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Risk identification, assessment and monitoring design of high cutting loess slope in heavy haul railway

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Abstract. The stability of cutting slope influences the safety of railway operation, and how to identify the stability of the slope quickly and determine the rational monitoring plan is a pressing problem at present. In this study, the attribute recognition model of risk assessment for high cutting slope stability in the heavy haul railway is established based on attribute mathematics theory, followed by the consequent monitoring scheme design. Firstly, based on comprehensive analysis on the risk factors of heavy haul railway loess slope, collapsibility, tectonic feature, slope shape, rainfall, vegetation conditions, train speed are selected as the indexes of the risk assessment, and the grading criteria of each index is established. Meanwhile, the weights of the assessment indexes are determined by AHP judgment matrix. Secondly, The attribute measurement functions are given to compute attribute measurement of single index and synthetic attribute, and the attribute recognition model was used to assess the risk of a typical heavy haul railway loess slope, Finally, according to the risk assessment results, the monitoring content and method of this loess slope were determined to avoid geological disasters and ensure the security of the railway infrastructure. This attribute identification- risk assessment- monitoring design mode could provide an effective way for the risk assessment and control of heavy haul railway in the loess plateau.

Keywords: loess cutting slope; risk assessment; attribute recognition; geological hazard monitoring

1. Introduction

With the rapid increase of infrastructure investment, a large number of heavy haul railways have been built in Loess Plateau - the second step in China. Due to the influence of geological conditions and environmental factors, especially the gravity and weathering force, earthquake, precipitation and train load, subgrade settlement and local block invasion occurred in heavy haul railway cutting slope, even lead to landslide hazard. The disaster above would affect traffic safety and destroy railway infrastructure, causing serious property losses and personnel casualties. Therefore, it is necessary to carry out an in-depth study on the stability of the heavy load railway cutting slope (Qian and Rong 2008).

Among the existing research methods, the risk assessment of cutting slope considering the influence of multiple factors gained more and more attention (Li and Li 2002). Risk assessment is

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belonged to pre-evaluation, which can identify the danger degree of the cutting slope in advance, and provide the basis for targeted monitoring, prevention and treatment, so as to achieve the aim of improving the driving safety and reducing the cost.

Luo *et al*. (1998) studied the characteristics of geological hazards, the composition of risk, vulnerability and status in disaster risk assessment; Yin and Yan (2000) carried out systematic study on the spatial prediction and regionalization of landslide hazards, successively put forward the quantitative evaluation information analysis model and multiple factor regression analysis model, conducted risk analysis of landslide disaster in Qinba mountains and the Three Gorges Reservoir area. Zhang *et al*. (2017) focused on slope collapse risk of tunnel entrance, and established the indexes and their weights that influence the stability of the slope of above the cave, putting forward the reasonable treatment scheme for grouting. Remondo (2006) carried out a detailed study of landslide occurrence and damage in the recent past years, implemented a quantitative procedure with analyses and mapping in a GIS to access the direct and indirect losses caused by landside. Van Den Eeckhaut (2011) also suggested to create national and/or regional landslide databases (LDBs) that give insight into the location, date, type, size, activity and causal factors of landslides as well as resultant damage to perform national-scale landslide susceptibility, hazard and risk analyses.

However, in the cutting slope stability evaluation, it is difficult to accurately predict and evaluate slope stability in the future according to the survey data in a certain period of time or in a particular natural condition because the membership function is Randomness and the classification is not clear. Cheng (1997) proposed a theoretical model of attribute recognition, which is based on the concept of attribute set, attribute measure space and ordered segmentation, making the comprehensive evaluation results more reliable.

Today, attribute mathematics theory has been successfully applied in the field of geotechnical engineering, and gained a certain degree of research. However, applications of attribute mathematics theory on risk evaluation of cutting slope were relatively lack. In this study, based on attribute mathematics theory, attribute recognition model for high cutting loess slope in the heavy haul railway was established, followed by a case study of the typical railway cutting slope engineering. This model combines the characteristics of the two methods above to establish the evaluation matrix, thus the evaluation results could have a good agreement with the actual situation. It is hoped that this method could provide certain reference for the slope monitoring plan formulation and protective measure optimization.

