

# Application status and development of expansion soil slope protection and management technology

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**Abstract.** In the context of the Belt and Road, the protection and management of expansive soil slopes has been a hot issue that has attracted much attention. This paper mainly focuses on the current situation and development of expansive soil slopes, aiming to summarize the current research results and progress in this field, status and management technology of expansive soil slopes, points out the problems of slope management in this pain points. This study provides guidance and reference for the actual engineering of expansive soil slopes and further promotes the research progress of slope management.

**Keywords:** Expansive Soil Slopes, Management Techniques, Stability, Protective measures.

## 1. Introduction

Globally, infrastructure development faces many challenges, including geotechnical engineering problems involving geological materials such as soil and rock. And the stability and management of expansiveness of expansive soil slope problems make them one of the major challenges in geoengineering. The stability and management of expansive soil slope problems involves complex mechanics problems and engineering measures, and its study has important theoretical and practical value for the field of geology.

With the progress of the times, the construction of infrastructures is generally increased all over the world, so the development and utilization of expansive soil stability areas are becoming more and more prominent. The special nature and deformation characteristics of expansive soil make the slope prone to large-scale damage in the stress process. If the expansion of the soil is not preventive management, then for engineering construction and people's lives and property is a huge safety hazard. Therefore, it is very necessary to carry out scientific and reasonable management measures for expansive soil slopes.

At present, expansion soil slope management technology has made some progress in engineering practice. Mainly through the use of various technical means, including “anti-seepage moisturizing”, drainage measures and reinforcement control, etc., the stability and safety of expansive soil slopes have been effectively improved, and the potential engineering risks have been reduced at still faces a series of difficult problems and challenges. First, the stability and sustainability of the treatment effect is a key issue. Since expansive soils are highly affected by seasonal climate change and fluctuations in atmospheric water content, the treatment effect may change over time, thus requiring continuous monitoring and observation. In addition, in response to the complexity of expansive soil texture, different control technologies may be required at different locations, which further increases the complexity of the treatment technologies. Secondly, the expensive cost of treatment is also a challenge. The adoption of efficient management techniques for expansive soil slopes usually requires large capital investment, which may have an impact on the feasibility of the project. Therefore, there is an urgent need for further in-depth research and development of new technologies to explore economically practical, environmentally sound and reasonable methods of expansive soil control, which is of vital importance in addressing the issues of stability and cost.

The purpose of this paper is to analyze the current status of the application of expanded soil slope management technology, to summarize the progress of the current research results in this field, and to provide suggestions for the development of the coming year.

## **2. The nature of expansive soils and management difficulties**

### **2.1. Physical and chemical properties of expansive soils**

#### **2.1.1. Chemical property**

The physical and chemical properties of expansive soil are the important basis for the study of expansive soil slope management. Through in-depth study of the physical and chemical properties of expansive soils, it is possible to more accurately select and design the management program of expansive soil slopes and improve the effectiveness and safety of the management.

Expansive soils, also known as "expansive soils", are usually defined as a fractured and expansive geology. Its ability to change volume significantly in both the water-bearing and dry states is called expansive and contractive, which is manifested by expansion on absorption, contraction on loss of water, and the ability to deform repeatedly [1]. Benjamin Loret et al. classified the causes of soil expansion into two types, matrix expansion driven by capillary forces that occurs when the soil is not saturated, and chemical swelling [2]. Among them, hydrophilic clay minerals in expansive soils are considered to be the main factor controlling soil swelling and contraction, and this view is widely recognized by scholars at home and abroad [3-5].

Numerous researchers and scholars [6-8] have extensively studied the composition of clay minerals in expansive soils, and the results show that expansive soils contain a high percentage of clay minerals, such as bentonite and illite. The particle structure of these clay minerals has a laminar structure, which can adsorb a large amount of water, leading to the expansion of the interstices between the soil particles, which in turn causes the volume expansion of the soil. This is the material basis for the significant expansion and contraction characteristics of expansive soils [9]. It can be seen that it is the presence of these hydrophilic minerals in the geotechnical soil that creates the basic conditions for expansion to occur in the geotechnical soil, and water is the important switch that triggers the expansion and contraction properties of the geotechnical soil. In short, the presence of a large number of swelling clay minerals is the main reason for swelling soils to exhibit swelling and contraction.

