Risk map analysis of subway construction project in China*

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Abstract: There are many uncertainties in the implementation of subway construction project. This paper aims to identify the potential safety risk in each stage of shield subway construction project. Risk map method is introduced into this study in order to find out and analyze the relationship among those risks. The study results show that specific risks based on the characteristics of each project stage should be paid more attention in shield subway construction. In addition, a study case of Hangzhou subway construction site collapse accident in 2008 is introduced as a typical example. Project managers and risk managers can get the general idea of potential risks of subway construction project and improve the early warning and risk control management by using risk map method.

Key-Words: *Subway construction, shield tunneling project, risk recognition, risk map, unconventional emergency*

1. Introduction

With the efforts to expand domestic demand to further increase in China, subway construction has become an important force in stimulating domestic demand. It is predicted that the country will build a 1700 km of urban rail transit till 2015, with a total investment of more than 6000 billion RMB[1]. However, large-scale, high-speed development and construction will inevitably involve high risk. Most subways are built below the surface of built-up areas, in which the underground pipelines are closely, geological conditions are complex. In addition, the subway construction normally involves various specialized fields, large amount of investment and long construction period. Therefore, there are many unpredictable factors and risks in subway construction projects which should be paid much attention.

There are many uncertainties in the implementation of subway construction project, which has significant impact throughout every stage of the construction projects. Choi et al. (2004)[2] present a formalized procedure and associated tools to assess the risk in underground construction projects. Wang et al. (2009)[3] propose the frame of risk management in the construction of subway tunnel. The analysis tools in previous research can evaluate the risk and its level by expert experience and computer identification. However, they can not find the fundamental cause of subway construction risk.

Risk map method was firstly used in earthquake analysis by Lomnitz in 1969[4]. Later, research on malaria mortality by risk map analysis aims to find the root of the disease disaster and predict the spreading trend which could be important tools for planning efficient malaria control measures (Snow et al., 1999[5]; Hoek et al., 2003[6]; Rosenstiel et al., 2009[7]). Recently, risk map method is used more widely to research field. For example, Ogawa et al. (2007)[8] propose risk map system to improve the safety and comfort of the vehicle driving. Cecchetti et al. (2010)[9] analyze the global financial market risk by the risk map method. Therefore, based on the above research, risk map analysis in this paper refers to identify, evaluate and prioritize the risk and its causality which could significantly impact abilities to accomplish projects or business.

Comprehensive project risk recognition and forecast, and

*: Project No. 90924010 supported by NSFC
Received: 5 September 2011, Accepted: 9 October 2011
Available online: 11 October 2011

effective safety measures are two core aspects in order to ensure the smooth implementation of subway construction project. Therefore, the study in this paper for the first time introduces risk recognition analysis and risk map system into the implementation of subway construction project to identify critical risk factors and find out the causality of those risks which could reflect the risk root of subway construction.

2. Risk analysis in subway construction

2.1 Risk classification of subway construction by shield tunneling method

Shield tunneling method has been widely adopted as an advanced technology in mechanized subway construction, which has more advantage than open excavation and mining method in construction efficiency, labor saving, and construction safety. However, shield tunneling method could inevitably cause safety risk. As seen in Table 1, there are generally three stages in the shield tunneling process, i.e. construction of working well, shield driving, and passing in and out construction. Each stage has different safety risk with variety characteristics. It is noted that conventional emergency is represented by CE; sub-unconventional emergency is represented by SCE; unconventional emergency is represented by UCE.

