Research on Subgrade Treatment Technology for Highways in Expansive Soil Areas

Bing Liu
CSCEC Road and Bridge Group Co., Ltd., Shijiazhuang 050000, Hebei, China
DOI: 10.32629/aes.v5i3.2555

Abstract: Expansive soil is a type of soil with significant expansion and shrinkage characteristics, posing a major threat to the stability and durability of highway subgrades. This paper reviews the impact of expansive soil on highway subgrades, explores common subgrade issues, and introduces treatment technologies for subgrades in expansive soil areas. The study shows that reasonable pretreatment, reinforcement, and drainage techniques can effectively mitigate the damage caused by expansive soil to subgrades, enhancing the service life and safety of highways.
***Keywords*:** Expansive soil, highway, subgrade treatment technology, pretreatment, reinforcement, drainage

1. Introduction

Expansive soil is a special type of soil characterized by significant swelling upon water absorption and shrinkage upon dehydration, due to its unique mineral composition and microstructure. This soil is widely distributed globally, and its volume change properties cause significant expansion and contraction under varying moisture conditions, adversely affecting road infrastructure. Deformation, settlement, and cracking induced by expansive soil directly impact the smoothness and structural stability of roads. With the rapid development of transportation, constructing highways in expansive soil regions presents significant engineering challenges, particularly in ensuring long-term stability and durability of the subgrade. This paper delves into the engineering properties of expansive soil and its impact on highway subgrades, proposing various feasible subgrade treatment methods aimed at addressing the engineering problems caused by expansive soil and enhancing highway safety and durability[1].

2. Impact of Expansive Soil on Highway Subgrades

2.1 Impact of Expansive Soil Swelling and Shrinking on Subgrades

Expansive soil has notable swelling and shrinking properties when absorbing and losing water, respectively, potentially leading to significant shape changes in engineering practice. Studies indicate that a 10% increase in the moisture content of expansive soil can cause its volume to expand by 30% to 50%. Such significant volume changes can cause uneven settlement in subgrades. For instance, in a specific engineering project, the expansive soil experienced a settlement difference of up to 20 centimeters due to dehydration shrinkage during the dry season, directly affecting the road surface comfort. Uneven settlement poses a significant threat to the smoothness and functionality of the road, exacerbating driver discomfort and reducing driving safety[2].

Subgrade materials are prone to fatigue damage under long-term cycles of swelling and shrinkage. In some cases, the service life of concrete pavement slabs has been reduced from 20 years to less than 10 years due to such damage. Fatigue damage leads to the continuous expansion of microcracks, gradually weakening subgrade strength, thereby severely damaging the overall integrity of the road structure. The cumulative effect of long-term fatigue damage significantly reduces the elastic modulus of subgrade materials, ultimately causing more extensive deformation and subsidence. To address these issues, frequent road maintenance is often required, inevitably increasing the financial and operational complexity of road upkeep.

2.2 Deformation and Damage Caused by Expansive Soil

The swelling pressure of expansive soil can reach relatively high ranges. Studies show that the swelling pressure of some expansive soils can range from 200 kPa to 500 kPa, causing subgrade uplift and crack formation. In practical engineering applications, certain road sections have experienced subgrade uplift of up to 30 centimeters due to expansive soil effects, posing severe threats to driving safety. The unevenness caused by road surface uplift not only reduces driving comfort but also increases the risk of traffic accidents[3].

The compressive effect of expansive soil can cause uneven settlement and cracking in the road base. For example, in the construction of a highway in an expansive soil area, cracks in the pavement caused by subgrade uneven settlement exceeded 5 centimeters in width and extended over 100 meters in length. These cracks not only undermine the structural integrity of the road but also facilitate moisture intrusion, leading to further damage. Road deformation and damage reduce its functionality and significantly increase subsequent repair and maintenance costs. The gradual increase in cracks and deformation often requires frequent maintenance and repair operations, inevitably raising the operational costs of the road.

2.3 Analysis of Common Subgrade Diseases in Expansive Soil Areas

In regions with expansive soils, highway subgrades often experience issues such as pavement uplift, cracking, subsidence, and irregular deformations. For instance, in a particular highway construction project, during the rainy season, the expansive soil absorbed water and caused the pavement height to rise by up to 15 centimeters. Conversely, during the dry season, the expansive soil contracted due to dehydration, resulting in subgrade settlement exceeding 10 centimeters, leading to significant uneven settlement and cracks on the road surface. These diseases are mainly caused by volume changes in the expansive soil. Such volume changes not only affect the stability and durability of the subgrade but also increase the frequency of road repairs.

When water infiltrates the subgrade, it can reduce the binding capacity of soil particles, leading to material degradation. For example, in a specific case, water intrusion reduced the compressive strength of the subgrade soil by 30%, further exacerbating subgrade deformation and cracking. Due to material degradation and decreased compressive strength, the subgrade becomes more prone to deformation and damage, disrupting normal road use. Overall, the extent of damage to highway subgrades caused by expansive soils is multifaceted. Thus, effective treatment methods are necessary to prevent and address these potential damage issues. Using efficient treatment methods can significantly enhance the stability of the road foundation, extend its service life, and reduce maintenance costs and operational risks.

