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Construction risk assessment on deep foundation pits due to confined water

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ABSTRACT: The confined water is a very important risk source for deep excavation especially in saturated soft soils because failure in control measurements will lead serious consequence not only for the project itself but also for adjacent buildings. There are many risk sources that have close relation with the risks in deep excavation relating to the confined water. Based on the probability and losses of the risk sources, a risk assessment method is given to assess the construction risks combined with Analytic Hierarchy Process (AHP) and fuzzy synthetic evaluation. At last, the feasibility of this method is proved by a practical example.

1 INTRODUCTION

Due to the characteristic of bearing pressure, the confined water may lead to soil protrusion at the bottom when its pressure is close to the gravity of the above soils of deep foundation pits. The water and sands will suddenly surge out once the gravity of residual soils above aquifer can’t balance the water pressure any more in certain area. If this accident happened, it will not only produce direct substantial economic losses, but also bring negative effects to the safety of adjacent buildings, pipelines and subways. Therefore, it is very important to assess the confined water risk before excavation if there is aquifer subjacent to deep foundation pits.

2 RISK ASSESSMENT SYSTEM

According to ITA (International Tunnel Association) guidelines, risk is a combination of the frequency and the consequences of the occurrence of a defined situation or condition that has the potential for human injury, damage to property, damage to environment, economic loss or delay to project completion (Eskesen, 2004). There are 2 implications in this risk definition: uncertainties and losses. The former is described with probability and the latter is identified by risk degree. It can be expressed in equation (1):

$$R = f(p, q) \tag{1}$$

In this equation, R represents risk index, p represents probability and q is the consequence.

The above equation actually is a model of risk evaluation which is a comparison of the results of a risk analysis according to risk acceptance criteria or other decision criteria. Risk analysis includes identification of hazards and description of risks which may be qualitative or quantitative, which is a structured process identifying both the probability and extent of adverse consequences of a given activity. And risk assessment is an integrated analysis of risk analysis plus risk evaluation. The relations among risk identification, analyses, evaluations and assessments are shown in Fig. 1.

2.1 Risk identification

The hydrological geology condition is a prerequisite to artesian risk in that if artesian aquifer is far away from the pit bottom, there is no risk relating to confined water. The risk level of artesian is relevant not only to the distance between pit bottom and the artesian aquifer, but also to the artesian pressure. The surface buildings surrounded are subsidiary risk sources because adjacent surface loads are negative condition for resisting artesian pressure. These two conditions are objective risk sources.

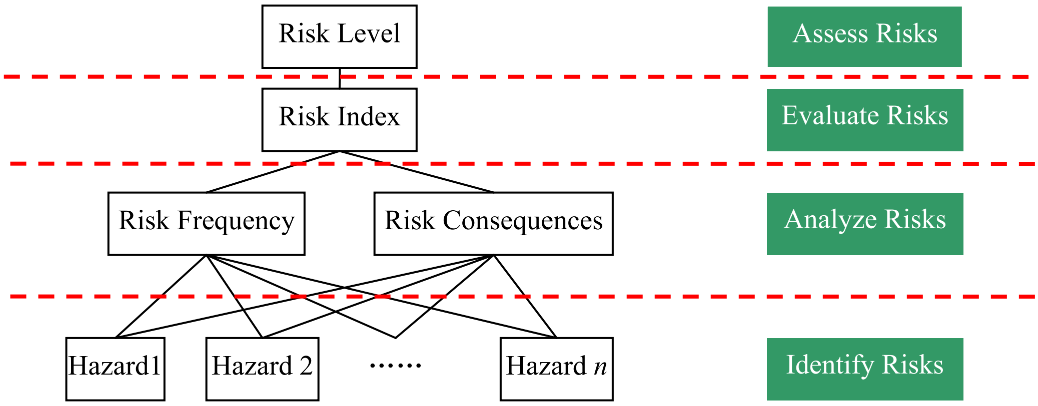

Fig.1 Risk assessment system of the confined water

Dewatering measurements are often applied to assuring the safety of deep excavation. Dewatering failure may lead to support structures collapsed and slope failure bringing great economic losses. The retaining structures and reinforcement on bottom soils also play important role in controlling the artesian risk of foundation pits. The risks in the unit project of dewatering, retaining structures and soil reinforcement can be further divided into 5 parts: survey, design, construction, monitoring and supervisory. Risk sources relating to confined water are shown in Fig. 2.