2. Attribute recognition model of risk assessment on the high cutting loess slope in heavy haul railway

The risk assessment on the stability of slope is a comprehensive assessment system with discrimination or prediction for slope instability by using the influencing factors. The measurement problems with qualitative descriptions can be solved based on attribute mathematics theory. The attribute comprehensive assessment system can be divided into three subsystems: attribute measure system of single index, comprehensive attribute measure system of multiple indices and attribute recognition analysis.X is assumed as the evaluated object space, and the evaluated object x_i (i=1, 2, …,n) has m evaluated indices I_j (j =1, 2, …, m). The value of the j-th evaluated index $I_j$in x_i, t_j, is divided into K kinds of assessment grades C_k(k=1, 2, …,K). The attribute space F taken as {grades of slope stability of tunnel portal} is assumed to equal to {C_1,

C_2, …,C_K}, where each kind of circumstance is the attribute set.

The corresponding attribute measures of different attribute sets satisfying additivity rule can be obtained from the attribute arithmetic. The single-index attribute measure μ_{xjk} shows that the measured value of the *j*-th evaluated index $I_j$of evaluated object, t_j,can be computed with the size of attribute C_k, and the comprehensive attribute measure μ_{xk} shows that the evaluated object can be calculated using the size of grade C_k.

The purpose of attribute recognition is that the comprehensive attribute measure μ_{xk}. is used to estimate which assessment grade(C_k) *x* should belong to. In general, the assessment set (C_1, C_2, …,C_K) is a ordered set in the attribute comprehensive assessment estimated by confidence criterion.

The confidence criterion is that (C_1, C_2, …,C_K) is taken as one ordered assessment set of attribute space *F*. λ is the confidence coefficient with the range of $0.5<\lambda\leq 1$, and the value of λ is commonly taken as 0.6~0.7.

For the case of $C_1>C_2>\ldots>C_K$, if the value of k_0 can be adopted Eq. (1), *x* can be considered to be belonged to the gradeof C_{k0}.

$$k_0 = \min\left\{k : \sum_{l=1}^{k} \mu_{xl} \geqslant \lambda, 1 \leqslant k \leqslant K\right\} \tag{1}$$

For the case of $C_1<C_2<\ldots<C_K$, if the value of k_0 can be adopted Eq. (2), *x* can be considered to be belonged to the gradeof C_{k0}.

$$k_0 = \max\left\{k : \sum_{l=k}^{K} \mu_{xl} \geqslant \lambda, 1 \leqslant k \leqslant K\right\} \tag{2}$$

The analysis process is as follows:

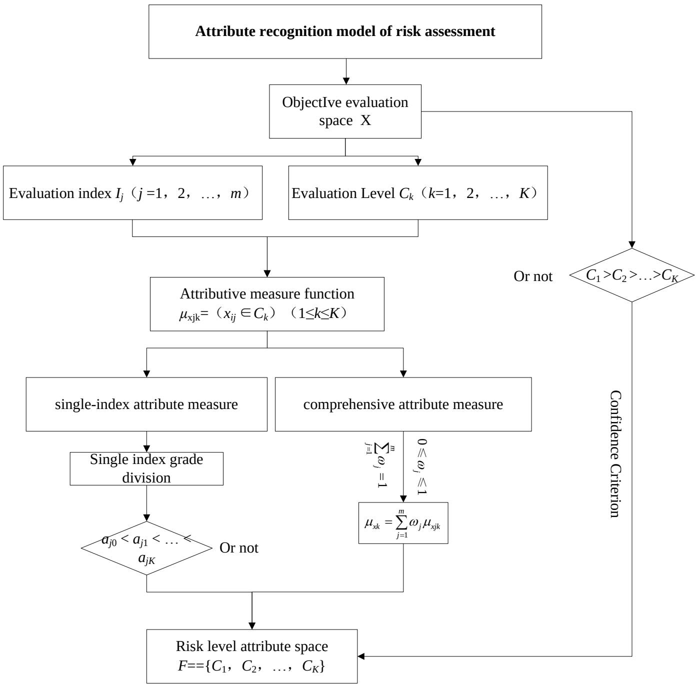

Fig. 1 The steps of assessment

The single-index attribute measure functions $\mu_{xjk}(t)$are as follows

$$\mu_{xj1}(t)=\begin{cases} 1, & t<a_{j1}-d_{j1} \\ \dfrac{a_{j1}+d_{j1}-t}{2d_{j1}}, & a_{j1}-d_{j1}\leqslant t\leqslant a_{j1}+d_{j1} \\ 0, & t>a_{j1}+d_{j1} \end{cases} \tag{3}$$