2.2 Safety risk map of subway construction by shield tunneling method

Based on the construction stages and subway construction processes, safety risk can be identified, so as to the relationship among the risk events. Figure 1 shows the risk map of subway construction by shield tunneling method. The

Table 1 Safety risk in shielding subway construction

Stage	Basic process	Emergency	Event rarity	Time urgency	Consequence seriousness	Type
Construction of working well	Ground construction work	Formwork collapse	common	sub-urgent	serious	CE
		Electric fire	rare	urgent	sub-serious	SCE
		Scaffolding dumping	rare	urgent	serious	UCE
		Electric shock, burns	common	sub-urgent	sub-serious	CE
	Enclosure structure construction	Underground obstructions	common	ordinary	serious	CE
		Steel pile deflection, deformation, and snapping	common	sub-urgent	sub-serious	SCE
		Mixing drill pipe break	rare	ordinary	ordinary	UCE
		Reaming, shrinkage	common	ordinary	ordinary	CE
		Pile broke by mixed mud and sand	common	sub-urgent	sub-serious	SCE
	Dewatering of foundation pit	Water table can not go down	common	sub-urgent	sub-serious	CE
		Pipe mouth has no water	rare	ordinary	ordinary	UCE
		Retaining structural instability	common	urgent	serious	CE
		Tilting and cracking of surrounding buildings	common	ordinary	ordinary	CE
		Piping quicksand	common	urgent	sub-serious	SCE
	Excavation of foundation pit	Pit collapse	common	urgent	serious	UCE
		Pit leakage	common	ordinary	sub-serious	CE
		Button uplift	common	ordinary	sub-serious	SCE
		Water pouring and sand drifting	common	urgent	sub-serious	SCE
		Soil sliding	common	sub-urgent	sub-serious	CE
Shield driving	Shield machine driving	Head wear	rare	ordinary	ordinary	CE
		Large bearing fracture	rare	ordinary	ordinary	CE
		Shield tail sealing failure	rare	sub-urgent	sub-serious	UCE
		Tunnel face instability, water recharge	rare	sub-urgent	serious	SCE
		Surface collapse or upheaval	common	sub-urgent	sub-serious	SCE
		Axis un properly controlled	rare	urgent	serious	UCE
	Tube production, transporting, assembling	Tube producer injured	rare	urgent	serious	UCE
		Injured by tube heap collapsing	rare	urgent	serious	UCE
		Platform trailer derail and collide	rare	ordinary	ordinary	SCE
		Tube installing inaccurate	rare	urgent	serious	SCE
		Tube assembling breakage	common	ordinary	ordinary	CE

continue

Stage	Basic process	Emergency	Event rarity	Time urgency	Consequence seriousness	Type
Shield driving	Grouting system	Grouting machine malfunction	rare	sub-urgent	serious	UCE
		grouting line blocking	common	sub-urgent	serious	UCE
		Water leak in tube	rare	urgent	sub-serious	SCE
	Slurry treatment system	Line blocking	common	urgent	sub-serious	SCE
		Separation and sedimentation process failure	rare	sub-urgent	sub-serious	UCE
		Environmental pollution of trash	common	ordinary	ordinary	CE
		Underground water pollution	rare	sub-urgent	sub-serious	UCE
	Construction of electricity	Electric shock accident	common	urgent	serious	CE
		Sudden electricity failure	rare	ordinary	ordinary	UCE
	Connecting passage construction	Drilled hole deviating	common	urgent	sub-serious	UCE
		Frozen wall incomplete	rare	ordinary	ordinary	UCE
		Overlying soil settlement	common	ordinary	sub-serious	CE
		Tunnel and connecting passage destroying	common	sub-urgent	sub-serious	UCE
		Saline leak caused by Fractured frozen tube	rare	urgent	serious	UCE
		Water and sand leak, causing tube distortion and damage	rare	urgent	serious	UCE
Passing in and out construction	Shield assembling	Building settlement cracking	rare	sub-urgent	sub-serious	CE
		Shield type improper	rare	urgent	serious	UCE
		Shield machine damage	rare	ordinary	ordinary	UCE
		Shield machine underground assembling failure	rare	urgent	sub-serious	UCE
		Shield head elevation or kowtow	rare	ordinary	ordinary	SCE
	Shield passing out and in	Shield machine damage	rare	ordinary	ordinary	SCE
		Hole face leaking	common	urgent	sub-serious	SCE
		Pit collapsing by shield drilling out of hole	rare	urgent	serious	UCE
		Surface subsiding or upheaving	common	ordinary	ordinary	CE
	Shield U-turn	Shield damage	rare	sub-urgent	ordinary	SCE
		Casualty	rare	urgent	serious	CE
		Shield can not assemble	rare	sub-urgent	sub-serious	UCE