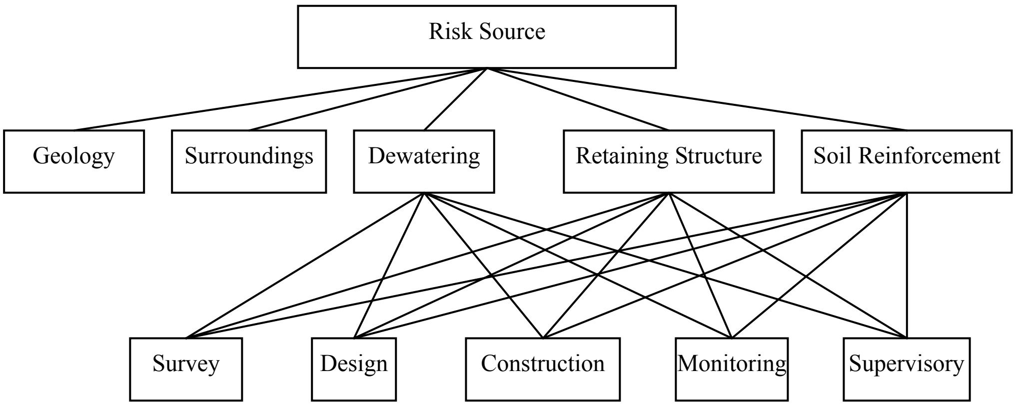

Fig.2 Risk sources of foundation pits near confined water

2.2 Risk analyses and evaluation

To evaluate the risk level of artesian water, a risk classification system should be established based on the frequency and consequence classification. According to ITA guidelines, the recommending frequency classification into 5 classes can be set up relating to the potential number of events (hazard occurring) during the whole construction period. (Eskesen, 2004) An example of such classification is shown in table 1.

Table 1 Frequency classification

Probability level	Frequency	Central value	Description
1	>0.3	1	Very Likely
2	0.03 to 0.3	0.1	Likely
3	0.003 to 0.03	0.01	Occasional
4	0.0003 to 0.003	0.001	Unlikely
5	<0.0003	0.0001	Very unlikely

It is difficult to calculate the consequence accurately special for confined water. Consequences are classified into 5 intervals according to international convention based on technical specification (CABR, 1999) showing in Table 2.

Table 2 Consequence classification of foundation pits

Consequence Class	Consequence	Description
1	Disastrous	There are important buildings and structures such as, metro lines, municipal pipe tunnels, gas pipes and large pressure water pipes adjacent to the foundation pits within 0.7H. And the hazards will produce huge direct economic losses.
2	Severe	There are important buildings or structures adjacent to the foundation pits within 0.7H~1.4H. And the hazards will produce great direct economic losses.
3	Serious	There are important buildings or structures adjacent to the foundation pits within 1.4H~2H. And the hazards will produce big direct economic losses.
4	Considerable	There is no important building or structure adjacent to the foundation pits within 2H. And the hazards will produce some direct economic losses.
5	Insignificant	There is no important building or structure adjacent to the foundation pits within 2H. And the hazards will produce small direct economic losses.

H: the depth of the foundation pit

3 RISK ASSESSMENT TOOLS

3.1 The analytic hierarchy process (AHP)

The AHP (Saaty, 1980) is a known multi-attribute weighting method for decision support (Madu, 1994). As such, the AHP has been used for solving complex decision-making problems in various disciplines which follows an approach of pair-wise comparison, provides a way for calibrating a numerical scale (Table 3), particularly in new areas where measurements and quantitative comparisons do not exist. All importance scales of individual criteria are compiled in matrix form which can provide the weight vectors of different facts after passing the consistency check.

Table 3. Linguistic measures of importance (Saaty, 1980)

Intensity of importance	Definition
1	Equal importance
3	Weak importance
5	Strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values

3.2 Multi-level Fuzzy synthetic evaluation

Linguistic and vague descriptions could not be solved easily by AHP in that it cannot fully reflect the human thinking style. The fuzzy set theory provides a useful tool to deal effectively with uncertain, vague and linguistic variables, which can be used for approximate reasoning and subsequently manipulated to propagate the uncertainties.

A fuzzy set describes the relationship between an uncertain quantity x and a membership function μ, which ranges between 0 and 1. This is an extension to the traditional set theory (in which x is either a member of set A or not) in that an x can be a member of set A with a certain degree of membershipμ.

