ISGSR2007 First International Symposium on Geotechnical Safety & Risk
Oct. 18~19, 2007 Shanghai
Tongji University, China

The Practice of Risk Identification and Assessment of Shield Tunnelling in Chengdu Metro

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ABSTRACT: It is the first time that Earth Pressure Balance machine is used to construct metro tunnel in Chengdu. The ground condition is full of water and the content of cobble is very high. The risk mechanism of this project is studied, and the main risks are found out. The main risks are assessed and classified employing the method of $P=R\times C$, then the risk classification is determined. These studies ensure the project advance successfully.

1 INTRODUCTION

Risk management is a course of identification, analysis, assessment and treatment for the risk. The study of risk management has achieved many outcomes since it is first introduced into tunnel engineering by Pro. Einstein H.H (MIT) in 1970s.

There exist various kinds of risks in the city underground projects due to the special location. Especially for the line one of Chengdu metro, it is the first time to construct metro tunnel employing EPB method in Chengdu. Saturation, coppers and boulders and high permeability are the main features of the strata. So, it's necessary to assess and evaluate the construction risk which can guarantee the project construction efficiently and safely.

2 PROJECT CONDITIONS

The lot 2 of period 1 of Chengdu Metro line 1 is from north Renmin road station to Tianfu square station. The tunnel is excavated by a shield TBM. The total length of this lot is 4729.31m. It's divided into three sections by Luomashi station and Wenwulu station. This tunnel has 8 plane curve with min radii 400m, and 14 vertical curve with max vertical ramp 27%. The burden depth of the tunnel is between 8.3m and 20m.

2.1 Geological condition

The whole tunnel is all in stratum of Quaternary. The upper are mainly Artificial Filling, under which are: clay, scree gravel inter bedded with silt sand; mid Pleistocene series' depositional and alluvial cobble of Quaternary inter layered with sand lens; and the underlaying bed with mudstone of Guankou Formation cretaceous. The strata's details are as below:

<2-8> Cobble soil: Yellow and grey, medium compacting, wet to saturated. The cobble content is between 70% and 85% and the size ranges between 30mm and 70mm, which are filled with silt sand and gravel. This layer's the burden depth is about 4.9-8.6m and the layer thickness is about 6.2-10.2m.

<3-7> Cobble soil: brown yellow, yellow, medium and close-grained, saturated. The content of cobble of this layer is about 60%-70%, and the size mainly about 30-70mm. The cobbles are filled

with sand and gravel whose content is about 10%-30%. This layer's burden depth is 14.8-15.1m, and the layer depth is 4.9-5.2m.

<4-4> Cobble soil: gray, deep gray, medium and close-grained, saturated. The content of cobble of this layer is about 75%-85%, and the size mainly about 30-60mm. The cobbles are filled with sand and gravel whose content is about 15%-30%. The fillings are argillaceous and light calcareous cement. This layer's burden depth is 21.9-23.7m, and the depth is 5.2-6.8m.

Pore water is filled in the three cobble layers. So the water content of the layers is very rich, which foam a whole water bearing layer with thickness of 18.2m-23.8m. This layer is highly permeable, and the permeability coefficient reaches 35m/d. The shield tunnel traverses the strata: <2-8>、<3-7> and <4-4>. Fig.1. shows the cobble mucks excavated from the starting pit. The grain composition of the strata is shown as Fig.2.

Fig.1 Cobbles exposed during pit excavation

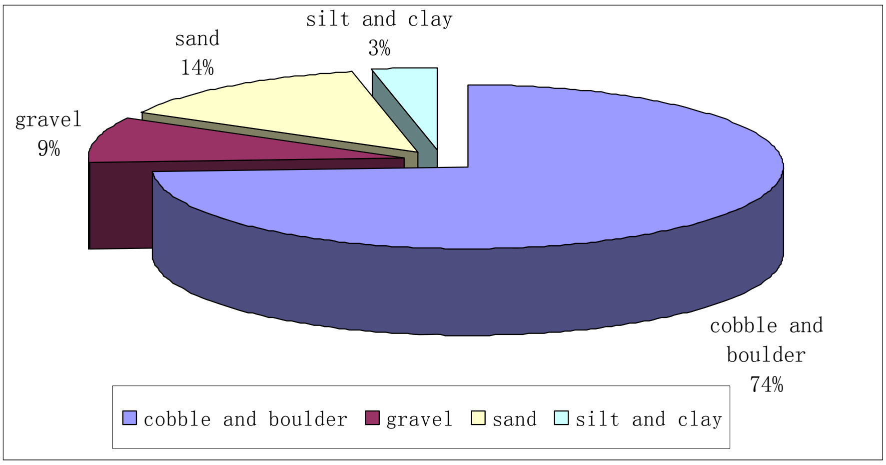

Fig.2 Proportion of the ground particle

(Cobble and boulder>20mm, gravel: 20-2mm, sand: 2-0.075, silt and clay<0.075)

