Study on Construction Safety Risk Assessment of Mountainous Area Highway through Karst Roadbed

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Abstract. In combination of construction safety status of a certain mountainous area highway through karst roadbed in Zhejiang Province, investigation and analysis on influencing factors for karst roadbed construction safety are conducted from the aspects of hydrogeologic condition, blanket condition, inducing factor and construction environment. Reasonable risk assessment indexes are selected on this basis. Establishment of construction safety risk assessment system on basis of analytic hierarchy process realizes quantitative analysis and evaluation of risk source of karst roadbed construction. Research findings are of important reference value and guiding significance to perfection of construction safety risk assessment of mountainous area highway.

Keywords. karst roadbed; construction safety; risk assessment

1. Introduction
In the course of mountainous area highway construction, although avoidance from karst and other unfavorable geology sections is sufficiently considered, the route inevitably needs to pass through this kind of unfavorable geology structures in most cases. However, such project is geotechnical engineering object subject to greatest influence of uncertain factors and many uncertain factors make an important impact on highway construction safety and have the direct bearing on engineering safety.

2. Safety problem of karst roadbed
In highway construction, in the absence of roadbed underlying karst area, karst cave may collapse and upper roadbed and auxiliary structure may collapse, sink or craze due to the influence of additional load and vibratory action within main stressed scope of roadbed, which will generate adverse effect on engineering construction and operation. Safety and stability for mountainous area highway passing through karst roadbed become prominent problems in engineering construction.

Roadbed safety problems triggered by karst mainly include the following categories.

(1) Differential roadbed settlement and deformation
Major cause for differential settlement occurred to roadbed in karst area is that clint, pillar, groove, karren, funnel and other karst forms rise and fall on bedrock surface of earth surface. Especially high-angle karst free face is frequently formed on the edge of a depression or groove. Under the action of load, bearing rock mass under highway base may slide along weak structural surface with adverse tendency to free face or shear failure surface to bring about roadbed instability, erode and hollow out foundation bed and roadbed filling together with underground water softening, and intensify differential settlement so as to cause a series of safety problems including cavity beneath slab, stressing deformation and fracture of works such as barricade.

(2) Roadbed collapse
Primary cause for karst roadbed collapse is that rock and earth mass concealedly lying above karst cave gap collapses due to the influence of nature or external force. According to collapse position, it is generally divided into overlying soil collapse and bedrock collapse. The former is generated under the action of factors such as human activity or underground water activity because blanket is hollowed out by karst underground water and cavity is formed. The latter is caused by rock mass instability due to insufficient intensity of karst cave roof. Occurrence of karst roadbed collapse generally has secrecy and abruptness so that it is extremely harmful to roadbed construction safety.

(3) Roadbed damaged under the action of karst ground water
Karst ground water generally includes karst spring, karst water in contact zone and underground stream. Surface water and underground water in karst area are closely related and underground geological conditions are complicated and changeable so it is easy for roadbed to get corroded and damaged by underground water.

3. Analysis on influencing factors for karst roadbed construction safety
On basis of karst roadbed safety problem, influencing factors for karst roadbed construction safety are analyzed from the aspects of geological condition, condition of blanket, hydrologic condition, external inducement, construction environment, data integrity and other inducing factors for mountainous area highway passing through karst roadbed.

3.1. Influencing factor of geological condition
Geological condition of karst roadbed area is one of important factors influencing roadbed construction safety. Geological condition of karst mainly includes three aspects, i.e., formation lithology, geologic structure and landform. It is found through previous geological survey into a certain mountainous highway construction in Zhejiang Province that carbonate rocks within engineering area show zonal distribution due to the influence of tectonic control. At the same time, geological fold, fracture and bedrock fissure development within engineering area constitute a criss-cross water-conducting channel and make underground water flow along synclinal axis and major joint fissures so as to cause the development of linear karst and simultaneously pose a risk to engineering safety.

3.2. Influencing factor of blanket
The influence of karst overlay structure to roadbed safety in karst area is mainly reflected in the respect of resistance to seepage deformation. In combination of field survey, previous investigation and research findings, overlay structure in engineering area can be divided into unitary structure, dual structure and multiple structures. Unitary structure is generally composed of homogenous material structure such as clay, secondary clay and silty clay; dual structure usually refers to blanket composed of cohesive soil and crushed stone blanket composed of cohesive soil and gravel for instance; multiple structure usually refers to blanket composed of at least three material structures, blanket composed of clay, crushed stone and silty clay from above to below for instance. Statistics show that among blankets with unitary structure, homogeneous and single clay blanket has the highest possibility of karst collapse.
3.3. Influencing factor of hydrogeologic condition
The influence of karst groundwater to karst development is mainly reflected in dissolving action of
differences in groundwater recharge, runoff and discharge conditions on carbonate rocks. In
engineering practice, underground water flow net can be used as analysis tool. More intensive flow
lines in karst water system indicate further developed karst. Besides, underground water-level
fluctuation will change soil behavior of blanket, intensify submarine erosion action on soil mass, and
generate adverse impact on the safety of upper structures including roadbed.