$$\mu_{xjk}(t)=\begin{cases} 0, & t<a_{jk-1}-d_{jk-1} \\ \dfrac{t-a_{jk-1}+d_{jk-1}}{2d_{jk-1}}, & a_{jk-1}-d_{jk-1}\leqslant t\leqslant a_{jk-1}+d_{jk-1} \\ 1 & a_{jk-1}+d_{jk-1}<t<a_{jk}-d_{jk} \\ \dfrac{a_{jk}+d_{jk}-t}{2d_{jk}}, & a_{jk}-d_{jk}\leqslant t\leqslant a_{jk}+d_{jk} \\ 0, & t>a_{jk}+d_{jk} \end{cases} \tag{4}$$

$$\mu_{xjK}(t)=\begin{cases} 0, & t<a_{jK-1}-d_{jK-1} \\ \dfrac{t-a_{jK-1}+d_{jK-1}}{2d_{jK-1}}, & a_{jK-1}-d_{jK-1}\leqslant t\leqslant a_{jK-1}+d_{jK-1} \\ 1, & t>a_{jK-1}+d_{jK-1} \end{cases} \tag{5}$$

In which：k=1， 2, … ,K-1; j=1, 2, …, m。

3. Attribute evaluation index system and weight analysis

According to the previous engineering examples and experience, the risk of cutting slope is affected by many complex factors in various ways and different degree (Zhang *et al*. 2017). As is difficult to analyze each factor, only the most important and influential factors should be selected (Remondo *et al*. 2006). In this study, collapsibility, tectonic feature, slope shape, rainfall, vegetation conditions, train speed were selected as the indexes of the risk assessment to cutting slop in heavy haul railway, in which topography, landforms, structure features, natural factors and hydro geological conditions of loess slope were overall considered. Therefore, these indexes have good operability, universality and applicability in engineering practice (Wen 2008). Furthermore, the risk factors in this paper are relatively independent. Factors of ground water table and freeze-thaw have some relevance with the loess collapsibility and precipitation. If these factors were all taken into account in the assessment, it will lead to irrational weight, affecting the evaluation result correctness.

3.1 Attribute evaluation index analysis

3.1.1 Loess collapsibility I_1

The type and nature of soil have a significant effect on the instability of the cutting slope. Collapsible loess is a special type of soil with uniform quality, loose structure, developed void.

Dry loess has relatively high strength and low compressibility, whereas the soil strength reduced and its structure destroyed rapidly rapid reduction with great additional subsidence when soaked by water. Collapsibility of loess is related to its physical, chemical, hydraulic and mechanical properties, affecting the stability of slopes to a certain extent.

Loess collapsible degree is decided by coefficient δ_s according to the indoor compression test, Calculated by the Collapse coefficient formula

$$d_s = \frac{h_p - h_p^{'}}{h_0} \tag{6}$$

In which: h_p—the height of undisturbed soil sample under pressure s after the stabilization of; h'_p -- the sample above saturated after stability; h_0-- soil original height.

When $\delta_s > 0.07$, determined as strong collapsible loess

$0.03 < \delta_s < 0.07$, determined as medium collapsible loess;

$0.015 \le \delta_s < 0.03$, determined as weakly collapsible loess;

$\delta_s < 0.015$, determined as non-collapsible loess.

3.1.2 Geological structure characteristic I_2

Geological structure characteristic is one of the most important factors for the cutting slop failure and instability, mainly refers to the regional geology feature, the fold form, joint fissure and regional neotectonic activities. The effect of soil joints and cracks play an important role on the deformation and failure of the slope and some cracks constitute the failure surface or sliding surface of the landslide themselves. In addition, the spacing of soil cracks is a relatively easy value to obtain, which can objectively reflect the geological structure and structural characteristics. According to the historical measurement statistics, the stability degree of geological structure can be divided into four levels from high to low concerning joint spacing J_d, i.e., 0.01 m<J_d≤0.1 m, 0.1 m<J_d≤0.3 m, 0.3 m<J_d≤0.8 m and 0.8 m<J_d≤2.0 m.