2.2 Equipment condition

The first TBM (model type S-365) is supplied by Herrenknecht AG of German company. The TBM is a EPB(Earth Pressure Balance) machine. The main indexes of the TBM are shown as table1.

Table1 Main index of the EPB (S365)

Items	index
Machine type	mixed EPB
Excavation diameter（m）	6.28
Max. working pressure（bar）	3
Total power（kW）	App.1800
Rating torque（KN·m）	5980
Max. thrust（KN）	34210
Max. speed（mm/min）	80
Cutter head	disk cutter and scrape cutter
cutter head Opening ratio	26%

The cutter head is designed to mixed type which is not only installed disk cutter but also installed scrape cutter. The photo of the cutter head is shown as Fig.3.

Fig.3 Photo of cutters and cutter head

3 MAIN RISK ANALYSIS AND IDENTIFICATION

It's the fist case to construct metro tunnel employing EPB tunnelling method in the saturated and cobble strata in china. There are hardly any precedents in the word. So, the shield tunnelling construction in these strata will be a high-risk project.

In order to reduce this construction risk and make the project perform smoothly, systematic analysis of EPB tunnelling are made. The risks sources are found out, and managing risk according to risk mechanism, therewith ensure construction safely and successfully.

3.1 Identification method

Risk identification is probing the items which may evolve into accidents using systematic ways. The procedure is based on the ascertainment of the relationships between the project, environment and the features of elements and variables of this project.

Risk identification is the first and important step when analyzing a risk. Being ignored, it often hinders long-term and comprehensive consideration for problems. There are many factors which can result in risk when metro tunnel is being built. These factors can lead to vary effect. It is wrong to omit the primary factors; but it can also make the problems complication to consider every factor. So, the risk identification is to reduce this uncertainty. Here, the combination methods of static and dynamic analysis are used to identify the risk (shown in Fig.4.).

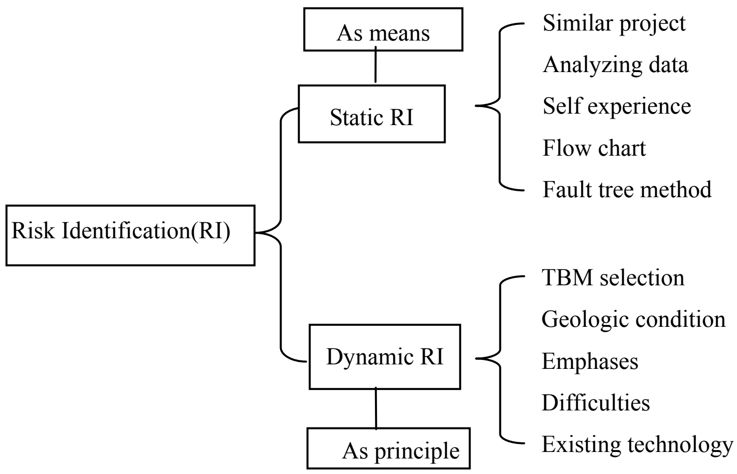

Fig.4 Method of risk identification

3.2 Risk environment

Risk environment is the fundamental factor which can determine the happening of an accident. It is also looked as the internal cause of risk. For this project, the environment is referred to the special geology and the surrounding environment. The first is the properties and difficulties of these strata: the content of cobbles and boulders is high, the permeability is big and water level is high. The second is that a large number of underground pipelines are dense and buildings are close to tunnel. The geological exploration shows that these strata have exceeded the limitation of EPB. That is to say it is not suitable for EPB tunnelling.