3.4. Influencing factor of external inducement
Factors inducing karst roadbed construction safety risk are mainly external factors including the
influence of construction season and natural hazard. The factor of construction season is determined
according to rainfall level in the engineering area. Heavy and continuous rainfall may cause changes
of groundwater level in the engineering area and influence stability of karst roadbed so rainfall
parameter in the engineering area is taken as index factor of construction season. The factor of natural
hazard is that risk analysis is made according to the frequency of hazards such as rainstorm, flood and
debris flow within construction area and larger risk value-at-risk can be selected during construction in
the season with frequent natural hazards.

3.5. Influencing factor of construction environment
Construction environment is one of external factors influencing karst roadbed construction safety. Analysis on the factor of construction environment is mainly made from two aspects, i.e.,
surroundings of construction site and types of engineering measures. Surroundings include distribution
of underground utilities, high voltage tower and urban and rural buildings within the scope of karst
roadbed construction; types of engineering measures has relatively large relation with construction
complexity and can be comprehensively judged from the aspects of technical maturity of engineering
measures, concealing, complexity of temporary construction measures, and special circumstances that
may occur in the construction process.

3.6. Influencing factor of data integrity
Data integrity is comprehensively judged mainly from the aspects of reliability of geological data and
integrity of design documents. Reliability of geological data can be comprehensively judged from
description of engineering geological conditions, predictive analysis on hazards that may occur in
roadbed construction, rationality of stability evaluation method and parameter selection and solidness
of geological foundation work.

4. Karst roadbed construction safety risk assessment system
Karst roadbed construction safety risk assessment work is to take karst roadbed engineering of
mountainous area highway as assessment object, evaluate safety risk in karst roadbed construction,
determine risk grade and propose risk control measures and suggestions according to engineering
construction scale, geological conditions, engineering characteristics, inducing factors, construction
environment and data integrity. Risk assessment work is implemented before construction and
assessment conclusion will be the basis for formulation of engineering construction organization
design.

4.1. Selection of assessment indexes
Primary task of risk assessment work is the selection of assessment indexes. There are many factors
influencing karst roadbed construction safety, qualitative factor, quantitative factor, simple factor and
complicated factor for instance. Thus, how to correctly select and determine assessment index of karst
roadbed construction safety is complicated and relatively difficult system engineering. Thus,
 systematic, flexible, targeted and practical principles shall be obeyed in selection of assessment
indexes.
In combination of principles for selecting assessment indexes of karst roadbed construction safety risk and factors influencing karst roadbed construction safety, assessment indexes of karst roadbed construction safety risk are classified from six aspects, i.e., geological conditions of karst area, blanket condition, hydrologic condition, inducing factor, construction environment and data integrity. See figure 1.

![Figure 1](image)

Figure 1. Assessment indexes of karst roadbed construction safety risk

4.2. Establishment of assessment system

In combination of practical karst roadbed construction safety problems encountered during the construction of a mountainous area highway in Zhejiang Province, with reference to assessment indexes selected, according to relevant data including standard specification and operative construction organization design, and on basis of geological condition of karst roadbed, blanket condition, hydrogeologic condition, construction environment and other inducing factors, influencing degrees of karst on roadbed construction safety risks are analyzed one by one and then assessment index system for karst roadbed construction safety risk is established.

In the process of risk assessment, many different methods such as key informant survey, decision tree method, fuzzy comprehensive evaluation, analytic hierarchy process and index system method can
be utilized to analyse problems for different engineering risks. Assessor shall determine feasible assessment organization form and reasonably select assessment method according to assessment purpose and object characteristics of engineering risk.

In combination of characteristics of karst roadbed construction safety risk of the mountainous area highway in Zhejiang Province, key informant survey and index system method are adopted to conduct assessment work in consideration of usability, practicability and operability of risk assessment method and scientific, feasibility and rationality of assessment process and conclusion. Among these two methods, key informant survey is based on experts’ rich practical experience so factors in all respects including professional background of geotechnical engineering, geological survey, design, construction experience and assessment experience shall all be considered in expert selection to guarantee the complementarity of experts’ specialties. Index system method can be adopted under the condition that assessment team members have insufficient work experience in a similar position.

