Risk Assessment of the construction of metro stations with open cut method based on fuzzy comprehensive evaluation method

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Abstract: Due to the loose structure, high moisture content and easy liquefaction of the sandy land layer in the coastal area, the construction of subway station open excavation has a high safety risk. Taking the deep foundation pit of Yufengwei station of Guangzhou Metro Line 7 as an example, this paper adopts fuzzy comprehensive evaluation method to evaluate the construction risk of Guangzhou metro station with open excavation method in the coastal area. The results are accurate and reliable, which can provide a reference for similar projects.

1. Introduction
With the rapid development of coastal city construction, the scale of urban rail transit construction is unprecedented. However, it is inevitable to encounter sandy soil layer when building subway in coastal area, which is characterized by loose structure, high moisture content and easy liquefaction. The excavation of deep foundation pit in sandy soil will cause the displacement of surrounding soil, and the uncertainty of construction will bring great safety risk to the construction. Therefore, it is particularly important to carry out risk assessment for the construction of metro stations with open excavation in coastal areas. In recent years, scholars and experts [1-5] have used fuzzy mathematics and improvement methods to evaluate and improve safety risks in foundation pit construction. This method can avoid the uncertainty of qualitative analysis.

In this paper, a risk assessment index system is established by combining with the station project of Yufengwei Station of Guangzhou Metro Line 7, and the weight of the evaluation index is calculated by using the fuzzy analytic hierarchy process to overcome the influence of subjective factors and carry out the risk assessment in the construction stage.

2. Project Overview
Yufengwei Station is a three-storey underground island platform with a single crossing line. It is 326 meters in length, 24.1 meters in standard width, 26.98 meters in depth of foundation pit, and 30110 square meters in construction area. Surrounding environment: The station is north-south along Fengle South Road, who transfers with the T model of line 13 already in operation. To the south lies the Pearl River at 300m as the crow flies; 2m of the 8-storey house on the north side; The station is closed to the community and village community. The tributary of Wu Chung river runs across the North foundation
pit. Geological conditions: the depth of soft permeable formation is up to 18m, and the average depth of basement rock layer is 6m. Groundwater is located 1.5m underground and abundant in water. The station overview is shown in Table 1.

Table 1. Station overview of Guangzhou Metro Line 7, Yufengwei Station

| N.O. | Length x width | The depth of foundation pit | The construction way | Retaining structure |
|------|----------------|----------------------------|----------------------|--------------------|
| 1    | 323m×24.1m     | about 26.98m               | Open cut method      | 1000mm thick underground diaphragm wall + internal support |

The depth of the geological weak permeable stratum (silt and sand) within the scope of the site's enclosure structure is up to 18m, and the construction of the enclosure structure is prone to hole collapse. Moreover, the east side of the foundation pit is the main road of Fengle South Road, which is prone to surface collapse due to heavy vehicle flow and high construction risk.

3. Risk assessment indicator system

This paper is based on the interim provisions on the risk assessment and Management of railway tunnels(2007) issued by the Ministry of Railways, and the risk management guidelines for subway and underground Engineering(2007) issued by the Ministry of Construction. At the same time, by referring to relevant foundation pit accident statistical literature [6-7], the construction risk assessment system of Yufengwei station was established. There are many factors affecting the safety and stability of foundation pit construction, so the actual risk analysis should be done on a case-by-case basis. Taking the excavation of subway foundation pit in Yufengwei Station as the analysis object, the construction risk assessment index system is obtained, as shown in Figure 1.

![Figure 1. Index system of foundation pit excavation risk assessment](image)

4. Risk assessment of foundation pit construction based on fuzzy comprehensive evaluation method

4.1. Fuzzy comprehensive evaluation

At present, the most effective risk assessment methods for foundation pit engineering is generally the systematic method combining qualitative and quantitative methods. The fuzzy comprehensive assessment method has six basic elements: 1. The evaluation factor field U, which is the set of the factors being evaluated; 2. The evaluation hierarchy theory domain V, namely the set constituted by
the evaluation, which is essentially a division of the evaluation interval of things; 3. Fuzzy relation matrix R, which is a single factor evaluation matrix; 4. Judging factor weight vector A, which is judging factor relative importance degree; 5. Fuzzy operator, which is the calculation method of A and R; 6. Evaluation result B. The flow chart of fuzzy comprehensive evaluation method is shown in Figure 2.

