Engineering Advances, 2025, 5(4), 226-229
https://www.hillpublisher.com/journals/ea/
ISSN Online: 2768-7961

Remediation Technology and Engineering Application of Cutting Slope Diseases in Red Bed Soft Rock Areas

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How to cite this paper: Hasitire Kurmanbayi. (2025) Remediation Technology and Engineering Application of Cutting Slope Diseases in Red Bed Soft Rock Areas. *Engineering Advances*, 5(4), 226-229.
DOI: 10.26855/ea.2025.10.016

Received: October 30, 2025
Accepted: November 28, 2025
Published: December 24, 2025

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Abstract

The stability of soft rock embankment slopes in red-bed soft rock regions is a key problem in the field of modern geotechnical engineering in arid areas, and it can be significantly affected by environmental changes. This paper provides detailed research about engineering properties, disease mechanisms, and remediation technology for cutting slope along the G575 highway (from Hami to Nanhu section) passing through Paleogene - Neogene Taoshuyuan Formation (E_3N_1t). The area researches the extensive occurrences of brick-red and brownish-red mudstones interspersed with gypsum, which are considered exceedingly soft rocks by the natural uniaxial compressive strength tests of 0.172-2.11 MPa. This is in addition to the laboratory findings that these rocks also possess a considerable expansive capability and are categorized as weak to strong expansion according to their free swelling rate. It is found that the main cause of slope failure in this area is a dual disaster mechanism, in which the rock matrix undergoes rapid physical disintegration when in contact with water, and the cyclic volumetric deformation caused by the repeated process of absorbing and evaporating moisture. In order to solve those kinds of things, we've made and done a very systematic engineering remedial plan. Use geometric optimization by flattening slope ratios (up to 1:2.5) and having wide platforms together with strong, fully enclosed, solid surface protection systems like masonry plastering, skeleton protection. Roadbed base, deep replacement with lime soil, gravel cushion with geomembrane lining to isolate the roadbed from the underlying expansive rock-soil substrate. These technologies' applications have successfully controlled slope deformations and have also formed a good theoretical basis and practice reference for highway constructions in these red bed's soft rocks of a similar kind.

Keywords

Red bed soft rock; Slope stability; Expansive soil; Taoshuyuan Formation; Engineering remediation; Roadbed diseases

1. Introduction

The building of the transportation system in Northwest China encounters a lot of big trouble due to the red bed soft rock on the vast, varied geographical site. This kind of sedimentary formations, which mostly form in the Mesozoic and Cenozoic basins, also carries a reputation due to their unique color—the iron oxide that gives them a red hue and tough engineering traits. Compared with hard rock mass, which mainly depends on its own strength to stabilize itself, red bed soft rock is an individual with unique diagenetic conditions, resulting in its low cementation and sensitivity to changes in the environment [1]. In the arid hinterland of Xinjiang, there is a place in Hami where these rocks are in a kind of equilibrium with the dryness. But the building of roads by digging deep cuts in the hills causes a change to this balance and the effect of air and different degrees of wetness. The main problem studied in this paper is the rapid degradation of slope stability on the G575 Hami to Nanhu township section. The majority of this area consists of the Paleogene - Neogene Taoshuyuan Formation(E_3N_1t), a stratum containing unfavorable geological phenomena. the rock mass shows that low-mechanical-strength characteristic of soft rock, as well as having expansive properties because there is hydrophilic clay mineral and soluble salt like gypsum [2].

2. Geological Environment and Lithological Characterization

The engineering geological environment of the project area is mainly determined by its location in the central erosion plain and denudation terrace between Hami City and Nanhu Township. Here, the climate is more of a very arid continental one, where the evaporation outstrips what precipitation gives us, and these factors result in particular weathering and sediment properties [3]. The primary focus of the highway construction, the core stratigraphic unit is the Paleogene-Neogene Taoshuyuan Formation (E_3N_1t), which extends throughout the project section. This formation has different kinds of rock in it, and it keeps information about how the weather used to be a long time ago. It mainly comprises thick-bedded mudstone with a brick red-brownish red color due to the oxidation condition when these beds were deposited. The intercalated mudstone contains many gypsum deposition horizons. These deposits of gypsum usually appear as lens-shaped bodies, which means that these layers have been created in an ancient super-saline, dry, and hot place. And from an engineering perspective, these evaporites are of great significance: gypsum is soluble, and over time its dissolution will form voids, alter the chemical properties of groundwater, and generate substantial internal pressure within the rock mass in the rock mass because of the hydration expansion of gypsum.