Establishing process of assessment index system for karst roadbed construction safety risk is shown in figure 2 and divided into the following steps.

1. An on-the-spot survey into typical karst roadbed construction site is made to collect basic data related with construction safety risk assessment;

2. In combination of engineering reality and in accordance with relevant code requirements, influencing factors for karst roadbed construction safety risk are analyzed on basis of reference to domestic and foreign-related experience of karst roadbed construction safety risk assessment and research findings;

3. Assessment indexes are selected, determined and graded according to influencing factors for karst roadbed construction safety risk;

4. Basic scoring scopes of all assessment indexes are divided and assessment index system is initially established;

5. Weight of each index is determined on basis of analytic hierarchy process;

6. Safety risk grading standard is defined;

7. Total risk value is calculated and risk grade is determined.

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**Figure 2.** Establishment flow of risk assessment index system
4.3. Weight definition of assessment index

In risk assessment work, weight coefficient of each assessment index reflects influencing degree of the assessment index to risk but there are various influencing factors for karst roadbed construction safety risk, certain factor, uncertain factor, simple factor and complicated factor for instance. Thus, how to correctly determine the weight of each assessment index has the direct bearing on the accuracy of assessment result. On account of karst roadbed construction safety risk assessment model, this study establishes 15 assessment index factors in 6 categories in total. During judgment of relative importance of each index factor, pairwise comparison and analysis shall be made according to decision maker’s judgment of important relations among all index attributes to establish judgment matrix and then normalization processing is made to get weight coefficient of each index factor. At the same time, consistency check is made to guarantee the correctness of calculation result. Index judgment matrix for karst roadbed construction safety risk assessment is shown in table 1.

Table 1. Scale value table of index judgment matrix for karst roadbed construction safety risk assessment is shown

| Assessment index       | Formation lithology | Geologic structure | Landform | Blanket structure | Blanket thickness | Hydrogeological division | Hydrogeological subregion | Groundwater depth | Groundwater level fluctuation | Construction season | Influence of natural hazard | Type of engineering measure | Surroundings | Geological data | Design document |
|------------------------|---------------------|--------------------|----------|-------------------|-------------------|------------------------|--------------------------|-------------------|-----------------------------|---------------------|--------------------------|--------------------|--------------|---------------|----------------|
| Formation lithology    | 1                   | 1/3                | 1/2      | 2                 | 1                 | 1/4                   | 1/5                      | 1/7               | 1/7                         | 1/6                 | 1/6                      | 1/8                | 1/8          |                |                |
| Geologic structure     | 3                   | 1                  | 4        | 1                 | 4                 | 2                     | 1                        | 1/2               | 1/2                         | 1/3                 | 1/5                      | 1/4                | 1/4          | 1/6           | 1/7          |
| Landform               | 1                   | 1/4                | 1/3      | 1                 | 1/2               | 1/4                   | 1/5                      | 1/6               | 1/6                         | 1/7                 | 1/6                      | 1/8                | 1/8          | 1/9           | 1/9          |
| Blanket structure      | 2                   | 1                  | 3        | 1                 | 4                 | 1/2                   | 1/3                      | 1/4               | 1/6                         | 1/6                 | 1/6                      | 1/5                | 1/5          | 1/7           | 1/7          |
| Blanket thickness      | 1/2                 | 1/4                | 1        | 1/4               | 1                 | 1/3                   | 1/5                      | 1/6               | 1/8                         | 1/8                 | 1/8                      | 1/7                | 1/7          | 1/9           | 1/9          |
| Hydrogeological division| 1/2                | 2                  | 1        | 3                 | 1                 | 1/3                   | 1/4                      | 1/4               | 1/6                         | 1/7                 | 1/6                      | 1/7                | 1/7          | 1/8           | 1/8          |
| Hydrogeological subregion| 1/2                | 4                  | 4        | 2                 | 5                 | 3                     | 1                        | 1/2               | 1/5                         | 1/4                 | 1/4                      | 1/3                | 1/3          | 1/6           | 1/6          |
| Groundwater depth      | 4                   | 2                  | 5        | 3                 | 6                 | 4                     | 1                        | 1                 | 1/4                         | 1/4                 | 1/4                      | 1/3                | 1/3          | 1/5           | 1/5          |
| Groundwater level fluctuation| 5                   | 3                  | 6        | 4                 | 6                 | 4                     | 2                        | 1                 | 1/4                         | 1/3                 | 1/2                      | 1/2                | 1/2          | 1/4           | 1/5          |
| Construction season    | 7                   | 6                  | 8        | 6                 | 8                 | 7                     | 5                        | 4                 | 4                          | 1                   | 1                       | 3                  | 1            | 2             | 1/2          |
| Influence of natural hazard| 5                   | 7                  | 6        | 8                 | 6                 | 4                     | 4                        | 3                 | 1                          | 1                   | 1                       | 2                  | 1            | 1/2           | 1/3          |
| Type of engineering measure| 6                   | 4                  | 6        | 4                 | 7                 | 5                     | 3                        | 2                 | 1                          | 1                   | 1                       | 3                  | 1            | 1/4           | 1/4          |
| Surroundings           | 6                   | 4                  | 7        | 5                 | 7                 | 6                     | 4                        | 3                 | 2                          | 1/2                 | 1                       | 1                  | 1            | 1/3           | 1/4          |
| Geological data        | 8                   | 6                  | 8        | 7                 | 9                 | 7                     | 6                        | 5                 | 4                          | 1                   | 2                       | 4                  | 3            | 1             | 1            |
| Design document        | 8                   | 7                  | 9        | 7                 | 9                 | 8                     | 6                        | 5                 | 2                          | 3                   | 4                       | 4                  | 1            | 1             | 1            |