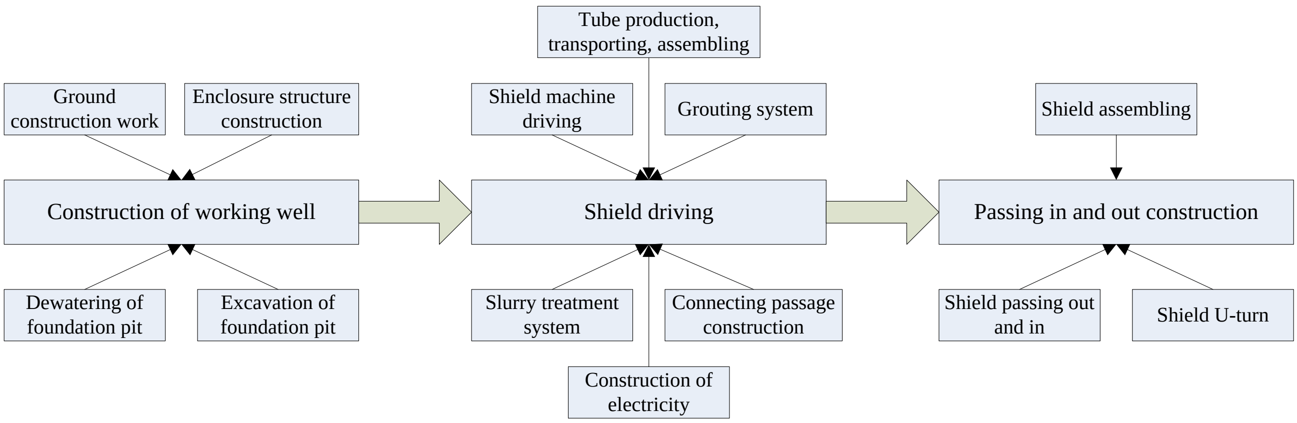

Figure 1 Risk map of subway construction process

emergencies which happen in the corresponding processes of subway construction are described by three core characteristics, including event rarity, time urgency, and consequence seriousness.

(1) Safety risk is based on the subway construction process. The first stage of subway construction project is construction of working well, in which the main task is foundation pit shaping. Therefore, the potential and major risks in the first stage can be caused by geological problem and improper pit construction. Similarly, the main risks in the second stage can result from the assembly and operation of shield machine, and improper pit construction. The main risks in the third stage can be caused by operation of shield machine. It can be seen from Table 1 and Figure 1 that leaders