These lithological distributions relative to the road alignment are controlled very strongly by the local geomorphology, creating different engineering sectors. In areas of aeolian landforms or alluvial-proluvial plains environments where it occurs, the Taoshuyuan Formation mudstone is generally buried relatively deeply, with more than 4 m being the case. at those places, the bedrock gets buried deeply by loose Quaternary stuff - it is often windy sand or alluvial soil which becomes a cushion between roadbed and bad rock. Consequently, the direct influence of the mudstone on the roadbed stability in these sections is relatively minor. However, the area is completely different on denudation terraces, mainly on 10km~K31+000 to K47+800. Here, the ground is set up relatively above the plain areas, and the geological process has eroded a lot of the overlying material that lies on top of the young rocks. In this area, the quaternary coverage on those terraces is very loose, with a thickness of just between 0.3~1.0 meters. This is to say that the roadbed excavation work will penetrate directly into the thin cover and then expose the underlying Taoshuyuan Formation mudstone [4].

3. Physical and Mechanical Property Analysis of the Rock Mass

In order to accurately measure the engineering risks presented by the Taoshuyuan formation, we carried out a strict laboratory activity with a focus on the mechanical strength and disintegration traits of the rocks. The primary aim was to classify the rock according to common engineering standards and to determine the parameters for the slope geometry design. According to the "Code for investigation of geotechnical engineering" (GB 50021 - 2001 revised edition of 2009), the classification of soft rock is very important for deciding suitable excavation and support techniques. Because the Taoshuyuan mudstone has certain distinct characteristics and will rapidly disintegrate after being immersed in water, making saturated test specimens is actually very difficult and cannot be completed without changing the basic structure of the rock [5]. Therefore, the investigation has chosen that provision of code which permits the testing of soft as well as very soft materials in a natural moisture condition. There were a total of 14 moderately weathered mudstone groups collected from different boreholes on the route, with special attention paid to the critical K31 to K47 section.

These mechanical test results gave it a stark quantification of its weakness. As shown in Table 1, the natural uniaxial compressive strength of all 14 sample groups was very low. Data shows strengths within a range of a minimum value of 0.172MPa and a maximum value of 2.11MPa. All samples return a strength value very far from, or much less than, the 5MPa threshold. In the category of geotechnics, rocks are definitely classified as “extremely soft rock” when they have saturated uniaxial compressive strength standard values lower than or equal to 5MPa. The fact that very low numbers are achieved even at the natural humidity level, where the rock still retains some matric suction and capillary tension, is an indicator of its fragile nature. if these rocks become saturated, they are likely to lose almost all of their strength, behaving more like a slurry than a solid rock mass.[6]. The differences in the data can be seen between the data from SQZK-12 at 1.49 MPa and SQZK-16 at 0.285MPa.

Table 1. Natural Uniaxial Compressive Strength Test Results of Mudstone Samples

Exploration Point No.	Depth (m)	Natural Uniaxial Compressive Strength (MPa)
SQZK-12	9.0 - 9.2	1.49
SQZK-12	16.7 - 16.9	0.801
SQZK-12	22.3 - 22.5	0.215
SQZK-14	5.4 - 5.6	0.222
SQZK-14	18.7 - 18.9	0.394
SQZK-16	13.8 - 14.0	0.285
SLJZK-1	9.8 - 10.0	0.172
SLJZK-2	9.7 - 9.9	1.37
SLJZK-3	7.5 - 7.7	0.464
SHTZK-9	13.6 - 13.8	0.557
SHTZK-9	15.3 - 15.5	1.65
SHTZK-9	18.5 - 18.7	2.11
SFJZK-13	11.6 - 11.8	0.87
SFJZK-13	11.8 - 12.0	1.44

4. Expansive Characteristics and Regional Distribution

In addition to the problem of being of low strength, there is a secondary, equally destructive characteristic that must be mentioned with regard to Taoshuyuan formation; it also becomes highly expansile. To further clarify the engineering risks, specific expansive soil tests were conducted, including free swelling rate tests and standard water absorption tests and free swelling rate tests. They are important in assessing the tendency of swelling when wet and shrinkage when wet in volume terms, which can impose tremendous distress upon rigid roads and slope aspects. Laboratory tests found that the mudstone is basically an expansive rock and soil; the expansion degree across the entire highway alignment ranges from moderate to strong [7]. And the engineer's answer is complex - she needs support to stop a soft rock from falling in on itself, but also she needs containment to stop an expansive rock from swelling and cracking.

