Typhoon triggered operation tunnel debris flow disaster in coastal areas of SE China

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ABSTRACT

Typhoons have inflicted significant damage and loss of life to China, a large number of typhoon–rainstorm–debris flow–tunnel accidents occur in the southeastern coastal areas each year. Considering the disaster prevention and mitigation decision-making of disaster accidents in coastal areas and the reduction of regional economic losses, this Express Letter presents some typical accident scenes and rescue measures in recent years and analyses the hazard mechanism from three aspects. On this basis, we propose some suggestions such as the monitoring and early-warning system, which can provide a few references for reducing disaster losses and improving disaster treatments.

1. Introduction

Historically, the southeastern coastline of China is prone to suffer typhoon each year (Figure 1) (Zhang et al. 2011, 2018; Yap et al. 2015). Typhoons are often accompanied by strong winds, rainstorms and storm surges which have the characteristics of high frequency, sudden occurrence and wide range of influence and great intensity of disaster (Yin et al. 2013). In the vulnerable area of geological environment, the rainstorm caused by typhoons is easy to trigger geological disasters such as collapse, landslide and debris flow and bring about heavy casualties and property losses. A large area of mountainous region is located in the southeast coast, owing to the advantages tunnels have such as overcoming topography or elevation obstacles, improving the linear and shortening mileage that the demand is determined to build more mountain tunnels when building rail or highway projects in these areas (Vu et al. 2015; Luo et al. 2018; Qiu et al. 2018a,b). Typhoon disasters greatly increase the vulnerability of traffic facilities and the susceptibility of disaster chain in southeast coastal area (Li et al. 2014; Lai et al. 2016a; Yan et al. 2018a,b; Zhang, Wang, et al.)

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An increasing number of tunnels are constructed in disadvantageous environments (Lai et al. 2015, 2016b,c, 2018a,b; Luo et al. 2019; Li, Qi, et al. 2018; Qiu et al. 2018c,d), the typhoon–rainstorm–debris flow disasters constitute serious threats to mountain tunnels. The Express Letter briefly reports the tunnel debris flow accidents triggered by typhoons in southeast coastal area of China in current years and discusses the hazard mechanism of typhoon–rainstorm–debris flow–tunnel accidents (Li, Wang, et al. 2018; Li, Xu, et al. 2018c; Qiao et al. 2018a,b).

2. Operation tunnel debris flow disaster

2.1. Overview

In this paper, some typical tunnel debris flow accidents triggered by typhoons in southeast coastal area in last several years are presented (Figure 2). To review the previous tunnel debris flow disasters triggered by typhoon, the occurrence period of accidents is more concentrated in June to October, which is the high frequency season of typhoon. Concretely, four typical accidents occurred in Zhejiang province (Table 1), one typical accident occurred in Fujian province (Table 2), two typical accidents occurred in Guangdong province (Table 3).

2.2. Rescue measures

After the dangerous omen occurred, the tunnel management unit immediately identified the accident from the monitoring system or the highway patrol, then controlled
Table 1. Accidents occurred in Zhejiang province: Sources: http://news.66wz.com/system/2013/10/07/103828122.shtml and http://zjnews.zjol.com.cn/system/2013/10/07/019628229.shtml and http://china.huanqiu.com/hot/2015-07/6975523.html and http://www.703804.com/thread-15909526-1-1.html and http://bbs.703804.com/thread-15909155-1-1.html and recounted by authors.

| Date       | Tunnel                      | Disaster (Figure 3)                                                                 |
|------------|-----------------------------|-------------------------------------------------------------------------------------|
| 2013.10.7  | Sanduling (SDL) tunnel      | The debris flow occurred at the tunnel portal, the pavement was covered by the mudslide washed down from the Sanduling hill. The accumulation on the road was about two meters high, the seepage inside the tunnel was half a meter deep. |
| 2013.10.7  | Liangtouwu (LTW) tunnel     | Mud rock flowed down the mountain which was beside the tunnel, the depth of surface gathered water was 5–6 cm. The highway imports were forced to close and the traffic was blocked. |
| 2015.7.11  | Banlingtou (BLT) tunnel     | The entrance accumulated hundreds of debris, the water inside the tunnel was about 50 cm deep, a lot of mud piled up over the tunnel. |
| 2016.9.15  | Danzhuyang (DZY) tunnel     | Mud rock blocked the ends of the tunnel several people and dozens of cars were trapped in the tunnel, landslide volume reached more than 2000 m³. |

Table 2. Accidents occurred in Fujian province: Sources: http://www.sohu.com/a/149289635_691795 and recounted by authors.

| Date       | Tunnel                      | Disaster (Figure 4)                                                                 |
|------------|-----------------------------|-------------------------------------------------------------------------------------|
| 2017.6.14  | Xiaojiangkeng (XJK) tunnel  | Mud-rock flow occurred at the tunnel entrance, the whole road was covered with sand and gravel, the debris flow accumulation on the road reached 1650 m³. |

