Research on Monitoring-based Risk Management of Deep Excavation Engineering

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***Abstract*—According to the study on risk identification, risk estimation, risk assessment and risk control of monitoring-based deep excavation engineering, a set of feasible risk management system of deep excavation engineering is built up in this paper. The expert surveys method (including Delphi), fault tree analysis, checklist are used in identifying risk factors in deep excavation engineering. The risk estimation method of deep excavation engineering based on subjective estimation is proposed. This paper has established a monitoring-based risk assessment system on deep excavation engineering, including the standards of risk probability classification and risk loss level, the risk assessment matrix, the risk acceptance criteria and risk levels. The relationship between risk level and monitoring level is set up. The risk control method on risk tracking and risk early warning is put forward.**

Keywords- deep excavation engineering; risk management; monitoring; risk analysis; risk control

The overall size and total quantity of urban underground space in China have been leading in the world at present [1]. With rapid development of city construction in China, a large number of high-rise buildings and underground space development and utilization make deep excavation engineering substantial increased. Because the design theory and calculation method is still not perfect and there are many uncertainties in construction, deep excavation engineering is always in great risk. The construction accidents of deep excavation engineering in the densely urban areas not only affect its own security, but also bring disaster to the safety of surrounding buildings, roads and pipeline. It will cause significant economic losses and social impact. As a result, the research on risk of deep excavation engineering has become one of the issues to be settled urgently. We will established a feasible risk management system of deep excavation engineering through the study on risk identification, risk estimation, risk assessment and risk control based on monitoring.

I. RISK IDENTIFICATION OF DEEP EXCAVATION ENGINEERING BASED ON MONITORING

In most cases, risk is not clear. Risk has a hidden feature, at least not easy to predict. Because some people are easy to be confused by the interests of surface phenomena or small lure and could not see the inherent danger, the risk identification is particularly important.

1.1 risk identification process

Risk identification is the prerequisite of risk assessment and the basis for project risk management system. Risk identification process is a realistic investigation process on the source of all possible risk events and results, which need continuous and strictly classification and appropriate evaluation on its severity. This phase mainly focused on qualitative analysis of risk.

Risk identification process usually divided into following five steps [2].

(1) Determine the participants

Deep excavation engineering's participants include the construction side, designers, general contractors, subcontractors, monitoring side, supervisors, and representatives of other interested parties. Since excavation works will affect the surrounding environment, the participants should include representatives of surrounding environment such as buildings, roads, pipelines, heritage-related departments if necessary.

(2) Field investigation, relevant information collection and expert advice

Collecting engineering data and advising experienced experts should be made during risk identification to ensure that no missing risk factors. Experts should be senior professionals with knowledge of structural engineering, geotechnical engineering, engineering surveying, safety engineering, municipal engineering and communication engineering.

(3) Risk identification

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① The various risk factors within each stages, activities and surrounding environment were analyzed after systematically analyzing the basic data of deep excavation engineering.

② The preliminary risk detailed list of deep excavation engineering is established using risk investigation table. The objective and potential risks are clearly recognized, which is the starting point of risk identification.

③ The risk accident is defined. According to the risk factor in preliminary risk detailed list, each potential loss or impact associated with risk factor is analyzed to determine the causes of risk accident in deep excavation engineering.

(4) Risk screening

The secondary identification is carried on results of risk identification to delete irrelevant or minimal risk factors and accident, and determine whether the risk of missing points. The further recognition can determine whether there are missing risk points.

(5) Reporting the risk identification

1.2 risk identification methods

Identification of risk factors mainly involves two aspects: the risk classification and identification method.

(1) Risk classification of deep excavation engineering

Deep excavation engineering risk can be divided into design risk, construction risk and monitoring risk according to stage by leading risk. The accident of deep excavation engineering is characterized by deformation and force exceeded its permitted limits whether the accident was caused by the unsafe action of people or objects unsafe condition. From analysis of this aspect, we believe that risk classification based on risk occurred object can provide an overall understanding of risk. Accordingly the risk of deep excavation engineering can be classified as support structure risk, foundation interface risk and surrounding environment risk.

(2) Risk identification method of deep excavation engineering

There are many ways to identify risk. According to characteristics of monitoring-based risk management of deep excavation engineering, we choose expert investigation (including Delphi technique, brainstorming), fault tree analysis and checklist in risk factors identification of deep excavation engineering.

1.3 study on risk identification in monitoring-based risk management of deep excavation engineering

The technique routing of study on risk identification in monitoring-based risk management of deep excavation engineering is as follow: collecting and organizing the accidents occurred in deep excavation engineering in recent years; initially identifying risk factors of deep excavation engineering based on accident causes by using fault tree analysis; establishing a preliminary list of risks with brainstorming and engineering practice; taking secondary identification and screening on initial list by expert investigation; finally identifying risk factors of monitoring-based deep excavation engineering.