3.3 Risk factors

Risk factors are the direct reason of risk accident. Risk environment and risk factors constitute the two necessary elements. This project's risk factors include: the invalidation of cutter and cutter head, destabilization of excavating face, collapse in the crown due to over discharge of mucks, the unsuitable excavation parameters of TBM and mechanical and electronic malfunction.

3.4 Risk happening mechanism

The existing of risk environment combining with inducing of the risk factors could result in subsiding, damage of buildings, casualty of personnel and so on. Thereby, they can cause the loss of economy, time, society, and ecology. According to the risk identification, the main risks of this project are obtained. These risks include: excessive settlement(u1), damage of buildings(u2), spraying of screw(u3), breakage of pipeline(u4), cutter wheel squeezed(u5), deviation of axis(u6), large malfunction of TBM(u7), casualty of personnel(u8), damage of cutter head(u9), inactivation of sealing(u10) (shown in Fig.5.).

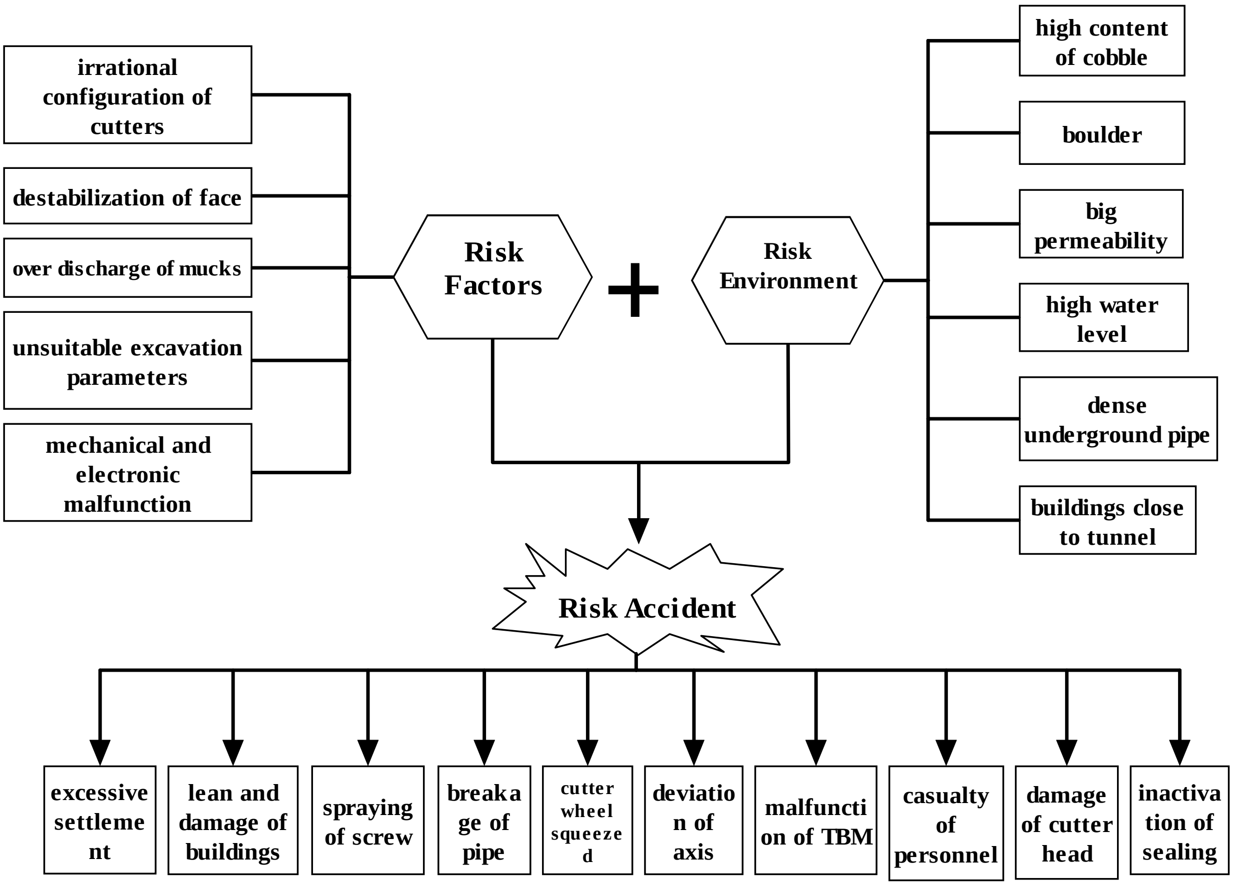

Fig.5 Risk mechanism of EPB tunneling in Chengdu strata

4 ASSESSMENT OF CONSTRUCTION RISK

The assessment method of R=P×C is considered with risk probability and consequence.