Table 3. Accidents occurred in Guangdong province: Sources: http://news.enorth.com.cn/system/2012/07/27/009717985.shtml and http://365jia.cn/news/2013-08-20/5E846E601FF265FE.html and recounted by authors.

| Date       | Tunnel                      | Disaster (Figure 5)                                                                 |
|------------|-----------------------------|-------------------------------------------------------------------------------------|
| 2012.7.25  | Jiamenshan (JMS) tunnel     | A mudslide occurred between the No. 1 JMS Tunnel and the No. 2 JMS Tunnel and plugged up the entrance of the tunnel. Large quantities of stones were washed to the road by water which resulted in traffic congestion. Landslide volume was about 2000 m³. |
| 2013.8.16  | Interval tunnel             | When the train was running during the tunnel between Lechang and Chenzhou, tunnel collapse accident occurred suddenly, mud rock flowed into the train, the train rocked violently, two men were buried in debris, two children were scratched by the window panes. |
information boards and traffic lights to close the tunnel. Tunnel maintenance supervision unit immediately started emergency plan: (1) Carry out traffic control in the tunnel section and divert traffic; (2) Organize rescue personnel and emergency machinery to the accident site at once; (3) Set up on-site command and carry out on-site emergency command right away. After the barrier had been set up, rescue personnel transferred personnel and vehicles to a refuge urgently and sent injured personnel to on-site medical staff or nearby hospitals. Subsequently, the machinery and equipment were organized to rush to repair roads. To resume traffic as soon as

**Figure 3.** Disaster scenes in Zhejiang province: SDL tunnel (a, b); LTW tunnel (c, d); BLT tunnel (e); DZY tunnel (f). Sources: [http://news.66wz.com/system/2013/10/07/103828122.shtml](http://news.66wz.com/system/2013/10/07/103828122.shtml) and [http://zjnews.zjol.com.cn/system/2013/10/07/019628229.shtml](http://zjnews.zjol.com.cn/system/2013/10/07/019628229.shtml) and [http://nb.ifeng.com/app/nb/detail_2015_07/12/4099629_0.shtml](http://nb.ifeng.com/app/nb/detail_2015_07/12/4099629_0.shtml) and [http://www.703804.com/thread-15909243-1-1.html](http://www.703804.com/thread-15909243-1-1.html).
possible, large engineering vehicles and excavating machinery were invoked to clear the gravel, mud and water of accident section (Figure 6).

3. Hazard mechanism

The necessary conditions leading to debris flow include topographic conditions, material reserves and excitation conditions. The geological structure and topography have provided favourable conditions for the development of debris flow in Southeast China,
such as a large amount of clastic loose sediments, and the place for debris flow forma-
tion, movement and accumulation. Rainstorm is the source and component of debris 
flow, and it is also the excitation condition and main driving force of most debris flow 
in Southeast China. Because of rainfall penetration, the soil on the hillside slope became 
unstable. Then debris flow is formed by mixture of the loose solid substances sliding 
down from the hillside slope and the water (Chen et al. 2013; Hungr et al. 2014).

3.1. Hazard factor

Typhoon and rainfall are considered to be hazard factors. The change of typhoon 
landing place and the impact area of disaster are closely related to moving path

Figure 6. Rescue scenes: Rescuer cleaned up debris flows in BLT tunnel (a, b); Rescue site in DZY 
tunnel (c, d); Excavators shoveled mud-rock in JMS tunnel (e, f). Sources: http://nb.ifeng.com/app/
 nb/detail_2015_07/12/4099629_0.shtml and http://news.k618.cn/society/201609/t20160917_
8970135.html and http://news.sohu.com/20120726/n349075089.shtml.
These typhoons which have caused disasters are all landfall typhoons, frequency of landfall location is shown in Figure 7. Except Severe Tropical Storm Merbok that generated in South China Sea, other typhoons formed in the Northwest Pacific, the statistics of path type are shown in Figure 8, typhoons of northwest path account for more than half, which need to be highly valued. Besides typhoon hazard factor, the critical rainfall that triggers debris flow can be determined by effective antecedent rainfall ($R_c$) and current day rainfall when debris flow occurred ($R_d$). The formula for effective rainfall is shown as follow:

$$R_c = \sum_{i=1}^{n} \alpha^n R_n, \quad (0 < \alpha < 1)$$  \hspace{1cm} (1)

In the formula, $R_c$ is the effective antecedent rainfall, $R_n$ is the rainfall at $n$ days before the occurrence of debris flow, $\alpha$ is the attenuation coefficient that can be considered as 0.7 during typhoon period. The relationship between $R_c$ and $R_d$ is shown in Figure 9 (Feng et al. 2013). Samples of debris flow in the southeast coast of China are collected, $F_1$ and $F_2$ are threshold lines of rainfall. There is no debris flow in area 1, the possibility of debris flow increases in area 2 and lots of debris flow disasters occurred in area 3. If a single parameter of the critical rainfall is considered, the day rainfall when debris flow occurred can be counted as critical rainfall (Figure 10).
When the amount of precipitation is over 200 mm, the risk of disaster is extremely large. The critical rainfall can be based on 100 mm, when the amount of precipitation is over 100 mm, relevant departments need to release early-warning and prediction.

