# Study on Risk Assessment of Slope Construction in Highway Expansion and Reconstruction Projects

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**Abstract.** Highway expansion projects involve slope demolition, which works differently from the newly built highways. The risk situation of slope demolition construction under the condition of uninterrupted traffic is more complicated. Considering factors such as the demolition of existing support structures and uninterrupted traffic flow, this paper investigates the construction risk assessment methods for slope demolition in highway expansion and reconstruction projects. The main conclusions of the study are as follows: (1) Project specificities should be considered in the risk assessment of slope construction for highway reconstruction and expansion projects, such as existing slope conditions, demolition methods, and environmental factors, to further enhance the practicality of the assessment method. (2) In terms of index weights, the demolition method accounts for the highest proportion, followed by geological conditions and slope conditions. (3) Case studies in the paper reveal that the risk level of slope construction is level III, indicating a high level of risk. Therefore, prior to construction, optimization should be done, effective personnel management and construction monitoring must be strengthened in the construction process, and data changes should be updated in time. In addition, the engineering personnel shall grasp the dynamics internal forces and deformation of slopes, and engage in timely feedback and communication with the design department to provide reference for design optimization.

**Keywords:** Highway; Reconstruction and Expansion; Slope Construction; Risk Assessmen

## 1 Introduction

With the increase in highway operation time, the traffic volume of highways built in the early stages grows year by year, resulting in changes in road traffic conditions. However, the traffic capacity fails to meet the current operational requirements, leading to an increasing demand for highway reconstruction and expansion. In the process of highway reconstruction and expansion projects, traffic flow typically is not interrupted to ensure the smoothness of traffic flow. Nevertheless, there is mutual influence between the construction work area and the passing vehicles, resulting in congestion problems and frequent traffic accidents. Therefore, the safety risk problems during the reconstruction and expansion projects should not be neglected.

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The construction process of highway reconstruction and expansion typically involves the demolition of existing slopes. Due to the existence of the established support structure, the construction process varies from that of newly built slopes, so it is necessary to conduct a study on the risk assessment of slope demolition construction in highway reconstruction and expansion projects.

Zhou [1] summarized the experience of highway management and maintenance and put forward major factors affecting highway construction safety. Wang [2] performed a study on the mutual impact between slope construction and operational safety in the reconstructed and expanded highway. They established a safety risk evaluation index system and analyzed a typical project to determine its safety risk level. Zhao [3] carried out numerical simulation analysis on the slope construction of highway expansion and reconstruction projects, obtaining the stable state of slopes at various construction steps and shedding light on the selection of construction programs. Zhong [4] analyzed the characteristics of highway slope construction and built an index system for safety influencing factors, based on which an assessment model was established by combining the FAHP method and SPA method, providing a reference for the safety risk assessment of slope construction. Wu [5] developed an overall risk assessment method for highway slope construction safety, constructing an index system and using Monte Carlo and K-S test methods for risk level classification. Engineering examples verify that the method is applicable to the safety risk assessment of slope construction on highways. Xie [6] and Zhang [7] applied the T-S fuzzy neural network analysis method to assess construction safety risks and analyze slope stability, which not only determined safety risk levels but also identified major risk factors, providing new insights for safety risk assessment. Ye [8] taking the actual excavation of highway slopes as an example, analyzed overall risk assessment approaches and processes. The stability of slop construction was explored through numerical simulation analysis, and the accuracy of the method was verified by comparing it with the overall risk assessment results. In addition, the probabilistic model [9] and the three-dimensional discrete element method [10] have been utilized to evaluate slope safety risks, offering an approach for identifying safety risks in slope construction.

Research on safety risk assessment methods for slope construction has enriched the related risk identification and estimation work. Expansion and reconstruction projects deal with the demolition of existing support structures and slope excavation. The diverse conditions of support structures can significantly affect construction difficulty, superimposed on the impact of traffic in the construction area, existing construction safety risk assessment methods may present limited applicability. Therefore, studies need to be carried out on risk assessment methods for slope construction in reconstructed and expanded highways.

