong heat or in contact with strong acid. The indirect causes could be listed as follows: (i) transportation enterprises privately changed dangerous chemical transportation vehicles, illegally transported dangerous cargo by covering dangerous transportation warning signs, used tarpaulins without flame retardant treatment; (ii) dangerous cargo transportation monitor did not record according to the prescribed procedures [4, 5].

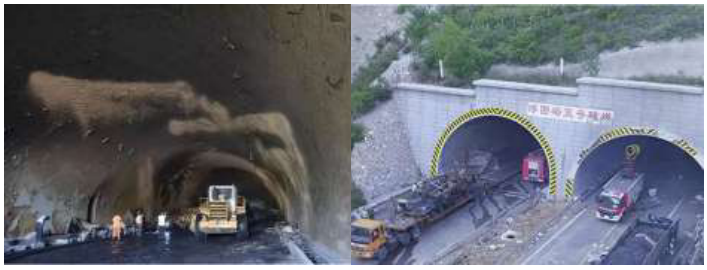

Figure 3. No. 5 Futuyu tunnel explosion accident.

2.4. Yanhou Tunnel Explosion Accident

As shown in figures 4 and 5, the accidental tunnel is Yanhou Tunnel of Jinji Expressway in Shanxi Province with tunnel length of 786.875 m, net width of 9.75 m, height limit of 5 m and the slope of 2.2 %. The accident occurred at about 40 m from the entrance of the tunnel in Jincheng section of Shanxi Province, which is due to the leakage of the front car caused by the rear-end collision of two dangerous chemical tankers loaded with methanol, in combination with the short circuit of the rear engine and the friction with the front car body produced sparks to ignite methanol, and then ignition of the remaining two dangerous chemical tankers (dimethyl ether, natural gas) and 31 coal tankers (1500 tons of coal). The explosion resulted in 40 civilian deaths, 12 injuries and direct property loss estimated at 81.9 million, and the fire was extinguished after burning for more than 73 hours. The spill fire induced by burning methanol ignited two semi-trailers in the accidental tunnel and quicky spread to five coal trucks, then develop the chain explosions. The explosion flame gushed out from the vent of the tunnel and a large amount of high temperature toxic gas quickly spread to the south entrance of the tunnel due to chimney effect. After the accident, the state administration of safety supervision, the ministry of public security, the ministry of transportation, the fire department and the local government participated in the rescue. The firefighters had to use the complete protective equipment and oxygen cylinders to enter the tunnel to extinguish the fire, but each operation time could not exceed 20 min, and the rescue was extremely difficult.

The direct cause of the accident is the leakage and combustion of methanol. Methanol as the volatile liquid could be classified to fire hazard class A. After leakage, methanol vapor could mix with air to form an explosive mixture, and then cause combustion and explosion in case of fire and high temperature. However, the management of the transportation enterprise is confused, and the driver and cargo attendant of the dangerous chemical transport vehicle are not operated according to the rules. The coal inspection station set up 3.8 km from the exit is not conducive to the rapid passage of vehicles in the tunnel. Meanwhile, there are some defects in the emergency disposal of the tunnel accident. For instance, forced separation of vehicles

after collision could generate sparks due to friction of metal body from vehicles, fire extinguishers equipped with the surrounding vehicles (such as dry powder, carbon dioxide fire extinguisher, sand) should be used to cover the leaked methanol before the arrival of professional firefighters. All of these could be recognized as the indirect cause of this explosion accident [6-9].

Figure 4. Internal arrangement of Yanhou tunnel

Figure 5. Yanhou tunnel explosion accident.

2.5. Vehicle Explosion Accident in Bapanshan Tunnel

In figure 6, the accident tunnel is Bapanshan Tunnel in Lvliang of Qingyin Expressway. The total length of the tunnel with three bends is about 4.1 km, and the height difference from east to west is 80 m. The accident occurred in the tunnel (Shaanxi direction) 1 km away from the exit, which resulted in 1 civilian death and trapped 49 vehicles and more than 80 civilians in the rear. The vehicle caught fire instantly after collision, and then the sudden explosion of the accidental vehicle's tires led to the second re-ignition during the period. The explosion accident was detected according to monitoring screen collected by the tunnel management station. After receiving the alarm, the emergency disposal plan was started immediately. The traffic police, the road administration, the fire department and other related departments participated in the rescue. During rescue, the tunnel entrance closed at the first time, and the rescuers decided to close the two-way tunnel and cut off the power supply in the tunnel. The emergency vehicle was used to assist the detained personnel to quickly withdraw from the accidental tunnel. Exhaust equipment was adopted to change the wind direction and deal with the heavy smoke caused by the explosion of the vehicle tire when the rescuers could not reach the accidental scene due to the heavy smoke in the tunnel. Then, on-site investigation and inventory confirmation operated after the removal of smoke in the accidental tunnel. The direct cause of the accident was the collision fire of the vehicles. During the period, the explosion of the vehicle tire near the accident site led to the second re-ignition, and the emergency disposal in this accident was successful. The tunnel was reopened 4 hours after the accident [10].

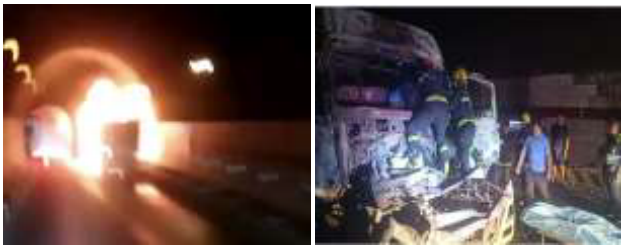

Figure 6. Vehicle explosion accident in Bapanshan tunnel.

