Safety Evaluation of Super Deep Shaft Construction of Donghu Deep Tunnel in Wuhan

Kai Hu, Junwu Wang, Han Wu
School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan Hubei 430070, China
Corresponding author: Junwu Wang, Eail: hu5555@163.com, TEL:13657267225

Abstract—With the rapid development of infrastructure construction in large and medium-sized cities in China, the development and utilization of underground space has been developed rapidly. The sewage transmission system engineering of Donghu core area in Wuhan is faced with the construction of shaft under smaller section, deeper foundation pit and more complex environment. The safety of super-deep shaft construction is evaluated and the important risk influencing factors are identified. From the point of view of construction process and method, this paper identifies and constructs the evaluation index system of safety risk in deep tunnel shaft construction, and then constructs the evaluation model with binary semantics and AHP and entropy weight method. Finally, the empirical analysis is carried out through the example of Wuhan East Lake deep tunnel project. The empirical results show that the foundation pit support, water stop curtain, wellhead instability, vertical ventilation of shaft and rock entry blasting are the factors that affect the construction safety risk of the project, and the construction safety risk evaluation grade of the project is low. This paper also puts forward effective measures to improve the construction safety of the project.

1. Introduction
The construction of foreign drainage deep tunnel has been for decades, but the domestic construction has just begun. The related research at home and abroad mainly focuses on the safety risk research of deep foundation pit engineering. At present, there is no research on the safety evaluation of deep tunnel shaft construction, and our research provides a new field of vision. At present, there are many construction safety risk evaluation for ordinary deep foundation pit, and there is a lack of safety evaluation research under specific construction conditions under specific environment. At present, the main methods are as follows: Cai L, Min L I, Zhang X1 used the WBSRBS method to analyze and identify the safety risk events and key risk factors of super-deep and super-large underground engineering structure reconstruction. Wei Y, Jian H E, Pan H Z, et al2. studied on foundation pit construction risk of metro station based on fuzzy entropy theory. Niu F Y, Wang J B, Zhao J, et al3.studied construction of metro pit security risk assessment based on the method of ANP and Grey Clustering. Jiang X4. Studied AHP-NET Risk evaluation model of Construction Programme. Ma G, Wu M5.set a big data and FMEA-based construction quality risk evaluation model for Shanghai apartment projects.

These studies are helpful for managers to grasp the risk degree of super-deep shaft construction, but mostly focus on the overall level evaluation of deep foundation pit engineering. The methods used still have some limitations in the analysis of the importance of each risk event. It is necessary to identify the key risks in the construction risk management of deep foundation pit in order to focus on and take
targeted measures to prevent and control and improve the safety of the project.

There are problems in previous studies: (1) the evaluation index is not uniform. A large number of experts and scholars have analyzed the safety risk in the construction of deep foundation pit or super-deep shaft engineering, but each project and every researcher has different emphases, which results in some differences in evaluation indexes. As a result, the evaluation index system is difficult to be widely used. (2) Inadequate evaluation indicators. With the national policy to the urban drainage deep tunnel project gradually strengthened, the construction method is also constantly changing and developing, the current deep foundation pit or super deep shaft construction safety risk evaluation index needs to be improved.

My research goal is mainly based on the existing Wuhan East Lake deep tunnel project super deep shaft project as the background, combined with the specific construction methods, safety construction risk index determination, set up a safety risk evaluation model, and safety comprehensive evaluation. The innovation of this study lies in the concrete construction plan, one is to put forward a set of safety risk evaluation index system which accords with the engineering reality, the other is to determine the objective weight through the analytic hierarchy process and the entropy weight method. The objectivity of evaluation is improved. Based on this work, it is helpful to combine the concrete construction method in the construction process, to provide reference for risk evaluation and early warning in the shaft construction of urban deep tunnel drainage system at home and abroad, and to provide theoretical basis for construction safety management. In order to reduce or avoid shaft construction safety accident loss.

2. Materials and Methods
This chapter mainly studies the safety risk assessment of Wuhan East Lake deep tunnel super deep shaft construction. In the process of research, the construction contents and characteristics of deep tunnel super deep shaft are analyzed and studied, and the risk index system is constructed by Delphi method. Then, the risk model is determined by introducing relevant binary semantics and other related theories, and the weight is calculated.