Based on the *Guidelines for Safety Risk Assessment of Highway Cut Slope Construction*, this paper delves into safety risk assessment methods for slope construction in highway reconstruction and expansion projects, providing a reference for the safety risk assessment of similar projects.

## 2 Establishment of overall risk assessment index system

According to the construction features of the highway reconstruction and expansion slope projects, coupled with on-site research, this study identified seven primary indicators, including demolition scale, slope condition, demolition method, geological condition, climatic factor, construction environment, and data integrity, as depicted in Fig. 1. The overall risk assessment index system is outlined in Tables 1 to 7.

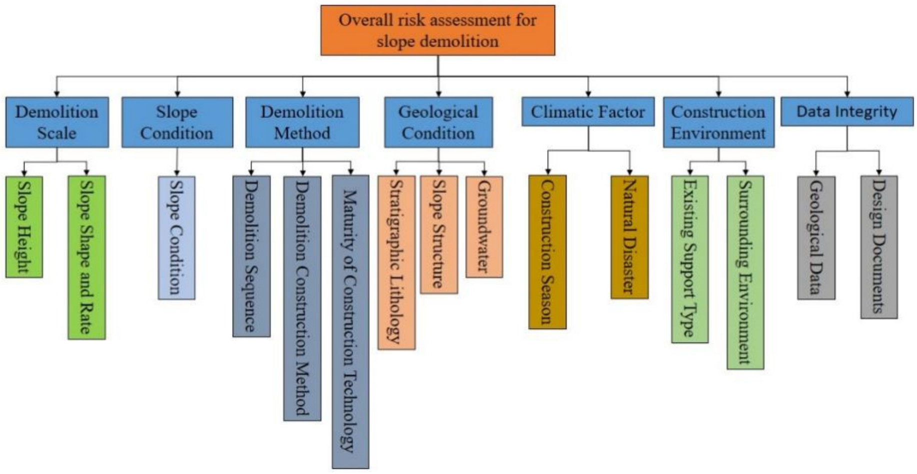


**Fig. 1.** Overall risk assessment indicators.

**Table 1.** Demolition scale index system.

| Primary Indicator | Secondary Indicator | Evaluation Basis | Score Range | Weight |
|---|---|---|---|---|
| Demolition Scale ($A_1$) | Slope Height ($R_{11}$) | Soil slope (H≥40 m) Rock slope (H≥60 m) | 75-100 | $\gamma_{11}$ |
| | | Soil slope 30 m≤H<40 m, Rock slope 40 m≤H<60 m | 50-74 | |
| | | Soil slope 20 m≤H<30 m, Rock slope 30 m≤H<40 m | 25-49 | |
| | | Soil slope H<20 m, Rock slope H<30 m | 0-24 | |
| | Slope Shape and Rate ($R_{12}$) | Cutting slope exceeds natural slope inclination value Δα≥15° | 75-100 | $\gamma_{12}$ |
| | | 10°≤Δα<15° | 50-74 | |
| | | 5°≤Δα<10° | 25-49 | |
| | | Δα<5° | 0-24 | |

**Table 2.** Slope condition index system.

| Primary Indicator | Secondary Indicator | Evaluation Basis | Score Range | Weight |
|---|---|---|---|---|
| Slope Condition ($A_2$) | Condition of Slops ($R_{21}$) | Serious deformation of slopes, severe damage to supporting structures, heavy loss of anchor cable force. | 75-100 | $\gamma_{21}$ |

| | | | | |
|---|---|---|---|---|
| | | Large slope deformation, high damage to supporting structures, high loss of axial force of anchor cable force. | 50-74 | |
| | | Moderate slope deformation, moderate damage to support structures, moderate anchor cable force loss. | 25-49 | |
| | | Slight slope deformation, light damage to support structures, low anchor cable force loss. | 0-24 | |