![Flow chart of fuzzy comprehensive evaluation](image)

**Figure 2. Flow chart of fuzzy comprehensive evaluation**

### 4.2. Foundation pit excavation construction risk index weight

According to the risk evaluation index system in Figure 1, experts in the industry were invited to score and evaluate, and finally the risk index weight of foundation pit excavation construction was determined again as shown in Table 2.

| Risk event               | Serial number | Weight | Risk factor                                           | Serial number | Weight |
|-------------------------|---------------|--------|------------------------------------------------------|---------------|--------|
| Soil landslid           | T1            | 0.487  | Overcut                                               | C1            | 0.391  |
|                         |               |        | Pit side overloading                                  | C2            | 0.391  |
|                         |               |        | Improper selection of slope                           | C3            | 0.151  |
|                         |               |        | Soak in the rain                                      | C4            | 0.067  |
| Bottom heave            | T2            | 0.209  | Unreasonable excavation without considering the effect of time and space | C5            | 0.250  |
|                         |               |        | The construction of cushion floor is not timely       | C6            | 0.750  |
| Support to fall         | T3            | 0.095  | Mechanical collision                                  | C7            | 1.000  |
| Artesian water surges   | T4            | 0.209  | The presence of undesirable geology                   | C8            | 0.250  |
|                         |               |        | Artesian head is underestimated                       | C9            | 0.750  |
4.3. Probability fuzzy interval of foundation pit excavation risk factors

The probability estimation of risk factors adopts the expert survey method, and the membership function is determined according to its degree of certainty. The fuzzy range is determined by solving the cut set of the fuzzy set. The confidence level is 0.9. The paste interval is between the abscissa of the intersection of \( f(u)=0.9 \) and the membership function curve. Take C1 as an example:

The comprehensive probability estimation of overcut C1 is 0.368, and the degree of certainty is very close to \( C \), that is \( n=4 \). Then the membership function expression of C1 is \( f(u) = e^{-0.368(4-u)} \), and the probability fuzzy interval is \([0.338,0.398]\), as shown in Figure 3. Therefore, a similar method is adopted to calculate the probability fuzzy interval of risk factors, as shown in Table 3.

![Figure 3. Overcut C1 membership function](image)

| Risk events | Risk factors | The degree of certainty | The probability of valuation | Probability range at confidence level 0.9 |
|-------------|--------------|------------------------|------------------------------|------------------------------------------|
| T1          | C1           | C                      | 0.368                        | [0.338,0.398]                            |
|             | C2           | FC                     | 0.330                        | [0.297,0.363]                            |
|             | C3           | FC                     | 0.303                        | [0.270,0.336]                            |
|             | C4           | VC                     | 0.335                        | [0.307,0.363]                            |
| T2          | C5           | C                      | 0.344                        | [0.314,0.374]                            |
|             | C6           | C                      | 0.370                        | [0.340,0.400]                            |
| T3          | C7           | C                      | 0.304                        | [0.274,0.334]                            |
| T4          | C8           | C                      | 0.302                        | [0.272,0.332]                            |
|             | C9           | C                      | 0.335                        | [0.305,0.365]                            |

4.4. Determination of fuzzy interval of risk loss

Subway station safety accident risk loss can be divided into economic losses, casualties, construction time loss and so on. This paper investigates and analyzes the three types of losses that may be caused by screened risk factors, first using the analytic hierarchy process (ahp) to determine the weight of three types of losses, and then concluding that comprehensive loss, finally concluding the loss fuzzy interval. The judgment matrix of each loss is shown in Table 4.

![Table 4. Loss judgment matrix and calculation results](image)

| Economic losses | Casualties | Construction time loss | Weight vector | Consistency check |
|-----------------|------------|------------------------|---------------|------------------|
| Economic losses | 1          | 3                      | 5             | 0.637            | \( \lambda_{max}=3.0385 \) |
| Casualties      | 1/3        | 1                      | 3             | 0.258            | CI=0.0193 |
| Construction time loss | 1/5 | 1/3 | 1 | 0.105 | CR=0.037 |
By processing the expert's loss evaluation results, the comprehensive loss and loss fuzzy interval are obtained. The determination method of loss fuzzy interval refers to the method of probability interval. The specific results are listed in Table 5.