#### **2.1.2. Physical property and expansion mechanism**

On the other hand, i.e. physical properties, the relevant studies of previous scholars show that the expansion and deformation of soil body is also correlated with its own dry density, water content, overburden pressure and clay mineral content [10-13]. Some researchers [14] further investigated the relationship between the deformation characteristics of expansive soils and the number of dry and wet cycles under loaded conditions, and proposed relevant indicators. Environmental factors such as climatic conditions, water table, and seismic activities also play an important role in the formation and development of expansive soils [15-18]. Various scholars have different opinions on the mechanism of how clay minerals trigger soil expansion, but the viewpoint of "water film mechanism" [19-20] is recognized by most scholars, when clay minerals interact with water, due to the hydrophilicity of the surface of the clay mineral particles and the polar structural characteristics of water molecules, the water molecules will be adsorbed around the mineral particles and form a layer of water film under the action of the electric field force. The water molecules will be adsorbed around the mineral particles under the action of electric field force, forming a layer of water film. The thickness of the water film is affected by physical and chemical properties and environmental factors, and the change of the thickness of the water film directly reflects the expansion and contraction of the expanded clay. The process of swelling caused by water adsorption in expanded clay is essentially the formation and thickening of the water film. This process leads to the formation of a "wedge" force between the clay particles, which increases the spacing between the particles and enlarges the pore space, and ultimately triggers the swelling phenomenon of the soil [20].

## 2.2. Distribution of expansive soils and severity of hazards

According to previous studies and field investigations, expansive soils are widely distributed globally, with a particular concentration in arid and semi-arid areas and where humid conditions occur after long periods of drought. Their distribution depends on geology, climate, hydrology, geomorphology and vegetation. Countries where expansive soils are usually present have higher construction costs because of the additional resources and costs required to deal with the challenges of expansive soils. Jones conducted a research study on the distribution of expansive soils affecting construction costs globally (by region) and summarized them by region [21]. Large areas of these countries have one thing in common: evaporation rates are higher than annual rainfall, resulting in soils that usually suffer from moisture deficits. It is easy to see that expansive soils are widely distributed and therefore their impact is quite significant. According to statistics, the annual economic loss caused by expansive soil problems is at least 15 billion dollars worldwide [22]. China is one of the countries with the most extensive distribution of expansive soils in the world, covering a vast area, and more than a quarter of its population lives in the expansive soil's distribution area. Chinese highway and railroad infrastructure construction also extensively involves expansive soil areas, making the problems caused by these soils a significant factor in China's accidental disasters and economic construction. As shown in Table 1, the impact of expansive soils is evident in various aspects of China's infrastructure development, as well as in its disaster prevention and relief efforts [23].

The data in the table demonstrate that expansive soils have a wide-ranging impact on China's infrastructure, affecting both its quality and stability. This is further compounded by the frequency and severity of natural disasters in areas with expansive soils, leading to significant losses in terms of human life, property, and economic activity. In conclusion, China's expansive soils present a significant challenge to its infrastructure development and disaster prevention efforts.

**Table 1.** Damage to domestic roads and railroads due to expansive soils

Form	Type of damage	Example
railroads	roadbed subsidence	The cost of the Xiangyu-Chongqing Railway increased by more than 900,000 yuan per kilometer [24]
	Slurry and mud on the bed	The cost of slope disaster management and roadbed maintenance on the Nankun Railway is as much as 30 million yuan per year [25]
	landslide	
highway	repeatedly slide and collapse	A highway in Henan Province retained only about 2km of intact section in 3 years due to swelling soil damage [26]
	Severe deformation or cracking of the roadbed settlement	Embankment collapse and slope destabilization on Xiaoxiang Expressway [27]
	Water-absorbing expansion softening	Almost all of the road graben slopes experienced different degrees of landslides during the construction of the Nanning-Friendship Pass Adjustment Highway [24]
	superficial dropsy	

## 2.3. Difficulties in the management of expansive soil slopes

The triggering of deformation problems in expansive soils is usually considered to be caused by two reasons, i.e., elastic-plastic deformation produced by external loading stresses and expansion and contraction deformation produced by internal water content changes, the latter reflecting the essential characteristics of expansive soils [28]. Therefore, different measures need to be taken for its different characteristic triggers, including reasonable drainage, soil strengthening and reinforcement measures. For the slope projects in different situations, it is necessary to choose appropriate management methods to control the deformation and damage of expansive soil according to the actual situation.

(1) It is more difficult to manage. Due to the characteristics of expansive soils, their slopes will expand and contract when subjected to water immersion or alternating wet and dry effects, leading to slope instability and damage

(2) Difficulties in identification and monitoring. Expansive soils are widely distributed and often hidden in deeper underground strata, making it difficult to directly observe and indeed. As for the expansion soil slopes that have already appeared, it is even more difficult to monitor them due to their intense deformation and instability.