(1) establishing a preliminary list of risks by using fault tree analysis

Fault tree analysis method, also known as FAT, is a special logic tree diagram of cause and effect. One of the main tasks of FAT is to find all accident modes that led to system failure, in which the accident with maximum probability of occurrence is the system's weak part. To find such accidents can guide people to take measures on strengthening the weak parts, thereby improving system reliability [3].

We have made accident analysis of pile retaining wall, composite soil nailing wall and other commonly used support system in deep excavation engineering by using FAT. Figure 1 is the accident analysis of composite soil nailing wall in deep excavation engineering by using FAT.

The minimum set of basic events led to top event occurrence is calculated first in FAT analysis on probability calculation of top event, which is to find minimal cut sets of fault tree. Each minimal cut set corresponds to an accident pattern. A fault tree has several minimum cut set, but the occurrence probability of each minimum cut set is different. The minimum cut sets with the highest probability is the most likely risk source of accident.

Based on those analyses, we made a preliminary list of risks and risk checklist of deep excavation engineering.

(2)taking secondary identification and screening on preliminary list of risks by expert investigation, and determining the monitoring projects

We have solicited 103 expert advices on preliminary list of risks to determine that which risk factor takes the monitoring project in deep excavation engineering. Based on expert investigation results, we have got early warning value of deep excavation engineering after data processing and analysis [4]. We have recommended the monitoring projects with reference to the current national standards, some local standards and engineering practices. We have selected 20 well-known experts on Delphi method for advising repeatedly, and finally determined the instrument monitoring projects of deep excavation engineering shown in Table 1 [5] .

Table 1 Instrument monitoring projects of deep excavation engineering

Category	No	Instrument monitoring project
foundation pit and supporting structure	1	horizontal displacement at the top of retaining wall (slope)
	2	vertical displacement at the top of retaining wall (slope)
	3	deep horizontal displacement
	4	vertical displacement in column
	5	internal force of retaining wall
	6	internal force of bracing
	7	internal force of column
	8	internal force of anchor bar
	9	internal force of soil nail
	10	uplift (rebound) at bottom

	11	lateral earth pressure of retaining wall
	12	pore water pressure
surrounding environment	13	groundwater
	14	vertical displacement of soil in layers
	15	vertical displacement of surrounding ground surface
	16	vertical displacement of surrounding buildings
	17	tilt of surrounding buildings
	18	horizontal displacement of surrounding buildings
	19	cracks of surrounding buildings and ground surface
	20	deformation of surrounding pipelines

II. RISK ESTIMATION OF DEEP EXCAVATION ENGINEERING BASED ON MONITORING

Risk estimation of deep excavation engineering is the measurement of risk, and estimates the risk probability of occurrence and the consequence loss under certain conditions.

Risk estimation methods are both subjective and objective. As the complexity of deep excavation we often carry on the analysis after the limited data and then estimate the possible distribution, or synthesize the objective estimate through the massive subjective estimates.

The fault tree analysis shows the source event with greater occurrence probability is key risk event. Since the probability of basic events is difficult to determine and this probability is a function of time and environmental change, it is difficult to determine accurately which fail path model has the maximum probability of occurrence. According to different geological conditions, surrounding environment, supporting structure and calculating results, as well as the engineering analogy, the decision makers will determine the probability of accident occurrence and the possible losses suffered.

III. RISK ASSESSMENT OF DEEP EXCAVATION ENGINEERING BASED ON MONITORING

3.1 risk assessment methods

General process of risk assessment can be divided into three steps: (1) determining the risk assessment datum; (2) determining the appraisal risk level; (3) comparing the single risk with the single appraisal datum (the project overall risk with the whole appraisal datum) to see whether the project risk is in acceptable scope.

3.2 study on risk assessment in monitoring-based risk management of deep excavation engineering

(1) the grading standards of risk probability in deep excavation engineering

The grading standards of risk probability in deep excavation engineering can be divided into five levels, which are shown as Table 2.

(2) the grading standards of risk loss in deep excavation engineering

The accident loss includes economic loss, personnel casualty, time delay and environment destruction. The grading standards of risk loss can be divided into five levels, which are shown as Table 3.

(3) risk assessment matrix of deep excavation engineering

According to different risk probability level and the risk loss level, we could establish the risk assessment matrix, which is shown as Table 4.

Table 2 the grading standards of risk probability in deep excavation engineering

Probability range	Probability grading	Description of probability grading
>20%	5	Frequent
10%~20%	4	Possible
1.0%~10%	3	Incidental
0.1%~1.0%	2	Rare
<0.1%	1	Impossible

Table 3 the grading standards of risk loss in deep excavation engineering

Grading	5	4	3	2	1
Description of loss	catastrophic	very serious	serious	To be considered	negligible

Table 4 Risk assessment matrix of deep excavation engineering

Probability grading		Loss grading				
		5	4	3	2	1
		catastrophic	very serious	serious	To be considered	negligible
5	Frequent	Level 5	Level 5	Level 4	Level 3	Level 2
4	Possible	Level 5	Level 4	Level 4	Level 3	Level 2
3	Incidental	Level 5	Level 4	Level 3	Level 2	Level 1
2	Rare	Level 4	Level 3	Level 3	Level 2	Level 1
1	Impossible	Level 4	Level 3	Level 2	Level 2	Level 1

(4) risk acceptance criteria of deep excavation engineering [2]

Different levels of risk require different risk control measures. For the risk degree at risk assessment matrix, the acceptance criteria are proposed in Table 5.