3.1.3 Slope shapeI_3

Slope shape reflects the overall undulation of slope (Ye and Chen 2010). Generally, when partial slope collapsed, the slump soil would get larger kinetic energy at the slope bottom of the concave slope, while for the convex slope, the kinetic energy became smaller at the corresponding bottom of the slope because of the early kinetic energy loss. Slope with straight surface was in the middle[4]. The upper-convex and lower-concave slopes have a better energy dissipating effect on the collapsed soil on the account of the collision between collapsed soil and slope surface. Correspondingly, the upper-concave and lower-convex slopes would increase the kinetic energy and scattered area of slump soil. In addition, the energy dissipation effect will increase with the undulating quantity and height of the slope surface. According to the difference of slope shape, the risk degree can be divided into four levels from high to low, shown in Table 1.

3.1.4 Precipitation factorI_4

Precipitation is another important factor in inducing landslides. Precipitation not only increases the water content of the soil to increase the gravity and sliding force, but reduces the friction of sliding surface because of the rain infiltration (Wang *et al*. 2017). Under extreme conditions, it will trigger a massive land slide, seriously endanger the safe operation of the railway. Research shows that more than 80% of landslide, debris flow and rockfall occurred during the rainy season,

Table 1 Slope shape grade

Level grading	Description	Undulating height of slope surface
Ⅰ	straight slope, little undulation of the slope, upper-convex and lower-concave slopes	0 m~0.1 m
Ⅱ	convex slope with less undulation of the slope	0.1 m~0.3 m
Ⅲ	concave slope with more undulating slopes	0.3 m~0.4 m
Ⅳ	upper-concave and lower-convex，large undulating quantity	0.4 m~0.5 m

Table 2 Slope vegetation grading

grading	Slope vegetation description
Ⅰ	bare bedrock, undeveloped vegetation, and slope surface has no cover.
Ⅱ	rare vegetation, mainly with grass and a thinner covering layer
Ⅲ	generally developed vegetation, mainly with shrubs, and a covering layer with a certain thickness(< 1.0 m)
Ⅳ	Flourishing vegetation, mostly arbor, and a thicker soft cover.

especially in the rain or soon after the rain, rarely occurred in the dry season and rainy days. Therefore, based on the annual rainfall is divided relative risk degree into 4 levels: high rainfall zone (>800 mm), medium rainfall zone (800 mm~400 mm), low rainfall area (400 mm~200 mm), rare rainfall zone (0 mm~200 mm).

3.1.5 Slope vegetation I_5

The vegetation coverage and type have a certain influence on the slope risk. High vegetation coverage, especially arbor trees with the deep root, will helpfixing the surface weathering rock, controlling the slide effectively; On the contrary, low vegetation coverage, herbaceous botany with shallow root, easily occurs sliding.

In order to quantitative evaluation, grading standards is shown in Table 2

3.1.6 Heavy haul train speed I_6

Traffic vibration loads of heavy haul trains characterize "long duration" and "small amplitude" and its influence mechanism on the slope has not been fully understood. But the effect of heavy haul train vibration load can be considered from three aspects (Du 2015): (1) The micro vibration caused by heavy haul trains may lead to the change of slope pore water pressure; (2) It may cause loess liquefaction in the saturated condition, (3) It may influence the micro structure of soil, which will affect the mechanical properties[10]. Train impact load leads to the increase of dynamic stress and acceleration of cutting soil and rock. Meanwhile, the train’s impact will further reduce the soil capacity to resist deformation and increase the dynamic stress of roadbed, leading to the cutting deformation. The effect of vibration and impact increase with the speed of the heavy haul train. So in terms of the speed of heavy haul train the risk degree could be divided into 4 levels from high to low: ≥130 km/h, 130~100 km/h, 100~70 km/h and 70~60 km/h.

3.2 Grading criteria of attribute assessment indices

Based on above-mentioned analysis with grade division, the attribute assessment indices of slope stability are divided into four grades, as shown in Table 3.