Supposing A is a fuzzy set of weight vectors reflecting the importance of individual factors. R is a fuzzy evaluation matrix composed by fuzzy probability of different risks. B is the evaluation set remarking the level of risk probability. The principle of fuzzy synthetic evaluation is showed in formula (2).

$$B = A \circ R \tag{2}$$

In the above formula, $B=(b_1,b_2,\cdots,b_m)$, $A=(a_1,a_2,\cdots a_n)$, and $R=(r_{ij})_{n\times m}$.

"$\circ$"represents one certain fuzzy synthesis operational symbol. It can be given by weight average method, principle factor dominant method and principle factor prominent method.

4 APPLICATION

4.1 General situation

There is a deep foundation pit project situated in downtown. Its excavation depth is 16.5 m. There are 2 aquifers below this foundation pit: micro artesian aquifer in ⑤2 stratum and artesian aquifer in ⑦ stratum. And the water head of these two aquifers is about 5.0m and 4.9 m separately below the ground surface. The artesian aquifer is buried in the depth of 29m. There is local connection for these two aquifers. The thickness of the impervious stratum is about 5.5m. There are buildings and pipelines laid around the project within 1.5H distance from the foundation edges. The cross section is showed in Figure3.

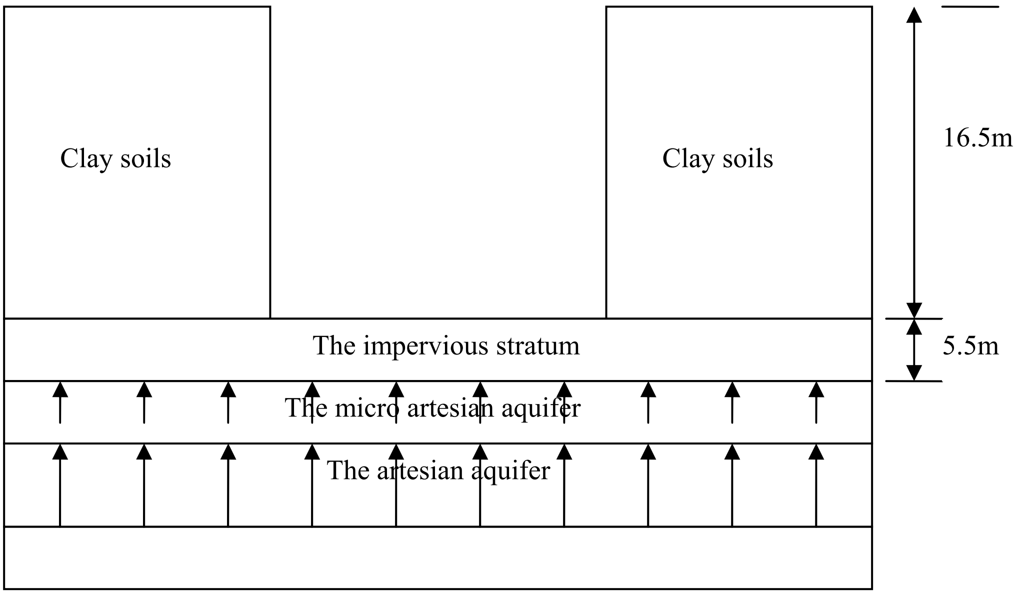

Fig.3 Cross section of the foundation pit

4.2 Risk Assessment

For the second level risk sources in Fig.2, dewatering for example, evaluation matrix is shown in Fig.4. The data in last column are weights of risk factors calculated by root-squaring method.

Table 4 The evaluation matrix of the dewatering unit

Dewatering	Survey	Design	Construction	Monitoring	Supervision	Weights
Survey	1.0000	1.2214	0.8187	1.2214	1.2214	0.2138
Design	0.8187	1.0000	0.6703	1.0000	1.0000	0.1750
Construction	1.2214	1.4918	1.0000	1.4918	1.4918	0.2612
Monitoring	0.8187	1.0000	0.6703	1.0000	1.0000	0.1750
Supervision	0.8187	1.0000	0.6703	1.0000	1.0000	0.1750

The consistency index CI of the above evaluation matrix is less than 0.1, so the corresponding eigenvalue can be used as weights. For the formula (2), A = (0.2138, 0.1750, 0.2612, 0.1750, 0.1750). The risk probabilities of convey, design, construction, monitoring and supervisory of different construction units are relating to the factors such as certificates, experience, instruments and workers, etc. According to comprehensive level of the companies engaging with the dewatering project unit, the corresponding frequency classes are given as 3, 3, 2, 4 and 4. The fuzzy evaluation matrix

$$R = \begin{bmatrix} 0.2 & 0.6 & 1 & 0.6 & 0.2 \\ 0.2 & 0.6 & 1 & 0.6 & 0.2 \\ 0.6 & 1 & 0.6 & 0.2 & 0 \\ 0 & 0.2 & 0.6 & 1 & 0.6 \\ 0 & 0.2 & 0.6 & 1 & 0.6 \end{bmatrix}$$