By means of analytic hierarchy process and in combination of expert opinion and actual situation at site, analytic hierarchy process model for karst roadbed construction safety risk assessment is built to calculate weight of each risk index so as to construct a safety risk assessment index system.

In risk assessment work, selection of assessment index and valuing of index weight are the key of risk assessment index system method. Each index weight coefficient is related with the accuracy and reliability of risk assessment conclusion. Thus, in actual assessment work, establishment of index system shall be a independent work step. Assessor is required to constantly accumulate experience and make correction in assessment practice to improve the scientificity and rationality of assessment work.

4.4. Risk ranking

Total safety risk value of karst roadbed construction in mountainous area highway can be calculated and determined according to the following formulas.
\[ F = \Sigma X_{ij} \]

\[ X_{ij} = \frac{R_{ij}}{\gamma_{ij}} \]

In the formulas, \( X_{ij} \) is final assessment value of each index, \( R_{ij} \) is value of index ranking, and \( \gamma_{ij} \) is weight coefficient of each index.

After \( F \) value is calculated, total risk level of construction safety is determined according to table 1.

5. Engineering application

The mountainous area highway in Zhejiang Province is 30.24km long in total and has 9 karst sections measuring 3955m and occupying 12.9% of total track length.

| Risk level                      | \( F \)       |
|---------------------------------|--------------|
| Level IV (extremely high risk) | \( F \geq 60 \) |
| Level III (high risk)          | 45 < \( F \) \leq 60 |
| Level II (medium risk)         | 30 < \( F \) \leq 45 |
| Level I (low risk)             | \( F \leq 30 \) |

According to geological exploration data, design information and site survey condition, general characteristics of karst development in this project are as follows. Limestone has relatively wide distribution range and limestone, argillaceous limestone and carbonaceous limestone are distributed in strata of Cambrian system, Ordovician system and carboniferous system. Some strata have mudstone and calcareous mudstone banded limestone; covered karst is the major type; the majority of rock strata is covered by Quaternary soil or all-powerful weathering bedrock. Quaternary stratum is mostly sanding soil or multiple structures and a small part of karst landscapes show through the ground. Surface water is closely connected with groundwater.

Karst geology constitutes influence to highway roadbed construction safety. Before commencement of works, risk assessment system established in this study is adopted to assess safety risks of karst roadbed construction. Safety risks of karst roadbed construction in 2 places are graded as high risks and these in 7 places are graded as medium risks. According to risk condition of each construction site and in combination of research findings, construction unit formulates “Special Risk Assessment Scheme for Construction Safety”, “Special Construction Technology Scheme for Karst Area” and other documents and carries out effectively risk management of the project so there is no construction safety accident in the process of karst roadbed construction.

6. Conclusion

In combination of current construction safety status of a certain mountainous area highway through karst roadbed in Zhejiang Province, investigation and analysis on influencing factors for karst roadbed construction safety from the aspects of hydrogeologic condition, blanket condition, inducing factor and construction environment, reasonable risk assessment indexes are selected on this basis, and construction safety risk assessment system is established on basis of analytic hierarchy process to realize quantitative analysis and evaluation of risk sources in karst roadbed construction and get applied in actual engineering. Research findings are of important reference value and guiding significance to perfection of perfection of construction safety risk assessment of mountainous area highway.

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