Table 3 Indexes and criteria for risk assessment of slope stability at tunnel portal

Risk level	Loess collapsibility	Joints spacing J_d/m	Undulation /m	Precipitation /mm	vegetation	train speed
high	$\delta_s > 0.07$	0.01~0.1	0.0~0.1	>800	Ⅰ	120
Relatively High	$0.03 < \delta_s < 0.07$	0.1~0.3	0.1~0.3	400~800	Ⅱ	120~105
medium	$0.015 \le \delta_s < 0.03$	0.3~0.8	0.3~0.4	200~400	Ⅲ	105~75
low	$\delta_s < 0.015$	0.8~2.0	0.4~0.5	0~200	Ⅳ	75~60

Table 4 Attribute measure functions of single index

C1	C2	C3	C4
$\mu_{x11}(t)=\begin{cases}0, & t<0.05\\ 25t-\frac{5}{4}, & 0.05\leqslant t\leqslant 0.09\\ 1, & t>0.09\end{cases}$	$\mu_{x12}(t)=\begin{cases}0, & t<0.0225\\ \frac{200t}{3}-\frac{3}{2}, & 0.0225\leqslant t\leqslant 0.0375\\ 1, & 0.0375<t<0.05\\ \frac{9}{4}-25t, & 0.05\leqslant t\leqslant 0.09\\ 0, & t>0.09\end{cases}$	$\mu_{x13}(t)=\begin{cases}0, & t<0.0075\\ \frac{200t}{3}-\frac{1}{2}, & 0.0075\leqslant t\leqslant 0.0225\\ \frac{5}{2}-\frac{200t}{3}, & 0.0225\leqslant t\leqslant 0.0375\\ 0, & t>0.0375\end{cases}$	$\mu_{x44}(t)=\begin{cases}1, & t<0.0075\\ \frac{3}{2}-\frac{200t}{3}, & 0.0075\leqslant t\leqslant 0.0225\\ 0, & t>0.0225\end{cases}$
$\mu_{x21}(t)=\begin{cases}1, & t<0.055\\ \frac{29}{18}-\frac{100t}{9}, & 0.055\leqslant t\leqslant 0.145\\ 0, & t>0.145\end{cases}$	$\mu_{x22}(t)=\begin{cases}0, & t<0.055\\ \frac{100t}{9}-\frac{11}{18}, & 0.055\leqslant t\leqslant 0.145\\ 1, & 0.145<t<0.2\\ 2-5t, & 0.2\leqslant t\leqslant 0.4\\ 0, & t>0.4\end{cases}$	$\mu_{x23}(t)=\begin{cases}0, & t<0.2\\ 5t-1, & 0.2\leqslant t\leqslant 0.4\\ 1, & 0.4<t<0.55\\ 2.1-2t, & 0.55\leqslant t\leqslant 1.05\\ 0, & t>1.05\end{cases}$	$\mu_{x24}(t)=\begin{cases}0, & t<0.55\\ 2t-1.1, & 0.55\leqslant t\leqslant 1.05\\ 1, & t>0.25\end{cases}$
$\mu_{x31}(t)=\begin{cases}1, & t<0.05\\ 1.5-10t, & 0.05\leqslant t\leqslant 0.15\\ 0, & t>0.15\end{cases}$	$\mu_{x32}(t)=\begin{cases}0, & t<0.05\\ 10t-0.5, & 0.05\leqslant t\leqslant 0.15\\ 1, & 0.15<t<0.25\\ 3.5-10t, & 0.25\leqslant t\leqslant 0.35\\ 0, & t>0.35\end{cases}$	$\mu_{x33}(t)=\begin{cases}0, & t<0.25\\ 10t-2.5, & 0.25\leqslant t\leqslant 0.35\\ 1, & <t<0.25\\ 4.5-10t, & 0.35\leqslant t\leqslant 0.45\\ 0, & t>0.45\end{cases}$	$\mu_{x34}(t)=\begin{cases}0, & t<0.35\\ 10t-3.5, & 0.35\leqslant t\leqslant 0.45\\ 1, & t>0.45\end{cases}$
$\mu_{x41}(t)=\begin{cases}0, & t<600\\ \frac{t}{2000}-\frac{3}{2}, & 600\leqslant t\leqslant 1000\\ 1, & t>1000\end{cases}$	$\mu_{x42}(t)=\begin{cases}0, & t<300\\ \frac{t}{200}-\frac{3}{2}, & 300\leqslant t\leqslant 500\\ 1, & 500<t<600\\ \frac{5}{2}-\frac{t}{400}, & 600\leqslant t\leqslant 1000\\ 0, & t>1000\end{cases}$	$\mu_{x43}(t)=\begin{cases}0, & t<100\\ \frac{t}{200}-\frac{1}{2}, & 100\leqslant t\leqslant 300\\ \frac{5}{2}-\frac{t}{200}, & 300\leqslant t\leqslant 500\\ 0, & t>500\end{cases}$	$\mu_{x44}(t)=\begin{cases}0, & t<100\\ \frac{3}{2}-\frac{t}{200}, & 100\leqslant t\leqslant 300\\ 1, & t>300\end{cases}$
$\mu_{x61}(t)=\begin{cases}0, & t<120\\ \frac{t}{20}-6, & 120\leqslant t\leqslant 140\\ 1, & t>140\end{cases}$	$\mu_{x62}(t)=\begin{cases}0, & t<85\\ \frac{t}{30}-\frac{17}{6}, & 85\leqslant t\leqslant 115\\ 1, & 115<t<120\\ 7-\frac{t}{20}, & 120\leqslant t\leqslant 140\\ 0, & t>140\end{cases}$	$\mu_{x63}(t)=\begin{cases}0, & t<65\\ \frac{t}{10}-\frac{13}{2}, & 65\leqslant t\leqslant 75\\ 1, & 75\leqslant t\leqslant 85\\ \frac{23}{6}-\frac{t}{30}, & 85\leqslant t\leqslant 115\\ 0, & t>115\end{cases}$	$\mu_{x64}(t)=\begin{cases}1, & t<65\\ \frac{15}{2}-\frac{t}{10}, & 65\leqslant t\leqslant 75\\ 0, & t>75\end{cases}$