3. Highway Subgrade Treatment Technologies in Expansive Soil Areas

3.1 Subgrade Pre-treatment Technologies

In expansive soil subgrade engineering projects, subgrade pre-treatment technologies are crucial preliminary operations aimed at reducing the adverse effects of expansive soil and improving subgrade structural stability. One effective method is the use of geotextile laying technology, which involves laying high-density polyethylene (HDPE) geotextiles outside the subgrade to prevent soil particle migration and maintain soil structure. HDPE geotextiles exhibit excellent tensile strength and durability, with tensile strength reaching 20 to 30 kN/m, ensuring superior physical properties over long-term use. In practice, geotextile materials are typically laid at the top or middle parts of the subgrade to achieve separation and strength enhancement.

Chemical modification using lime and cement is a common pre-treatment technology aimed at reducing the expansiveness of the soil. By adding 3% to 6% lime or 5% to 10% cement to the expansive soil, ion exchange and gel effects adjust the soil's mineral structure, effectively reducing its expansiveness. For example, expansive soil treated with lime shows a significant reduction in its expansion rate, dropping from 15% to less than 5%, greatly improving the soil's engineering properties.

Preloading is a method that involves applying static or dynamic loads before construction to allow the expansive soil to complete most of its deformation in advance, effectively reducing subsequent settlement. For instance, in a certain highway project, preloading reduced subgrade settlement by about 50%, significantly enhancing the stability and durability of the subgrade.

3.2 Subgrade Reinforcement Technologies

Subgrade reinforcement technologies aim to enhance the bearing capacity and shear resistance of the soil, further improving the overall stability of the subgrade. Gravel pile reinforcement is a common technique that involves adding numerous gravel piles into the expansive soil to form a reinforcing network. This network can disperse and bear upper loads while improving the soil's drainage capacity. Gravel piles typically have a diameter of 0.4 meters to 0.6 meters and a spacing of 1.5 meters to 2.5 meters. This design can greatly enhance the bearing and anti-deformation capacities of the subgrade.

Reinforced concrete piles are another key subgrade reinforcement method, involving embedding reinforced concrete piles into the subgrade to effectively improve its bearing capacity and shear strength. Soil nailing walls are widely used in slope and subgrade reinforcement. By installing steel nails on the slope or subgrade, the internal friction of the soil is significantly increased, enhancing the overall stability of the subgrade. For example, in a certain highway construction project, using 10-meter-long soil nails with six nails per meter significantly increased the slope's stability and reduced the risk of landslides.

3.3 Subgrade Drainage Techniques

In expansive soil areas, subgrade drainage techniques are particularly crucial because fluctuations in moisture are the core reason for volume changes in expansive soils. Blind ditches are one of the commonly used drainage methods, typically installed on both sides of the subgrade. By laying gravel and filter fabric materials, blind ditches can swiftly remove groundwater and prevent it from infiltrating the subgrade. In a specific case, the blind ditch has a depth of 1.5 meters and a width of 0.5 meters. This design significantly reduces moisture within the subgrade and successfully mitigates the extent of expansion and settlement. Introducing blind ditch technology optimizes the hydrological conditions of the subgrade, reducing fluctuations in expansive soil volume and enhancing subgrade stability.

Longitudinal drainage ditches installed above the subgrade aim to rapidly remove surface water and prevent its penetration into the subgrade. In practical projects, the depth of longitudinal drainage ditches ranges from 0.5 meters to 1 meter, with spacing between 50 meters to 100 meters. This design effectively manages the flow of surface water, preventing excessive accumulation at the road base.

Transverse drainage networks involve installing horizontal drainage pipes within the subgrade to swiftly remove excess moisture. For instance, using polyethylene drainage pipes with a diameter of 0.2 meters, and spacing lateral pipes every 10 meters significantly reduces the impact of subgrade expansion and contraction, thereby improving pavement stability.

4. Conclusion

Handling highway subgrades in expansive soil areas is a complex yet critical engineering task. Through proper pre-treatment, reinforcement, and drainage techniques, the adverse effects of expansive soil on subgrades can be effectively mitigated, ensuring the stability and durability of highways. Future research should further optimize these treatment technologies and develop new materials and methods to address subgrade treatment challenges under diverse conditions.

References

[1] Gu, C. P. (2013). Simulation Study on Deformation Characteristics of Lime-Modified Expansive Soil Subgrade. Highway Traffic Technology, 000(004), 1-5.

[2] Qin, Z. H. (2021). Study on Deformation Stability Characteristics and Treatment Technology of Expansive Soil Fill Subgrade. Guangxi University.

[3] Su, W. (2018). Improvement Methods and Construction Quality Control of Expansive Soil Subgrade on Yilou Expressway. Central South University of Forestry and Technology.