Hereon, P represents the risk probability. And C represents the consequence of risk accidents. R=P×C is a qualitative and quantitative method which is a popular way to analyze risk. The key steps are as below:

(1) Ascertainment of risk incident and probability;

(2) Consequence scoring;

(3) Risk assessment.

The construction risk probability is graded with five levels: A, B, C, D and E. Every level's probability is defined as table 2.

C represents risk consequence. In this project, the risk is graded with five levels: 1, 2, 3, 4 and 5 increasingly (as shown in table3).The description of risk levels is as table3.

The assessment results of the events shown in Table 2. and 3. are obtained by the method of expert inquiry and Analytic Hierarchy Process (AHP).

R represents risk which is also ranked with five levels: Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ. The criteria of risk rank are as table4.

Table 2 Grade of risk probability

Level No.	A	B	C	D	E
Probability range	$P<10^{-6}$	$10^{-6}<P<10^{-3}$	$10^{-3}<P<10^{-2}$	$10^{-2}<P<10^{-1}$	$P>10^{-1}$

Description	almost impossible	rare	sporadic	possible	frequently
Risk accident	u8, u10	u7, u6	u5, u9	u1, u2, u4	u3

Table 3 Classification for effect of the risk event

Risk consequence level	1	2	3	4	5
Scoring range	0~0.3	0.3~0.7	0.7~0.8	0.8~0.9	0.9~1
Description	slightly	medium	serious	grave	disaster
Risk accident	u6	u3, u5, u7	u10,u9	u4, u1	u2, u8

Table 4 Criteria of risk rank

Risk rank	I	II	III	IV	V
Description	negligible	can be accepted	medium, need attention considerable	mitigation measure is necessary	unacceptable

According to the P and C analysis, the assessment matrix (shown in table5) is obtained employing Delphi method (Shown in table5).

Table 5 Risk assessment matrix of $R=P\times C$ method

consequence / probability	1	2	3	4	5
A	1A	2A	3A	4A	5A
B	1B	2B	3B	4B	5B
C	1C	2C	3C	4C	5C
D	1D	2D	3D	4D	5D
E	1E	2E	3E	4E	5E

I: 1A, 1B, 1C; II: 1D, 1E, 2A, 2B, 3A, 4A; III: 2C, 2D, 3B, 3C, 4B; IV: 2E, 3D, 3E, 4C, 4D, 4E, 5A, 5B; V: 5C, 5D, 5E

According to the analysis and grading (as shown in table2, 3, 5), the probability and consequence of every risk event are integrated. Thereby, risk classifications of every risk event are obtained (shown in table6). The table7 is the summary of the risk assessment.

Table 6 Risk evaluation of every risk event

Risk event	evaluation	rank	Risk event	evaluation	rank
u1	4D	IV	u6	1B	I
u2	5D	V	u7	2B	II
u3	2E	IV	u8	5A	IV
u4	4D	IV	u9	3C	III
u5	2C	III	u10	3A	II

Risk event	evaluation	rank	Risk event	evaluation	rank
u1	4D	IV	u6	1B	I

Table 7 Summary of risk classification

Risk rank	I	II	III	IV	V
Risk event	u6	u7,u10	u9, u5	u1, u3, u4、u8	u2

From the risk classification we can conclude that: first, building damage (u2) is ranked V which is the most serious risk. Second, subside (u1), spraying of screw (u3), breakage of pipe (u4), casualty of personnel (u8) are the main risk for which Mitigation measures are necessary. Third, cutter wheel squeezed (u5) and damage of cutter head (u9) are the risk needs attention considerable. Forth, deviation of axis (u6), large malfunction of TBM (u7) and inactivation of sealing (u10) can be accepted or negligible.

5 CONCLUSIONS

The main risks are identified aiming at the special strata as for the first EPB shield tunneling in Chengdu. Then, the risk mechanism is studied. The main risks are evaluated and assessed. According to the assessing outcome, different measures can be taken on the risks, which make the project get on favorably.

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