2.6. Qidaoliang Tunnel Explosion Accident

Figure 7 shows that the accident tunnel is Qidaoliang Tunnel of Lanlin Expressway in Gansu Province, which is a double-line extra-long highway tunnel. The net width of the tunnel is 10.8 m, the net height is 7.1 m, the total length of the double-hole is about 8.1 km, and the design speed is 80 km/h. The accident occurred at 1500 m away from the entrance to Linxia due to the rear-end collision of two tanker cars and then combustion and explosion of 40 tons No. 190 solvent oil loaded, which resulted in 4 civilian deaths, 1 injury and property loss estimated at 1.0 billion, and serious damage in tunnel facilities. After the accident, a large amount of concrete from both sides and the top of the wall was blasted into fragments and scattered in the tunnel, facilities in the top and lighting system were deformed and destroyed, and damage length of tunnel structure reached up to 800 m. At the same time, the huge fire ball generated during combustion after explosion burned rapidly along the south exit of the tunnel, which has the distance of 700 m from the accidental tanker car. During rescue, the related management department immediately closed the highway and commanded 10 fire trucks to spray water for cooling the accidental tanker car and tunnel. The firefighters used emergency lighting facilities to operate in-site rescue, and remove the accidental tanker car after pumping all the solvent oil into other tanker cars, in order to prevent the re-explosion caused by the leakage of the accidental tanker car. The direct cause of the explosion accident was the combustion of No. 190 solvent oil, which could be classified to III type dangerous chemicals [11].

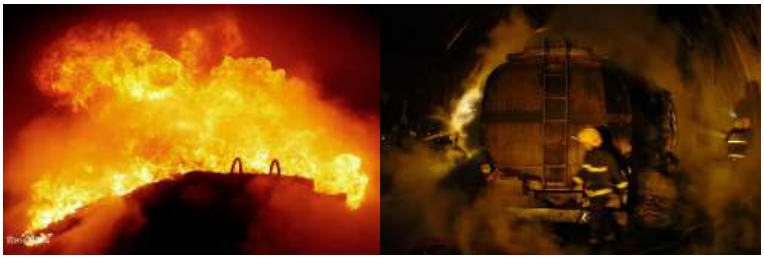

Figure 7. Qidaoliang tunnel explosion accident.

3. Emergency Disposal Process for Tunnel Explosion Accident

As mentioned above, tunnel explosion accident could be classified into explosion accident in tunnel under construction, non-large tunnel explosion accident and large tunnel explosion accident. According to related experience about settling these accidents, corresponding emergency disposal process and suggestion have been proposed as follows:

(i) Explosion accident in tunnel under construction has mainly been caused by use of explosives and leakage of mashgas during construction. Extra ventilation and smoke exhaust measure should be operated to improve the visibility and air quality due to its construction environment. Moreover, safety experts and professional coal mine rescue team could be invited to command and rescue, in order to prevent the tunnel collapse.

(ii) Non-large tunnel explosion accident is relatively common in comparison with other tunnel explosion accidents. After occurrence of the accident, the disposal process

could comply to the following procedure: closing the accident tunnel, cutting off the power supply, evacuating people and cars from the accident tunnel, searching and rescuing of firefighter, accessing the structural stability of the accident tunnel from experts. Meanwhile, some emergency measure, including suspension of searching and rescuing, operation of ventilation equipment, extra utilization of life detecting equipment, emergency lighting facilities and sprinkling tank car should be considered to take depending on fire and explosion circumstances on site.

(iii) Large tunnel explosion accident, such as Yanhou tunnel accident and Mont Blanc Tunnel Accident, always contains a series of explosions, large-scale burning and the release of the toxic and harmful smoke and gas, which could even result in the serious destruction of tunnel structure. During emergency disposal process of these accidents, firefighter should be equipped with the whole protective equipment and oxygen cylinders. However, it is still difficulty to operate the effective rescue and evacuation for the trapped vehicles and property. Therefore, it is necessary to strengthen the management and control of individuals, enterprises, management and monitoring departments, emergency rescue equipment configuration, etc., so as to eliminate the root causes of such vicious accidents.

4. Conclusion

Cause of explosion accidents in tunnel is various, which could be the leakage of mashgas and improper loading of explosives during construction, inflammable and explosive chemicals and materials transportation, vehicle crash and tire spontaneous combustion during operation. However, essential cause of these accidents could be attributed to ineffective implementation of relevant safety management regulations by constructors, operators and users.

There are usually more than two accident causes in the large tunnel explosion accident, such as overloaded chemicals transport, vehicle crash, tire spontaneous combustion, flammable particles friction, metal friction and ignition of vehicles loaded with hazardous goods, etc. The combination among these accident causes could finally lead to a series of explosions, large-scale burning, a large number of casualties and massive economic losses. Therefore, it is necessary to strengthen the supervision on transport vehicles, especially hazardous chemicals transport vehicles, conduct the safety and emergency disposal training for vehicle drivers and add the emergency disposal equipment in tunnels and hazardous chemicals vehicles.

Emergency disposal and rescue of explosion accidents in tunnel often involves multi-sectoral linkage. It includes local transportation department, public security department, fire department, various professional search and rescue teams and so on. Meanwhile, it also involves emergency response from other department based on the damage and casualties after accident.

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