**Table 3.** Demolition method index system.

| Primary Indicator | Secondary Indicator | Evaluation Basis | Score Range | Weight |
|---|---|---|---|---|
| Demolition Method ($A_3$) | Demolition Construction Method ($R_{31}$) | Blasting demolition | 67-100 | $\gamma_{31}$ |
| | | Mechanical demolition | 34-66 | |
| | | Manual demolition | 0-33 | |
| | Demolition Sequence ($R_{32}$) | From bottom to top | 51-100 | $\gamma_{32}$ |
| | | From top to bottom | 0-50 | |
| | Maturity of Construction Technology ($R_{33}$) | First domestic application of new technology, techniques, and equipment. | 51-100 | $\gamma_{33}$ |
| | | Mature construction technology with domestic applications. | 0-50 | |

**Table 4.** Geological condition index system.

| Primary Indicator | Secondary Indicator | Evaluation Basis | Score Range | Weight |
|---|---|---|---|---|
| Geological Condition ($A_4$) | Stratigraphic Lithology ($R_{41}$) | Slippery and weak strata | 75-100 | $\gamma_{41}$ |
| | | Fully weathered bedrock | 50-74 | |
| | | Strongly weathered bedrock | 25-49 | |
| | | Weakly weathered bedrock | 0-24 | |
| | Slope Structure ($R_{42}$) | Soft structures or combinations with a gentle inclination towards the slope are present in the slope (perforation). | 75-100 | $\gamma_{42}$ |
| | | Soft structures or combinations with a gentle inclination towards the slope (non- perforation) / Hard structures or combinations with a gentle inclination towards the slope (perforation). | 50-74 | |
| | | Hard structures or combinations with gentle inclination towards the slope (non-perforation) / Other structures are present in the slope (perforation and development). | 25-49 | |

| | | | | |
|---|---|---|---|---|
| | | Other structures are present in the slope, not perforating, not developed. | 0-24 | |
| | Groundwater ($R_{43}$) | Groundwater is present within 0.25*H* below the slope and drainage facilities are failing. | 75-100 | $\gamma_{43}$ |
| | | Groundwater is available within 0.25*H*-0.5*H* of the lower-middle portion of the slope and drainage facilities are not functioning. | 50-74 | |
| | | Groundwater is present within 0.5*H*-0.75*H* of the upper-middle portion of the slope and drainage facilities are failing. | 25-49 | |
| | | Groundwater is exposed in the upper 0.75*H*-1.0*H* of the slope and drainage facilities are ineffective. | 0-24 | |

**Table 5.** Climatic factor index system.

| Primary Indicator | Secondary Indicator | Evaluation Basis | Score Range | Weight |
|---|---|---|---|---|
| Climatic Factor ($A_5$) | Construction Season ($R_{51}$) | Rainy season construction with torrential rainfall during construction, or the average annual rainfall in the construction area exceeding 800mm in the past 5 years. | 75-100 | $\gamma_{51}$ |
| | | Rainy season construction with heavy rain within the construction period, or annual average rainfall exceeding 800mm in the construction area in the past 5 years. | 50-74 | |
| | | Rainy season construction with moderate rain within the construction period, or annual average rainfall between 300-600mm in the construction area in the past 5 years. | 25-49 | |
| | | Dry season construction with no rain or light rain during the construction, or annual average rainfall not exceeding 300mm in the construction area in the past 5 years. | 0-24 | |
| | Natural Disaster ($R_{52}$) | Frequent natural disasters | 75-100 | $\gamma_{52}$ |
| | | Multiple natural disasters | 50-74 | |
| | | Occasional natural disasters | 25-49 | |
| | | Rarely natural disasters | 0-24 | |