3.3 Attribute measure functions of single index

The attribute measure functions concerning single index could be established with formula (3)~(5), as shown in Table 4, in which there are 4 quantitate indexes I_1~I_4, I_6 and 2 qualitative index I_5, whose attribute measure expressed by 0 or 1.

3.4 Weight determination of index

The index weight reflects its importance to the evaluation objective. Expert scoring method, binomial coefficient method and analytic hierarchy process are commonly used to determine the weight. The analytic hierarchy process solving weight can be summarized as: (1) formation of judgment matrix; (2) solution of importance order; (3) consistency check. The rationality of weight solution is greatly affected by the scale determination in formation of judgment matrix, as the 10/10 ~ 18/2 scale method with well uniformity was adopted in this paper. Then the unit feature vector (weights) ω corresponding to the maximum eigenvalue λ_{max} of judgment matrix can be derived from square root method. Finally, comes the consistency check of judgment matrix, which can be considered to be reasonable weight assignment when the consistency ratio of judgment matrix C_R<0.10.

The solved weights of assessment indices were ω = (0.2514, 0.1778, 0.1778, 0.131, 0.131, 0.131), the maximum eigenvalue λ_{max}=8.0002, the consistency ratio of judgment matrix $C_R=2.382\times10^{-5}<0.10$, indicating the proposed weights can satisfy the consistency check.

4 Engineering application

4.1 Project overview

The target railway cutting slope located on the left side of the railway line. The slope of deep cutting is high and steep, whose surface is covered with sparse vegetation. The railway area is located in loess hilly area, where the gully is developed in east-west direction and the highest slope is nearly 30 m high. It is belonged to temperate continental monsoon climate, the seasonal changes significantly. The on-site conditions are shown in Fig. 2

Fig. 2 On-site conditions

4.2 Single-index attribute and comprehensive measure calculation

Table 5 showed the sample data, the single-index attribute measure calculated by Table 4 and the comprehensive attribute measure calculated by assessment step (shown in Fig. 1).

Table 6 Calculation table of attribute measures

evaluation Index	Details	Symbol	Value	Attribute measurement C1	C2	C3	C4
collapsibility	The monitoring area mainly develops the Mesozoic-Cenozoic strata, which are loess and argillaceous from shallow to deep successively. The collapsibility coefficient of the soil is 0.065 by experimental observations, belonging to medium collapsible loess.	I_1	0.065	0.375	0.625	0	0
Geological features	The monitoring area is located in the inter-basin basin between the Loess Plateau and the Feichuang River Basin. Although the geological structure is complex in the area, there is no large regional fault structure, mostly loess strata, with loose layer and weak bearing capacity.	I_2	0.13m	0.17	0.83	0	0
Slop shape	The topography shows as gentle slope - steep slope - gentle slope - steep slope from top to bottom, which is the concave upward and convex downward with less fluctuation, According to the site survey data, the average fluctuating height is 0.08 7m.	I_3	0.087m	0.63	0.37	0	0
precipitation	The precipitation in the monitoring area is mainly concentrated in July and August for two months, and the rainfall intensity is relatively large. The average annual precipitation in the area is 510 mm, the average monthly maximum rainfall is 150 mm.	I_4	510mm	0	1	0	0
Slope surface vegetation conditions	Vegetation (mostly Shrubs) develops at the top and cracks of the slope. Some of the cracks are filled with clay and the vegetation often grows along the fissures. Slope surface vegetation conditions for the poor level.	I_5	Ⅲ	0	0	1	0
Heavy haul train speed	In this section of the railway line the average train speed is 105 km / h.	I_6	105m/s	0	0.67	0.33	0
	Comprehensive attribute measurement			0.236	0.589	0.175	0