Table 2. Classification of Expansive Rock and Soil by Mileage Section

Mileage Range	Standard Moisture Absorption Water Content (%)	Free Swelling Rate (%)	Plasticity Index	Expansion Classification
K31+000 - K31+900	2.4 ~ 4.9	24 ~ 65	18.1 - 26.2	Medium Expansion
K31+900 - K39+000	1.3 ~ 3.6	14 ~ 40	15.5 - 21.5	Weak Expansion
K39+000 - K40+200	6.4 ~ 8.1	40 ~ 60	20.2 - 20.9	Strong Expansion
K40+200 - K44+000	1.8 ~ 5.0	34 ~ 70	17.3 - 24.8	Medium Expansion
K42+500 - K47+800	7.1	79	26.2	Strong Expansion
K47+800 - K52+000	Not Revealed	N/A	N/A	N/A
K52+000 - K53+400	/	120	/	Strong Expansion

These expanding characteristics are not evenly distributed and have an obvious zonal distribution, which needs to be regarded during the particular arrangement. Based on an analysis of the expansion indicators as they relate to the highway mileage. The routes were segmented into their respective hazard levels. From K39+000-K40+200 as a strong expansion, the free swelling rate is very high (40-60%), and the standard moisture absorption is also high, as shown in Table 2. The parts of the road sections that are of even greater concern are those from K42+500 - K47 plus 800, as well as sections from K52 plus 000 -K53 plus 400, which experience the highest free swelling rates at levels of 79% and 120%, respectively. However, others like K31+900-K39+000 show “Weak Expansion” characteristics. And so that variability is, we need to be a little more loose on our plans. A "one-size-fits-all" slope ratio would be either uneconomical for the weak expansion sections or dangerous for the strong expansion sections. Thus, the remediation measures, especially slope and platform widths, have to conform to those specific extension classifications [8].

5. Remediation Technology: Geometric Optimization and Protection

Formulation of the G575 cutting slope remediation technologies against the low-rock strength with high expansiveness was needed. In the adopted approach, the most effective line of defense is geometric optimization. Realizing that the rockmass had insufficient shear strength, the design utilizes extremely flattened slope ratios so as to compensate for any reduced effective stress resulting from the swelling pressure. Regarding sections which exhibit pronounced characteristics of expansion or which are rather tall, the slope ratio is softened down to as mild as 1: 2: 5; this change is for good reason to reduce the gravity shear that goes across the possible places where failure may occur, to make overall safety margin higher and also to diminish the unloading event that gives first push to expansion. And also, there must be wide platforms that are usually 2.0 to 3.0 meters wide situated between slope platforms.

Along with geometric reshaping, it uses a system where all surfaces are enclosures. Exposed mudstones of the Taoshuyuan Formation will result in the destruction of slope faces when they are exposed to the air, as a sequence of wetting (swelling/softening) and drying (shrinking/cracking) takes place. Therefore, this project uses rigid methods like masonry plastering or skeletal arches filled with masonry or concrete. Unlike vegetative slopes, which might be appropriate for areas where conditions are wetter, the dry and briny nature of this place means that any form of “green” is going to prove to be dangerous and out of place. It provides an impermeable barrier, sealing the moisture content of the slope and holding it at roughly the same level. This keeps the outside water from coming in and softening things up, and it stops the water from going away and making little cracks all over because it dried up.

6. Conclusion

The holistic approach to remediation covers more than just the slope face, but even the roadbed base itself, so that all parts of the paving system are shielded from the expansive force below. As for the places where the roads are sitting overtop the loamy mudstones, there’s quite a great possible danger of the swelling pressure leading them to swell up with differences and cause pavement cracks all up and down, and making some of those surfaces get bumpy. And to reduce the waste, engineering designs lay out a rigid exchange plan. Native expansive soil was excavated to below the roadbed base by 50cm. It is then replaced by the lime-soil mix, which provides higher strength and, importantly, it’s non-expansive. lime treatment has a chemical effect on the structure of the soil, reducing both plasticity and water vulnerability. Alternatively, if Gravel earth is chosen, then place a composite geomembrane at the bottom of the replacement. This is a definitive hydraulic boundary that blocks capillary rise and groundwater movement upwards from below the roadbed.

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