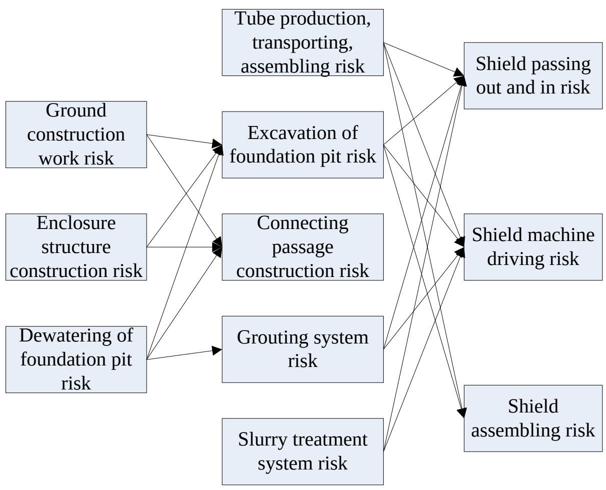

Figure 2 Risk causality of shield subway construction

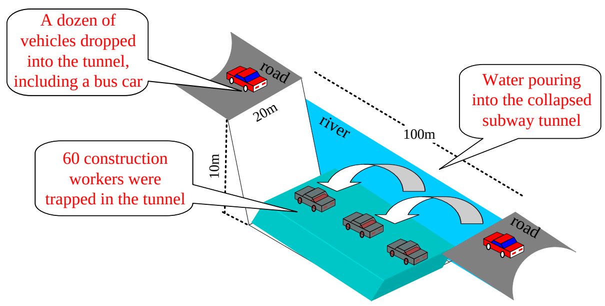

Figure 3 The scene of subway construction surface collapse accident in Hangzhou

and managers should pay more attention to specific risks of subway construction project in each stage based on the characteristics of certain scenario.

For instance, pit collapse is generally occurred in the processes of foundation pit excavation and usage. It is worthwhile to note that collapse is more likely to happen in the early and middle process of foundation pit excavation for the soil instability, while the probability of collapse will decrease for the foundation pit has been shaped. In addition, foundation pit collapse could be happened in the process of shield passing out and in. Therefore, shield passing out and in is another dangerous process to pit collapse.

(2) The causality relationship among the safety risks in shield subway construction shows the reason why certain risk happens. It is can be seen in Figure 2 that the risks in the first stage are the reasons to cause the risk consequences in the second stage. The risks in the second stage can also be the reason to cause the risk consequences in the third stage. The cause-effect relationship of safety risk based on the project process draws the risk map of the shield subway construction.

For instance, the corresponding risks, caused in the three working operations of ground construction, enclosure structure construction, and dewatering of foundation pit in the construction of working well process, will lead to safety emergencies in the current stage, which will be the cause reason of excavation of foundation pit risk, connecting passage construction risk, and grouting system risk in the next stage. The risk caused by the working operations of tube assembling, excavation of foundation pit, grouting system, and slurry treatment system, will lead to safety emergencies in the current stage, which will be the cause reason of the next project stage.

3. Case study — Hangzhou subway construction site collapse accident

The accident of subway construction site collapse, identified as unconventional emergency, was happened on the Fengqing highroad of Hangzhou city in China on 15th November 2008, which led to 4 people lost and 17 died. The accident caused the construction ground subsiding about 20 meters deep and 100 meters long, the foundation pit collapsing with damaged enclosure structure, and the nearby river water pouring into the accident site. The whole process of the subway construction accident is described in Figure 3 as follows.

3.1 Risk map analysis of case event

The subway construction site collapse accident is the biggest unconventional emergency in the subway construction history in China. The main causes of the accident are from two different aspects, i.e. natural factors and human factors. It can