(3) It is difficult to guarantee the effect of treatment. Due to the special nature of expansive soil, there are still some uncertainties and risks in the treated slope. For example, the treated slope may still expand and contract under the alternating wet and dry effects at a later stage, leading to slope instability again.

### 3. Application of expansive soil slope management technology

#### 3.1. Expansive soil slope damage management measures

The damage management measures of expansive soil slopes are one of the important contents of the management of expansive soil slopes. In order to ensure the stability and safety of slopes, appropriate measures need to be taken to deal with and prevent the damage of expansive soil slopes. Through the research of previous scholars, the expansion soil slope management measures are summarized (Table 2). It can be seen that the expansion soil slope damage management measures involve more abundant methods and technologies, but the specific choice of methods and technologies need to be determined according to the specific nature of the slope and construction conditions.

Many researchers have further explored new management methods and technologies to achieve the effect of integrated management, and have proposed two methods, "rigid and flexible". Rigid methods are physical resistance, such as prestressed anchors, reinforced concrete walls and anti-slip piles and other technologies, effective drainage of slopes and soil reinforcement for management measures. Flexible methods are mainly aimed at the physical and chemical properties of expansive soils themselves, using for soil modification, fly ash reinforcement, vegetation protection, geobags/chambers/grids, and condensed soil cover for management measures [29-31]. In recent years, a number of Chinese groups have devoted themselves to the study of new prevention and control techniques in the context of the continuous progress of science and technology, and have made significant progress and innovation in the application of new materials, big data and artificial intelligence [32-33].

**Table 2.** Summary Table of Governance Approaches

methodologies	principle
tamping	Strong tamping treatment is used to change the physical properties of the soil layer on the slope, increasing the compactness and resistance to expansion of the soil layer.
soil reinforcement	The strength and stability of the soil layer is improved by soil reinforcement of expansive soil slopes. Commonly used soil reinforcement methods include grouting reinforcement, reinforced concrete reinforcement, and compacting reinforcement.
drainage and desiccation	The stability and resistance to expansion of the soil layer is improved by reducing the water content and infiltration pressure of the soil layer through drainage and moisture reduction of the expansive soil slopes.
soil cover method	By covering the surface of expansive soil slopes with an impermeable or retaining layer, water is prevented from entering the soil layer thereby reducing expansiveness.

#### 3.2. Expansive soil slope protection measures and engineering practice

Protection measures and engineering practices for expansive soil slopes are important ways to prevent disasters and evaluate feasibility. In related papers, researchers have proposed different methods and techniques to cope with the stability of expansive soil slopes. Some studies focused on

the aspect of reinforcement measures and engineering practices, and they verified the feasibility and effectiveness of the method by practicing slope reinforcement works [33]. The main protection measures used are described below.

### 3.2.1. Geogrid reinforcement technology

Geogrid reinforcement technology is an effective method that is widely used for protection and reinforcement of expansive soil slopes [34-35]. The technology uses a grid made of geosynthetic materials to cover and fix on the slope surface to increase the slip stability and erosion resistance of the slope by interacting with the soil. Compared with traditional reinforcement methods, geogrid reinforcement technology has the following advantages. First of all, geogrid has high tensile strength and rigidity, which can effectively absorb and disperse the stress generated by the slope and improve the overall stability of the slope. Secondly, the construction of geogrid is relatively simple, does not require large-scale excavation and slope transformation, reducing the project cost and duration. In addition, the flexible characteristics of geogrid make it able to adapt to different shapes and sizes of slopes, with good adaptability and plasticity. Geogrid reinforcement technology is a widely used and effective expansion soil slope protection and reinforcement method. Through continuous improvement and optimization of technical parameters, geogrid reinforcement technology has a good application prospect in improving the stability and erosion resistance of slopes.

### 3.2.2. Protective measures under rainfall conditionseogrid reinforcement technology

Expansive soils are always affected by rainfall. In the management process of expansive soil slopes, the study of protection under rainfall conditions is a very important aspect. A number of scholars have already studied the damage mechanism of expansive soils under rainfall on expansive soils, but the prevention and control measures have not been studied accordingly in practice.

Zou Weilei et al. [33] studied the reinforcement technology of expansive soil slopes and proposed an integrated management technology, including impermeable concrete cover, prestressed anchors and drainage system. The application of this technology in actual projects shows that it can effectively improve the resistance of slopes to rain erosion and mitigate slope stability problems under heavy rain conditions. Yingzi Xu et al [36] proposed a protection measure based on anchored vegetation system (ARVS) by setting anchors and vegetation cover on the slope to form a kind of anchored vegetation system, which can effectively improve the stability of the slope and slow down the impact of soil and water erosion.