Table 5 Risk acceptance criteria of deep excavation engineering

Risk Degree	Acceptance Criteria	Handling Plan
5	rejective	Stop, avoid, and start plan immediately, or take the measure to reduce risk to the degree undesirable at least
4	unacceptable	Pay highly attention and avoid, take control and early warning measure, or take the measure to reduce risk to the degree undesirable at least
3	undesirable	Pay attention and take precautious and monitoring measure. The cost to reduce the risk could not be higher than the loss of risk occurrence.
2	tolerant	Concern and strengthen daily management. Do not need risk handling measure.
1	negligible	Take daily management. Do not need risk handling measure and monitoring.

(5)Risk assessment of deep excavation engineering based on monitoring

For different risk degree, monitoring requirements of deep excavation engineering may be different, which is shown as Table 6.

Table 6 Risk assessment of deep excavation engineering based on monitoring

Risk Degree	5	4	3	2	1
Instrument Monitoring	must	should	suitable	may	no

IV. RISK CONTROL OF DEEP EXCAVATION ENGINEERING BASED ON MONITORING

On the basis of risk analysis, risk control is the formulation and implementation of risk measures with monitoring of risk development. If the goal has the deviation, the corrective measures should be taken to achieve the desired goal. The key of risk control is to make decisive action.

4.1 risk tracking management of deep excavation engineering

Risk tracking management is the tracking, monitoring and managing the status of risk factor, supervising and checking the implementation of measures of risk evasion, and finding unidentified risk. Risk tracking management of deep excavation engineering includes monitoring and field observing the identified and unexpected risk, dynamic managing of monitoring data, and recording and checking the risk status. The purpose is to detect abnormal and dangerous situation and take measures to solve the problem in time.

The tracking and monitoring of risk should also control the monitoring frequency. Determining the monitoring frequency should reflect important changes of the monitoring items in the change process and without missing time of change. Monitoring frequency is not static, which should be adjusted based on excavation, construction process and working conditions of underground engineering and other changes in external factors.

4.2 construction risk early warning of deep excavation engineering

The key of construction risk early warning of deep excavation engineering is to develop risk early warning criteria according to the project characteristic. The work includes building the corresponding relationship between monitoring results and risk accident, and making dynamic risk assessment based on monitoring results. If the situation is abnormal or dangerous, we should warn in time, take evasive measures, and carry out the preparatory work for risk accident. We have proposed early warning value of foundation pit, supporting structure, and surrounding environment.[5]

4.3 risk notification and information feedback of deep excavation engineering

Risk notification of deep excavation engineering is an important aspect in risk management. Each interested sides should carry on the propaganda and education on various stages the risk point and the attention matters before starting deep excavation engineering.

The monitoring data of deep excavation engineering should be analyzed and processed in time. The monitoring data analysis should be combined with other related project monitoring data, natural environment conditions, construction conditions, and previous data etc. The analysis should make the forecast to its trend of development. The monitoring technical achievement should include daily report, interim report and summary report. The technical achievements should be true, accurate, complete, and is appropriate to elaborate the text with graphics or curves.

The technical achievement should send promptly. The professional software conforming to standard requirements should be used in monitoring data processing and information feedback. The monitoring record, calculating data and technical achievement of deep excavation engineering should be classified and kept on file.

V. CONCLUSION

By monitoring the physical change of material, this risk management pattern could distinguish and control the change of risk source to predict risk of incident with early warning, which improves the quantitative indexes in risk management of deep excavation engineering and make risk analysis and decision-making accurate and scientific.

The research on risk estimation has yet to be deepening. We shall establish the risk estimating method combined with statistical analysis and subjective judgment by inducting and summarizing the engineering practice, which could improve the research on monitoring-based risk management of deep excavation engineering further.

REFERENCES

[1] QIAN Qi-hu, RONG Xiao-li. Status, problems and recommendations on security risk management of underground structure in China [J]. Journal of Rock Mechanics and Engineering, 2008, 27(4) : 649-655

[2] China Civil Engineering Society, Tongji University. Guide to Risk Management of Subway and Underground Construction [M]. Beijing: China Building Industry Press, 2007

[3] ZHONG Jing-bing, LI Hui-qiang, WU Jing. FTA method in engineering failure path and factors of risk source [J]. Journal of Huazhong University of Science(Urban Science),2003, 20(1) : 14-17

[4] LIU Jun-yan. Research and preparation on "Technical Code for Monitoring of Building Excavation Engineering GB50497-2009" [J]. Construction Technology, 2009, 38(4) : 1-4

[5] University of Jinan. Technical Code for Monitoring of Building Excavation Engineering[S]. Beijing: China Planning Press, 2009