**Table 6.** Construction environment index system.

| Primary Indicator | Secondary Indicator | Evaluation Basis | Score Range | Weight |
| --- | --- | --- | --- | --- |
| Construction Environment ($A_6$) | Existing Support Type ($R_{61}$) | Retaining wall support | 67-100 | $\gamma_{61}$ |
| | | Anchor frame beam support | 34-66 | |
| | | Anti-sliding pile support | 0-33 | |
| | Surrounding Environment ($R_{62}$) | There are operational highways, buildings, buried objects, high-voltage towers, and water facilities within 0.5*H* outside the demolition construction line at the top of the slope and 1.0*H* below the roadbed. | 75-100 | $\gamma_{62}$ |
| | | Within 1.0*H* outside the demolition construction line at the top of the slope, and 1.5*H* below the roadbed, there are operational highways, buildings, buried objects, high-voltage towers, water facilities. | 50-74 | |
| | | Within 1.5*H* outside the demolition construction line at the top of the slope, and 2.0*H* below the roadbed, there are operational highways, buildings, buried objects, high-voltage towers, water facilities. | 25-49 | |
| | | Facilities located outside the above range. | 0-24 | |

**Table 7.** Data integrity index system.

| Primary Indicator | Secondary Indicator | Evaluation Basis | Score Range | Weight |
| --- | --- | --- | --- | --- |
| Data Integrity ($A_7$) | Geological Data ($R_{71}$) | One or no survey section per high slope site, and only one or no exploration point per section (drilling, excavation, geophysical exploration). | 75-100 | $\gamma_{71}$ |
| | | At least one survey section per high-slope site, with 2 exploration points per section (drilling, excavation, geophysical exploration). | 50-74 | |
| | | At least one survey section for each high slope site, with 3 exploration points for each section (drilling, excavation, geophysical exploration). | 25-49 | |
| | | At least one survey section for each high-slope work site, with at least 3 drilling and excavation points per section. | 0-24 | |

| | | | | |
|---|---|---|---|---|
| | Design Documents ($R_{72}$) | One slope, one drawing, an incomplete explanatory map. | 75-100 | $\gamma_{72}$ |
| | | One slope, one drawing, a relatively complete explanatory map. | 50-74 | |
| | | One slope, one drawing, and a complete illustration map with relevant calculation parameters. | 25-49 | |
| | | One slope, one drawing, a detailed and complete illustration map with relevant calculation parameters, construction safety conditions, special engineering techniques and precautions, construction risk analysis, and control measures. | 0-24 | |

## 3 Determination of indicator weights and risk level classification

Based on the established risk assessment index system, we built an indicator-to-indicator comparison judgment matrix, selected experienced personnel from construction, supervision, and construction units to carry out a questionnaire survey, all of whom have deputy senior titles or above and more than 10 years of relevant work experience. By summarizing 5 questionnaires and analyzing expert opinions, the weights of primary indicators were obtained after weight normalization and consistency testing, , as shown in Fig. 2.