2.1 Safety Risk Assessment Model for Deep Tunnel Construction

2.1.1 Dual Semantic Correlation Definition
Binary semantic information refers to a binary group \((s_k, \alpha_k)\) given for a target or object or criterion to represent the evaluation results. The meanings of element \(s_k\) and \(\alpha_k\) are described as follows:

(1) \(s_k\) is the \(k\) element in the \(S\) of a predefined language evaluation set. Such as a language evaluation set consisting of seven elements can be defined as: \(S=\{S_6=F\text{Z}(very\ important), S_5=HZ(important), S_4=Z(important), S_3=YB(average), S_2=C(poor), S_1=HC(poor), S_0=FC(very\ poor)\}\).

(2) \(\alpha_k\) is the symbolic transfer value, which represents the deviation between the calculated language information and the predefined language information set \(S\), is the closest to the language phrase, and it obviously satisfies the \(\alpha_k \in [-0.5, 0.5]\).

2.1.2 Construction Safety Evaluation Index System of Deep Tunnel Superdeep Shaft Construction
Among the five sub-projects, the main safety risks of deep tunnel super deep shaft are underground continuous wall, bored pile, well point dewatering and water stop curtain, earthwork excavation and support, wellhead layout, etc. According to the relevant specifications of JGJ 311-2013 《Construction Safety Technical Code for Deep Foundation Pit Engineering, and combined with the characteristics of the project, five engineering experts are invited to establish the construction risk list of deep foundation pit of the project by Delphi method, as shown in Table 1.
2.1.3 Determination of weights for indicators based on portfolio empowerment

Analytic hierarchy process (AHP) and entropy weight method (Entropy Weight) are two most commonly used weight determination methods. The comprehensive use of the two methods can improve the disadvantage that AHP is greatly affected by human factors, so as to obtain more objective weight. The combined weighting method is used to obtain the weights of 26 indexes, the results are shown in Table 1.

| Indicators                          | ωi  | ωj  | α  | β  | ω   | Score |
|-------------------------------------|-----|-----|----|----|-----|-------|
| R1: Guide wall foundation pit support is not in place | 0.043 | 0.042 | 0.5 | 0.5 | 0.0425 | 2 |
| R2: Crawler wire rope is worn seriously and not replaced in time | 0.038 | 0.039 | 0.5 | 0.5 | 0.0385 | 0 |
| R3: Two-machine coordination       | 0.033 | 0.034 | 0.5 | 0.5 | 0.0335 | 1 |
| R4: Construction power management is lax   | 0.041 | 0.042 | 0.5 | 0.5 | 0.0415 | 1 |
| R5: Lifting system falling from height | 0.022 | 0.023 | 0.5 | 0.5 | 0.0225 | 0 |
| R6: Pile diameter and perpendicularity deviation is too large | 0.041 | 0.042 | 0.5 | 0.5 | 0.0415 | 2 |
| R7: Collapse of concrete cast-in-place pile | 0.043 | 0.042 | 0.5 | 0.5 | 0.0425 | 2.5 |
| R8: Steel cage is not standard     | 0.027 | 0.026 | 0.5 | 0.5 | 0.0265 | 1 |
| R9: Mud cleaning is not required   | 0.022 | 0.023 | 0.5 | 0.5 | 0.0225 | 1.3 |
| R10: Bottom cleaning is not complete, sediment thickness is too large | 0.021 | 0.024 | 0.5 | 0.5 | 0.0225 | 2 |
| R11: Ducts speed up too fast, concrete pouring is not dense | 0.031 | 0.032 | 0.5 | 0.5 | 0.0315 | 2.1 |
| R12: Improper design of water stop and quick excavation | 0.039 | 0.038 | 0.5 | 0.5 | 0.0385 | 2.5 |
| R13: Damage to Water-stop Curtain Non-underground Diving Water Source | 0.036 | 0.035 | 0.5 | 0.5 | 0.0355 | 3.1 |
| R14: Well point pipe sealing is not good | 0.035 | 0.036 | 0.5 | 0.5 | 0.0355 | 1.4 |
| R15: Excavation precipitation not in place | 0.047 | 0.048 | 0.5 | 0.5 | 0.0475 | 1 |
| R16: During punching, the surrounding personnel within the rotary range of the crane | 0.045 | 0.042 | 0.5 | 0.5 | 0.0435 | 1 |
| R17: Blasting flystone, vibration effect | 0.051 | 0.049 | 0.5 | 0.5 | 0.05 | 5.4 |
| R18: Stacking near 1 m around foundation pit | 0.045 | 0.046 | 0.5 | 0.5 | 0.0455 | 2 |
| R19: Surrounding structures, pipeline deformation is too large | 0.058 | 0.048 | 0.5 | 0.5 | 0.053 | 1.6 |
| R20: No control measures taken for the sinking of surrounding roads | 0.041 | 0.043 | 0.5 | 0.5 | 0.042 | 1.8 |
| R21: Shaft vertical ventilation | 0.047 | 0.041 | 0.5 | 0.5 | 0.0415 | 5 |
| R22: Not supporting design and construction as required | 0.046 | 0.048 | 0.5 | 0.5 | 0.047 | 1.5 |
| R23: Wellhead instability | 0.044 | 0.045 | 0.5 | 0.5 | 0.0445 | 1 |
| R24: Support is not regularly monitored | 0.042 | 0.048 | 0.5 | 0.5 | 0.0475 | 1.8 |
| R25: Hoisting area, pedestrian zone, etc. Unreasonable | 0.031 | 0.032 | 0.5 | 0.5 | 0.0315 | 5.6 |
| R26: Unreasonable arrangement of elevator, pipeline and side protection | 0.031 | 0.032 | 0.5 | 0.5 | 0.0315 | 2.4 |