3.2. Hazard-formation environment

The southeast coast of China is adjacent to the Western Pacific, tropical cyclones occur frequently, and with the significant impact of subtropical monsoon climate, heavy rainfall and storm surge will occur frequently. The mountains and hills are widely distributed especially in Zhejiang, Fujian, Guangdong and other coastal provinces and the geological conditions are complex with lots of clastic loose sediments. When typhoons land, then climb or round hills, the mountain has induced and forced effects. With feedback effect of typhoon rainstorm, low pressure is beneficial to form and develop, the mountain will strengthen the intensity of typhoon rainstorm. In the hilly areas of the southeast coast, the disaster chain of typhoon–rainstorm–debris flow is prone to be triggered.

Recently, the rapid expansion of urban land and industrial land results in a significant reduction in area of farmland and forest. Urban and engineering construction has gradually extended from plain to mountain area, especially in last several years, large-scale traffic construction, mine exploitation and other mountain engineering construction destroy the stability of mountain and slope, thus the potential risk of geological disasters is increased (Lai et al. 2017; Qiu et al. 2017; Wang et al. 2018a,b). A large number of railway lines and mountain highway cross through the hilly areas, many tunnels have been constructed, which make the soil of fault fracture zone and the mountain with steep slope become more unstable (Lai et al. 2016d; Wang, Wang, et al. 2018; Wang, Song, et al. 2018; Zhang, Li, et al. 2018). Thus, landslides and

Figure 9. Relationship between effective antecedent rainfall ($R_c$) and the current day rainfall when debris flow occurred ($R_d$) in typhoon–debris flow disaster chain. Sources: re-drawn by authors (Feng et al. 2013).
3.3. Hazard bearing body

With the rapid development of transportation, infrastructure construction is getting faster, at the same time, the destruction of mountainous areas caused by traffic construction leads to tunnels in the hill areas most at risk (Chen et al. 2014; Wang et al. 2018e). To review the incident scene, tunnel debris flow will easily form the accumulation at the tunnel portal, and lead to water or mudflow rushing into tunnel. Seriously, people and traffic facilities will be washed away by the large mudflow at tunnel portal and traffic is prone to large jam. Disaster mechanism of typhoon disaster chain in coastal areas is shown in Figure 11.

4. Summary and perspective

Over the past several decades, the economic development has grown fast in the southeast coastal areas. When population and wealth are highly concentrated, a variety of natural disasters is frequently occurring. The period of high risk and profit has arrived (Liu et al. 2012, 2018a,b). Heavy rainfall caused by typhoons can easily induce mountain landslides, debris flow and other geological disasters in southeast coastal area (Hong et al. 2010; Nie et al. 2018; Ren et al. 2018a,b). In view of current situation, it is vital to investigate disaster prevention further.

(1) The study on the distribution law of debris flow in coastal areas of SE China should be improved. For tunnel debris flow hazard-prone areas, Air–Space–Ground Stereo monitoring network can be carried out (Figure 12). "Air" means applying oblique photography technology of low-altitude unmanned aerial vehicle (UAV). "Space" implies the application of GNSS satellite monitoring system that can
implement dynamic monitoring of all-day and all-weather in the area of geologic hazard. "Ground" means using 3D laser scanning and measuring robot to monitor depth displacement of soil. With the application of Air–Space–Ground 3D monitoring network, accurate and reliable dynamic monitoring data will be provided for the implementation of emergency investigation and treatment project in disaster areas, a security network with high degree of informatization, strong sensitivity of reaction, and timely early warning of geological disasters will be constructed, the smooth progress of the geological disaster treatment project is ensured effectively.

(2) After improvement of monitoring system, the perfect early-warning mechanism of debris flow disasters ought to be established (Figure 13). The study of the relationship between disasters and monitoring data such as rainfall or deformation should be strengthened and the rationality of forecasting methods and the timeliness of forecasting need to be advanced. Unified data acquisition platform needs to be established to analyse
the potential links between various data. Cloud platform should share and exchange information with various departments. After information has been summarized and processed, warning platform uniformly release to the masses through different ways.

(3) The land use structure can be adjusted reasonably. To evaluate the present situation of land use and the risk of geologic hazard. It is necessary to attach importance to ecological construction and human activities. The land use of urban construction and traffic construction should be controlled (Wang and Ling 2010; Wang et al. 2012; Zhou et al. 2017, 2019; Zheng et al. 2019a,b). Then, restoring vegetation in the area of debris flow in order to consolidate topsoil, reduce water loss and soil erosion.

(4) Comprehensive treatment of engineering measures and relocation can be carried out. Major engineering construction should avoid high risk areas of geologic hazard. Traffic engineering facilities that cannot be relocated could construct corresponding diversion, blocking, drainage and other projects.

(5) After disasters occur, all departments and related areas are supposed to establish advantageous cooperative linkage and information sharing mechanism, so as to ensure the efficient and orderly response.

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Disclosure statement

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