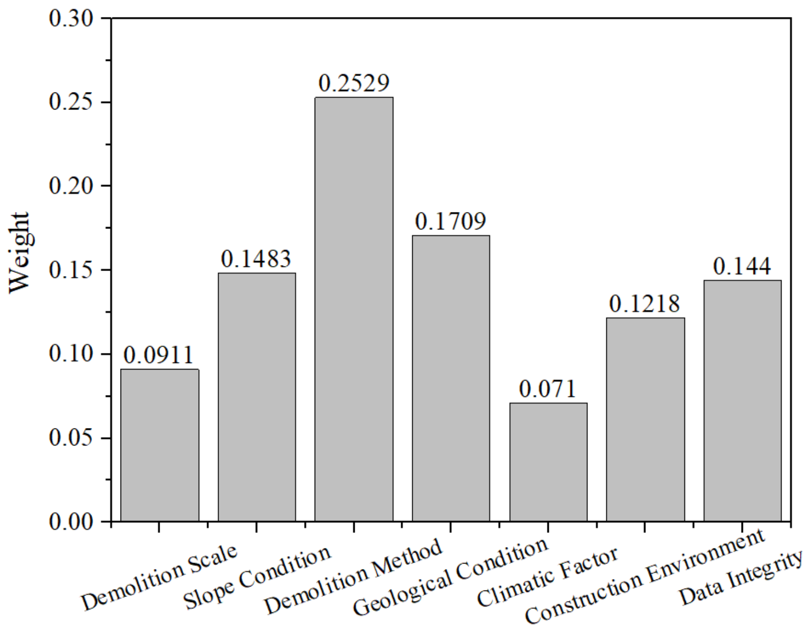


**Fig. 2.** Primary indicator weights.

The risk score $S$ is calculated as given in Formula (1),

$$S = \sum X_{ij}$$
$$X = R_{ij}\gamma_{ij} \quad (1)$$

where $R_{ij}$ refers to the secondary indicator score, $\gamma_{ij}$ denotes the statistically obtained weight value of the secondary indicators. Referring to the risk level division principles in the *Guidelines for Safety Risk Assessment of Highway Cut Slope Construction*, the classification criteria for risk level are indicated in Tab. 8.

**Table 8.** Classification criteria for risk level.

| Risk Level | Computed Score S |
|---|---|
| Extreme Risk Level IV | $S>60$ |
| High-Risk Level III | $45<S\leq60$ |
| Moderate Risk Level II | $30<S\leq45$ |
| Low-Risk Level I | $S\leq30$ |

## 4 Risk assessment of engineering cases

This section focuses on the risk assessment analysis of the existing anchor cable frame beam-supported slope project in the highway reconstruction and expansion project. The specific analysis process is outlined as follows:

(1) The slope is a soil slope, with a slope length of 200m, a height of about 54.5m, and a slope rate of around 45°. The value of $A_{11}$ is taken as 93 points, and the value of $A_{12}$ is 100 points.

(2) The slope experiences minimal deformation, with insignificant damage to the support structure, signifying good slope condition, and $A_{21}$ is set at 12 points.

(3) The slope demolition method proceeds from top to bottom. $A_{31}$ takes the value of 45 points, and $A_{32}$ is taken as 25 points. During construction, firstly, hydraulic breakers and excavators are utilized to demolish frame beams, cut steel bars, excavate soil around anchor cables, and then break mud blocks, cut anchor cables, and carry out earth excavation work. The construction process is relatively mature, with $A_{33}$ scored at 25 points.

(4) The upper part of the slope is powdery clay, and the lower part is fully weathered, sandy soil-like, and strongly weathered rock strata. The soil of the slope excavation is mainly a fully weathered and sandy weathered rock stratum, with loose soil and poor excavation stability. $A_{41}$ is rated at 65 points. There are no continuous or developed structural surfaces in the slope body, with $A_{42}$ scored at 15 points. There is no groundwater in the slope body, and $A_{43}$ takes the value of 8 points.

(5) The construction time of the slope is in the dry season. According to data, the average annual rainfall in the area is 1161.4 mm, with occasional geologic hazards. $A_{51}$ is assigned 85 points, and $A_{52}$ is scored at 40 points.

(6) The existing support structure for this slope is an anchor cable frame beam, which is assigned a value of 55 points for $A_{61}$. There is an operational highway within one times the height range below the roadbed, and the $A_{62}$ is taken to be 90 points.

(7) There is one survey section for the slope, with three drilling points per section. $A_{71}$ is valued at 40 points. The slope design documents are complete, in which special engineering construction techniques and matters are described, and appropriate control measures are formulated, with $A_{72}$ taking the value of 12 points.

Combining the determined indicator weights, the risk assessment scores for the slope construction project are calculated as listed in Table 9.