Table 5. Fuzzy loss range of excavation risk factors

| Risk event | Risk factor | Comprehensive\degree of\certainty | Economic\losses | Casualties | Estimation of time limit loss | Estimation of comprehensive loss | Loss range at confidence level 0.9 |
|------------|-------------|------------------------------------|----------------|-----------|------------------------------|---------------------------------|----------------------------------|
| T1         | C1          | C                                  | 0.354          | 0.246     | 0.254                        | 0.316                           | [0.286,0.346]                    |
|            | C2          | C                                  | 0.337          | 0.263     | 0.269                        | 0.311                           | [0.281,0.341]                    |
|            | C3          | C                                  | 0.331          | 0.237     | 0.174                        | 0.290                           | [0.260,0.320]                    |
|            | C4          | FC                                 | 0.268          | 0.169     | 0.231                        | 0.239                           | [0.206,0.272]                    |
| T2         | C5          | C                                  | 0.330          | 0.267     | 0.133                        | 0.293                           | [0.263,0.323]                    |
|            | C6          | C                                  | 0.270          | 0.233     | 0.170                        | 0.250                           | [0.220,0.280]                    |
| T3         | C7          | FC                                 | 0.263          | 0.270     | 0.233                        | 0.262                           | [0.229,0.295]                    |
| T4         | C8          | FC                                 | 0.263          | 0.204     | 0.167                        | 0.238                           | [0.205,0.271]                    |
|            | C9          | C                                  | 0.308          | 0.208     | 0.267                        | 0.278                           | [0.248,0.308]                    |

4.5. Determination of risk degree and risk level

In this paper, references [8-9] are used to determine the risk level determination criteria and risk acceptance criteria, as shown in Table 6 and 7.

Table 6. Risk level determination criteria

| Risk degree r | Level of risk |
|---------------|---------------|
| 0~0.25        | Grade I, low risk |
| 0.25~0.5      | Grade II, moderate risk |
| 0.5~0.75      | Grade III, high risk |
| 0.75~1        | Grade IV, higher risk |

Table 7. Risk acceptance criteria

| Grade       | Accept the rules | Risk decision |
|-------------|------------------|---------------|
| Grade I     | Ignorable        | Routine monitoring is performed without the need for risk management measures |
| Grade II    | Acceptable       | Risk management measures are not required, but monitoring is required |
| Grade III   | Unwilling to accept | Monitoring must be strengthened and risk management measures are taken to reduce risk levels |
| Grade IV    | Unacceptable     | Must pay high attention, and take measures to avoid, otherwise reduce the risk to an acceptable level |

The risk degree range of each risk event when the confidence level is \(\lambda = 0.9\) is calculated, and the risk level is determined by comparing the risk level determination criteria in Table 6, as shown in Table 8.

Table 8. Fuzzy interval of Risk degree S from T1 to T4

| Risk events | Risk range |
|-------------|------------|
| T1          | [0.499,0.583] |
| T2          | [0.487,0.570] |
| T3          | [0.473,0.557] |
| T4          | [0.463,0.549] |
| S           | [0.341,0.410] |
Refer to table 6 risk ratings determining standard, due to the risk degree exist across two risk level, we can assume risk values of risk events within the scope of its fuzzy linear uniform distribution here, so the risk events can be obtained respectively belong to two level of risk probability, which respectively belong to two risk grade of membership degree. Again according to the maximum membership degree principle, We can determine the risk level of risk events. According to the following foundation pit construction risk S of Yufengwei Station, the risk level is obtained. The membership of Risk events S who belongs to Grade II is $r_2=(0.5-0.341)/(0.410-0.341)=2.304$ and belongs to Grade III is $r_3=(0.410-0.5)/(0.410-0.341)=-0.130$, so the overall construction risk S of Yufengwei station is Grade II, belonging to the moderate risk, which is acceptable and risk management measures are not required, but monitoring is required. This is also basically consistent with the site construction conditions.

5. Conclusion
This paper mainly evaluates the safety risk of pit construction in Guangzhou coastal areas metro station by using the method of open excavation by fuzzy comprehensive analysis method.

(1) Based on risk analysis of foundation pit construction, we can set up a pot of Yufengwei Station excavation risk index system, build the open cut method subway station engineering overall risk evaluation model, and define the overall risk classification standard, which is divided into Grade I (low risk), Grade II (moderate risk), Grade III (high risk) and Grade IV (higher risk).

(2) The probability, loss estimation and confidence degree of risk factors are obtained by using expert investigation method. The normal distribution function is selected as the membership function to obtain the fuzzy interval of risk degree and determine the risk level according to the risk level standard.

(3) The fuzzy comprehensive analysis method can be used to effectively evaluate the safety risk of excavation construction of subway station foundation pit in Guangzhou coastal area, and the results are accurate and reliable, which can provide reference for similar projects.

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