Note: ωi, ωj are AHP, entropy weight method weight, α, β is distribution coefficient, meet α+β=1. w weighting weights for combinations, w=αωi +βωj.

The 26 indexes that affect the safety risk of super-deep shaft construction include qualitative and quantitative indexes. The qualitative indexes are mainly based on the form of expert scoring, and the binary semantic correlation definition is transformed into binary semantics. Divide the safety risk of super deep shaft construction into 5 grades and T1={a0=very low (VL), a1=Low (L), a2=Medium(M), a3=(H), a4=very high (VH)}, That is very low, low, medium, high, very high 5 grades. Set 5 grade expert evaluation scores, Very low (0-2), low (2-5), medium (5-7), high (7-9), very high (9-10) by collecting expert evaluations of indicators, The clustering weight vector is determined by grey
3. Results & Discussion

According to the above theoretical methods, the super-deep shaft of this project is selected as the research object, and the evaluation results are scored and counted. The results are in right side of table 1. The comprehensive score of shaft 3 of this project is 1.93, which is a low risk. From the actual project construction situation, the construction safety of shaft 3 is relatively good. Through the score table, it is easy to find that in this project, we should pay attention to the foundation pit support, the ventilation problem of shaft disposal, and the well head layout problems such as hoisting area and pedestrian area. In addition, the shaft is deep into the rock, and special attention should be paid to the special attention to.

In this paper, the construction safety risk list of super deep shaft is listed by Delphi method, which combines binary semantic method, analytic hierarchy process and entropy weight method to calculate the weight.

4. Conclusions

To sum up, this study has carried on the special research to the Wuhan Donghu deep tunnel super deep shaft construction safety appraisal, emphatically analyzed 26 factors which affect the super deep shaft construction safety risk, and calculated its weight, identified the foundation pit support, the water stop curtain, the wellhead instability, the shaft vertical ventilation, the rock entry blasting and so on are the most important factors. In the actual construction, according to the specific situation, we should formulate corresponding countermeasures to the 26 risk factors that affect safety, formulate safety control plans and strictly implement them. Once abnormal conditions are found, we should immediately stop to eliminate the hidden dangers before continuing construction. With the construction of urban deep tunnel, there will be more and more projects in super deep shaft construction. This study can be used as a reference for the construction side.

References

[1] Cai L, Min L I, Zhang X. Study on Safety Risk Identification and Evaluation System of Super-deep and Super-large Underground Engineering Structure Reconstruction[J]. Modern Tunnelling Technology, 2018.

[2] Wei Y, Jian H E, Pan H Z, et al. Research on Foundation Pit Construction Risk of Metro Station Based on Fuzzy Entropy Theory[C]// 0.

[3] Niu F Y, Wang J B, Zhao J, et al. Construction of metro pit security risk assessment based on the method of ANP and Grey Clustering[J]. Journal of Qingdao University of Technology, 2016.

[4] Jiang X. Study on AHP-NET Risk Evaluation Model of Construction Programme[J]. China Safety Science Journal, 2012.

[5] Ma G, Wu M. A Big Data and FMEA-based construction quality risk evaluation model considering project schedule for Shanghai apartment projects[J]. International Journal of Quality & Reliability Management, 2019, ahead-of-print (ahead-of-print).

[6] DAI Xiaosong, ZHU Haijun, CHEN Wei, HU Yichang, LIU Kaiyang. Comprehensive Construction Technology of Small Section Super Deep Shaft in Dadong Lake Deep Tunnel Project[J]. construction technology, 2019, v.48; No.542(19):88-91.