Therefore, the stability of expanded soil slopes can be effectively improved and the impact of rainfall on slopes can be mitigated by choosing appropriate protective measures, such as reasonable installation of protective layers, grouting reinforcement, anchor support and prestressing anchors.

### 3.2.3. Cement modification technology

Cement modification is a common method in expansive soil treatment and modification technology. Cement modification can improve the engineering performance of expansive soils by changing the physical and chemical properties of expansive soils, thus achieving the purpose of treating expansive soils.

Wang Pei et al [37] found that the improvement effect of cement modification on expansive soils was closely related to the cement dosage and curing time. The shear strength and expansion and contraction properties of expansive soils increased with the increase of cement dosage. The extension of curing time can further improve the strength and expansion/contraction properties of expansive soil. Through cement modification, the pore structure of expansive soil was improved, and the water content had less influence on the properties of expansive soil. He Yang et al. experimentally investigated the effect of cement modification on the properties of expansive soils in the Wanjiang Economic Zone [38], and reached similar conclusions.

Therefore, cement modification is an effective technique for the management and modification of expansive soils. Through cement modification, the engineering properties of expansive soils can be significantly improved and their overall stability can be enhanced. However, the effect of cement

modification on the properties of expansive soils still needs to be further studied and explored to improve the application of cement modification technology.

In addition to inorganic binding material modification, in recent years, some scholars have used biological enzymes or chemical reagents on the expansion of soil modification research, but the effect is still to be further examination. In addition, there are physical modification techniques, such as adding lignin fiber, sand and tire particles and so on. Yang Jun et al. [39] compared the modification effects of cement, lime and sand, as shown in Table 3. Research on new environmentally sustainable and economically appropriate modification materials is the current development trend.

**Table 3.** Comparison of change amplitudes of indexes of different modified expansive soils

Modification materials	Optimum mixing amount/%	Variation of index						
		Plasticity index	No load expansion rate	50 kPa loaded expansion	Expansion force	Cohesion	Angle of internal friction	Unconfined compressive strength
Cement	8	-30.50	-88.20	-92.40	-69.40	30.80	55.58	122.70
Lime	6	-55.40	-87.23	-90.80	-94.20	105.77	48.14	58.80
Sand	10	-26.32	-17.30	-59.80	-68.50	35.91	9.75	-21.01

#### 4. Development trends and prospects

(1) Application of new materials and technologies. With the continuous progress of science and technology, the application of a variety of new materials and technologies in the management of expansive soil slopes has gradually received attention. For example, nanotechnology, biotechnology, and groundwater level control technology can be applied in the stability analysis and management of expansive soil slopes.

(2) Improvement of numerical simulation and analysis methods. Currently, the common use of the limiting element method for slope stability analysis, etc. can further improve the reliability of numerical simulation and analysis by improving the model, correcting the parameters and increasing the accuracy of numerical calculations.

(3) The depth of multidisciplinary cross research. Expansive soil slope management technology belongs to the field of multidisciplinary cross-research, which requires comprehensive consideration of the knowledge of engineering geology, groundwater, civil engineering and other disciplines.

(4) Green and sustainable development requirements. In the management of expansive soil slopes, the requirements of green environmental protection and sustainable development should be emphasized. For example, through the vegetation restoration, environmental protection and other measures to improve the stability of the slope while protecting the ecological environment.

Therefore, the future research trends and prospects of expansive soil slope management technology should focus on the application of new materials and technologies, the improvement of numerical simulation and analysis methods, the depth of multidisciplinary cross-research, and the requirements of green environmental protection and sustainable development. The research in these aspects will help to improve the effect and feasibility of expansive soil slope management technology and further promote the development of this field.

#### 5. Recommendations

The following recommendations are made for future research on management techniques for expansive soil slopes:

(1) Strengthen the basic theoretical research in order to establish a better stability analysis model for expanded soil slopes.

(2) Developing new management techniques and researching and developing innovative means such as bioengineering and underground drainage systems to improve the stability of expansive soil slopes.

(3) Improve the evaluation index system, introduce a variety of quantitative evaluation indexes, such as slope deformation, seepage conditions and soil physical and mechanical properties and other parameters, and establish weighting coefficients to accurately and reliably assess the stability of expansive soil slopes and the management effect.

(4) Strengthen interdisciplinary research and draw on research results from other fields, such as geohazard management and environmental engineering, in order to promote the development of expanded soil slope management technology.

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