Considering that the weights of the second level risk sources have little difference, we can think that there is no determinant risk source in dewatering project and all of the risk sources should be considered. The fuzzy synthesis symbol adopts the weighted average method. The operational symbol is

$$b_j = \sum_{i=1}^{n} (a_i \bullet r_{ij}) \ (j = 1,2,\cdots,m) \tag{3}$$

The evaluation set of probability level of dewatering unit

$$B = A \circ R = (0.234,0.564,0.756,0.636,0.287)$$

The first level evaluation matrix is shown in Fig. 5, the last column of which is the characteristic values. This matrix is acceptable when the consistency index passing the checking condition.

Table 5 The evaluation matrix of the confined water

Confined water	Geology	Surroundings	Dewatering	Retaining structure	Soil reinforcement	Weights
Geology	1.0000	4.9530	1.4918	2.2255	1.8221	0.3574
Surroundings	0.2019	1.0000	0.6703	0.5488	0.3679	0.0881
Dewatering	0.6703	1.4918	1.0000	1.4918	1.2214	0.2041
Retaining structure	0.4493	1.8221	0.6703	1.0000	0.8187	0.1543
Soil reinforcement	0.5488	2.7183	0.8187	1.2214	1.0000	0.1961

According the above matrix, we can see that there is no simple paralleling relation among the first level risk sources. Geology factor is the dominant risk source because there will be no risk of confined water if there is no confined aquifer below the bottom of the pits nearby. The risk of the confined water also can be decreased by high level engaging companies even if there is confined water near the bottom. So, the fuzzy synthesis operational method should not choose the weighted average method, but dominant factor prominent method. The operational symbol is shown in equation (4).

$$b_j = \bigvee_{i=1}^{n} (a_i \bullet r_{ij}) \ (j = 1,2,\cdots,m) \tag{4}$$

Substituting the risk probabilities and the weights shown in table 5 into the equation (4), we can get the probability level of the confined water of this foundation pit.

$$B = A \circ R = \begin{pmatrix} 0.358 & 0.088 & 0.204 & 0.154 & 0.196 \end{pmatrix} \circ \begin{bmatrix} 1 & 0.600 & 0.200 & 0 & 0 \\ 0.200 & 0.600 & 1 & 0.600 & 0.200 \\ 0.234 & 0.564 & 0.756 & 0.636 & 0.287 \\ 0.339 & 0.704 & 0.756 & 0.496 & 0.183 \\ 0.251 & 0.616 & 0.844 & 0.584 & 0.227 \end{bmatrix}$$

$$= \begin{pmatrix} 0.358 & 0.215 & 0.165 & 0.130 & 0.059 \end{pmatrix}$$

It can be get that the probability level is 1 according to the principle of maximum membership.

There are a shopping mall, a theater and some pipelines adjacent to the foundation pits within 30m. And the hazards will produce big direct economic losses. The consequence class of this project can be set 3 according to Table 2. The risk index is 0.6. So the risk level is 2. Corresponding measurements must be taken to control the risk of the confined water so as to assure the consequences are acceptable.

5 CONCLUSIONS

Special for the risk of confined water relating to deep excavations, AHP and fuzzy synthetic evaluation method are integrated to assess the risk level of foundation pit projects. Some conclusions can be drawn from the process of risk identification, analysis, evaluation and assessment.

-AHP is often used to give the weight of individual risk sources, while the fuzzy synthetic evaluation method is fit for comprehensive evaluation considering the uncertainties of the probabilities.

-The fuzzy synthesis operational symbol is very important for fuzzy synthetic evaluation method. The weighted average method is applied in most cases. However, mistake conclusions maybe get if not considering the practical factors. For the risk of the confined water as an example, the hydrological condition of the foundation pits is the most important fact. There is no meaning to discuss the risk of confined water if there is no confined aquifer below the excavation.

-There are many accidents in deep foundation pit projects resulting from the confined water, such as the collapse of sustaining structures, the settlements of the ground surface, the splitting of the roads. All the consequence can be summed as the three key joints of dewatering, sustaining structures and soil reinforcement. Or else it is difficult to give the risk probability of the details, which decrease the feasibility of the risk assessment.

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