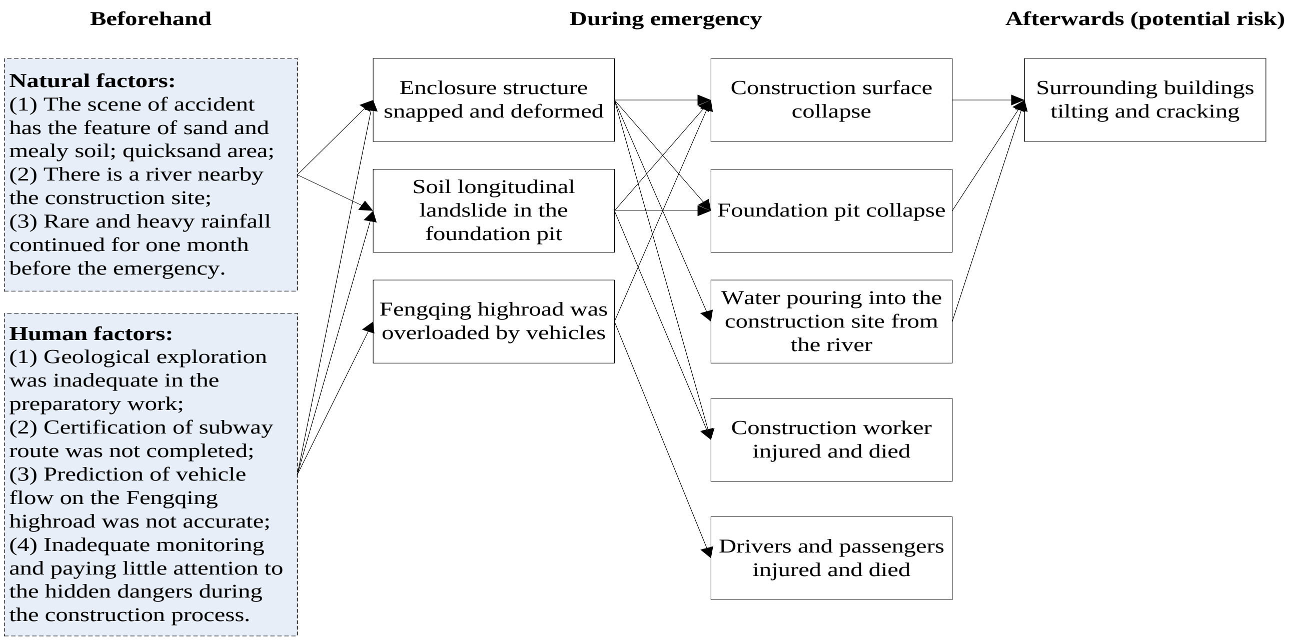

Figure 4 Risk map analysis of the case event

be seen in the Figure 4 that the nature and human factors are the root and crucial reasons to result in the subway construction accident. During the unconventional emergency, there are three events which lead to the final accident outbreak, i.e. enclosure structure snapping and deforming, soil longitudinal landslide in the foundation pit, and Fengqing highroad overloading. Figure 4 shows that human factors are more critical to the accident. It also shows that inadequate cognition to soil feature and inaccurate operation during the subway construction process are the key causes to result in the unconventional emergency.

3.1 Countermeasures

Based on the risk map analysis, the risk management of subway construction should be developed in three aspects as follows.

(1) Improving geological exploration in previous work

It is important to improve the geological exploration in the process of subway route certification. Based on the adequate investigation, leaders and managers should have comprehensive knowledge of soil feature along the subway route, which helps to delimit the dangerous area and choose the safe construction area.

(2) Developing whole process risk control

If previous work is incomplete and not careful, potential risks can happen during the subway construction. Therefore, monitor work has great contributions to the risk control. Potential risks should be paid attention and made further assessment to find out the risk factors and avoid the risks.

(3) Enhancing risk consciousness

Leaders and managers of the subway construction should enhance the risk consciousness. Scientific construction and management should be high valued in order to make high quality and safe project.

4. Discussions

(1) Management implication for risk recognition

Risk recognition is the first step of risk management, and the basis as well. Suitable and effective treatment methods can be actively chosen based on the correctly identifying the facing risk. There are several ways to identify the potential risk in certain activities, including flow chart method, risk experts enumerating, and decomposition analysis etc. This study analyzes the safety risk of shield subway construction by utilizing an integrated identification method with flow chart method and decomposition analysis, which can be seen in Table 1. The comprehensive method of risk recognition can deeply explore the undiscovered risk by detailed listing with order, which help risk managers to get more information about the potential risks.

(2) Management implication for risk prevention

Figure 2 also shows that risk consciousness should be set up in the initial stage to take precaution at beginning. Based on the risk map method to analyze the relationship among the safety risk of subway project, managers and risk managers can get the general idea of potential risks of subway construction project and improve the early warning and risk control management by using risk map method.

5. Conclusion

The paper analyzes the safety risk of shield subway construction project by introducing risk map method. The paper lists detailed potential risks in three stages of the whole project and discusses the relationship of those risks based on the three stage project processes. The study gives implication to risk recognition and risk management. In the future research, the study will continue the analysis of risk causality and make a deeper investigation on the response measures to the related risks and emergencies.

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