(a) Surface erosion (b) slop cracks

Fig. 3 Surface damage of the cutting slope

4.3 Attribute identification analysis

For it is hoped the risk to be lower, the evaluation set (C1, C2, C3, C4) should be an ordered set with C1 <C2 <C3 <C4. In accordance with the confidence criteria Eq. (2) to discriminate, take λ = 0.70, then the Eq. (12) is simplified to

$$k_0 = \max\left\{k : \sum_{l=k}^{4} \mu_{xl} \geqslant 0.7,\ 1 \leqslant k \leqslant 4\right\} \tag{7}$$

Calculated risk level was C2, Corresponding to high risk. Then the on-site manual inspection showed since the railway was opened to traffic, many bulges and fractures occurred on the surface of K3 + 0-410 section in this area. The fractures distributed longitudinally along the road and mostly located near the slope steps contacting the subgrade. Meanwhile, the surface rain erosion was serious with multiple cracks (as shown in Figs. 3(a) and 3(b)). The inspection indicated that to the slope was unstable and needed further tracking and monitoring. As a good agreement with the risk assessment, it is proved that the application of attribute mathematical theory to the risk assessment of high cutting loess slopes in heavy haul railway is reasonable and feasible.

4.4 Utilization of evaluation results and determination of monitoring scheme

Target monitoring area was established as section K3+0-410 in order to realize the slope disaster prediction and failure mechanism study. Combined with the preliminary investigation, landslide characteristics analysis and risk monitoring, the content of risk assessment conclusion was determined, mainly including: surface deformation, deep displacement, soil moisture, rainfall Crack width and system safety (shown in Table 7).

5 Conclusions

The study proposed a slope treatment model that combined with attribute identification, risk assessment, and monitoring design.

- The attribute recognition model of risk assessment for high cutting slope stability in the heavy haul railway is established based on attribute mathematics theory. 6 risk factors of collapsibility, tectonic feature, slope shape, rainfall, vegetation conditions and train speed are selected as the indexes of the risk assessment, and the grading criteria of each index is established. Meanwhile, the weights of the assessment indexes are determined by AHP judgment matrix.
- The attribute measurement functions are given to compute attribute measurement of single index and synthetic attribute, and the attribute recognition model was used to assess the risk of a typical heavy haul railway loess slope. The assessment result is in good agreement with the field investigation.
- The monitoring content and method of this loess slope were determined to avoid geological disasters and ensure the security of the railway infrastructure according to the risk assessment results. This study could improve security the railway construction and construction.

Table 7 Monitoring scheme

content	mode	Monitoring distribution or frequency	Describe
surface deformation	GNSS observation station	6 points in section K3+150， K3+200, K3+300, K3+4000	The surface deformation of the slope is an intuitive performance of the stability of the slope, monitoring of which could show the rough scale and the overall stability of the slope.
deep displacement	Optical / electric angle sensor	5 groups in Section K3+200, K3+300, K3+4000	The deep displacement could be used for analyzing the dynamic characteristics of landslide deformation, which plays an important role in determining the location of the slide zone (or surface) accurately, and studying the current characteristics and development trend of the landslide.
soil moisture	Water content sensor	36 positions	Water content is the key parameter of the soil mechanical properties, and it is also the control variable of the bearing performance of the loess slope.
Precipitation	Integrated sensor for rainfall	1	Precipitation is the main inducing factor of landslides in the monitoring area based on the risk assessment above.
Crack width and system safety	Manual inspection	Once a month	Inspection of the sensor and monitoring working state, as well as the cracks on the surface of the slope

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