**Table 9.** Calculation of slope construction risk assessment score.

| No. | Primary Indicator | Secondary Indicator | Weight | Total Weight | Assessment Score | Final Score |
|---|---|---|---|---|---|---|
| 1 | Demolition Scale ($A_1$) | Slope Height ($A_{11}$) | 0.0706 | 0.1412 | 93 | 6.57 |
| | | Slope Rate ($A_{12}$) | 0.0706 | | 100 | 7.06 |
| 2 | Slope Condition ($A_2$) | Self-condition of Slops ($A_{21}$) | 0.1345 | 0.1345 | 12 | 1.61 |
| 3 | Demolition Method ($A_3$) | Demolition Sequence ($A_{31}$) | 0.0736 | 0.2138 | 45 | 3.31 |
| | | Demolition Method ($A_{32}$) | 0.0675 | | 25 | 1.69 |
| | | Process Maturity ($A_{33}$) | 0.0727 | | 25 | 1.82 |
| 4 | Geological Condition ($A_4$) | Stratigraphic Lithology ($A_{41}$) | 0.0477 | 0.1519 | 65 | 3.10 |
| | | Slope Structure ($A_{42}$) | 0.0476 | | 15 | 0.71 |
| | | Groundwater ($A_{43}$) | 0.0566 | | 8 | 0.45 |
| 5 | Climatic Factor ($A_5$) | Construction Season ($A_{51}$) | 0.0646 | 0.1047 | 85 | 5.49 |
| | | Natural Disasters ($A_{52}$) | 0.0402 | | 40 | 1.61 |
| 6 | Construction Environment ($A_6$) | Existing Support Type ($A_{61}$) | 0.0809 | 0.1278 | 55 | 4.45 |
| | | Surrounding Environment ($A_{62}$) | 0.0469 | | 90 | 4.22 |
| 7 | Data Integrity ($A_7$) | Geological Data ($A_{71}$) | 0.0651 | 0.1260 | 40 | 2.60 |
| | | Design Documents ($A_{72}$) | 0.0609 | | 12 | 0.73 |
| Total Score: 45.43 points | | | | | | |

After calculation, the risk assessment score of the slope construction is 45.5 points, classifying it as Level III, signifying a high-risk level. Consequently, special attention should be given to the construction process, analyzing major risk factors, and implementing measures to prevent significant risks.

## 5 Risk control measures

The construction process primarily covers tasks such as anchor cable cutting, frame beam demolition, and earthwork excavation. The key control measures for various tasks are listed below:

(1) Effective personnel management: Targeted protection should be focused, with protective equipment providing adequate safety functions. The construction site shall be managed uniformly to ensure that each work is carried out systematically. Technical instructions should be delivered to ensure that personnel understand specific methods, technical points, and safety precautions.

(2) Optimization of construction methods: Anchor head anti-ejection measures should be done before construction to avoid ejection and potential injury. Abrasive disk cutters are preferred for cutting anchor cables instead of electric arc cutting. An orderly connection shall be made between different construction processes, and violent dismantling shall be prohibited.

(3) Strengthening of construction monitoring: In the construction process, construction monitoring should be emphasized and carried out strictly following the monitoring program. Then, personnel should monitor the data timely to track variations in data, master the internal forces and deformation dynamics of slopes, and communicate with the designers in a timely manner to offer references to the design department.

## 6 Conclusion

Aiming at the safety risk of slope construction in highway reconstruction and expansion projects, this paper proposes a risk assessment method from the perspective of construction characteristics and the surrounding environment, considering factors such as demolition scale, slope condition, demolition method, geological condition, climatic factors, construction environment, and data integrity. Furthermore, typical engineering cases are analyzed, leading to the following main conclusions:

(1) Engineering specificity should be considered in the risk assessment of slope construction for highway reconstruction and expansion projects, and the assessment method should encompass factors such as the demolition of support structures to better align with actual engineering conditions.

(2) During the establishment of the assessment index system, factors such as existing slope conditions, demolition methods, and construction environment are under consideration, further enhancing the practicality of the assessment method.

(3) The assessment and analysis of engineering cases classify the slope construction risk level as Level III, indicating a high-risk level. Further, during the construction process, risk control measures are proposed in terms of effective personnel management, optimization of construction methods, and strengthening of construction monitoring.

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