Study on Control Standard of Frost Heave Deformation and Freeze-thaw Strength of Cohesive Soil of Expressway Widening Subgrade in Seasonal Frozen Region

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Abstract. This paper is aiming at control standard of frost heave deformation and freeze-thaw strength of cohesive soil of expressway widening subgrade in seasonal frozen region. Research was proposed to study the deformation law of high water content clay subgrade in freeze-thaw condition through laboratory test, field monitoring and theoretical analysis. According to the results, frost heave deformation control standard of cohesive soil subgrade has been proposed. Considering the overload load, the subgrade's differential deformation rate should be less than 3.07‰ and the differential deformation rate must be less than 2.27‰. Considering the allowable bending tensile stress and the pavement structure service life, the differential deformation rate of the top surface of the subgrade under the effect of frost heaving of the high water content cohesive soil subgrade in the seasonal frost zone should be controlled within 2‰. After that, control standard for freeze-thaw strength of cohesive soil subgrade is put forward that, the subgrade-soil strength ratio of the high water content cohesive soil subgrade in the seasonal frost zone should be controlled within 0.75 under the standard load and within 1 under the overload load considering the allowable flexural stress and service life of the pavement structure.

1. Introduction

In recent years, China has carried out a number of highway expansion project, but a more general problem is that the new and old roadbed settlement of differences, and thus lead to more pavement and subgrade diseases, affecting driving comfort and quick, reducing road capacity, seriously affecting the economic and social benefits of the highway [1-3]. The key issue is the deformation of widening subgrade of high-grade way. It affects the life-span of the widened highway and driving comfort. As the area of seasonal frozen soil is more than half of the total land area in China, research on influence of widening in high-grade highway of seasonal frozen area on the deformation of subgrade makes a particular theoretical and practical significance on fully considering the influence of seasonal freezing-thawing in widening engineering, controlling the whole stability and asymmetrical settlement of new and old subgrade effectively, reducing the resulting cracking and damage of the layer on upper pavement [4-6]. Therefore, it is necessary to change the old and new highway extension difference subgrade settlement control technology [7-8].
Based on the study of the changes and influences of the strength, deformation and other road characteristics of the high-water content cohesive soil roadbed under freezing and thawing, this paper deeply studies the long-term performance of the high-water content cohesive soil roadbed in the seasonal freezing area, and clearly the performance change law of high water content cohesive soil roadbed in seasonal frost area and its influence on the pavement structure layer are discussed, and the frost heave deformation control standard of high water content cohesive soil roadbed is proposed. The project is the widening section of the old road, and the design standards are two-way four lane (Figure 1). The design speed of the new section is 100km/h, the subgrade width is 26m, the design speed of the widening old road is 80km/h, and the width of roadbed is 24.5m.

![Figure 1. Layout of settlement observation instruments of subgrade widening section.](image)

2. Engineering Characteristics of Cohesive Soil with High Water Content Subgrade Widening Section

2.1. Physical Characteristics of Cohesive Soil with High Water Content

The soil sample of K132+850 in the Expressway, and the test results are shown in Figure 2.

![Figure 2. The relationship between penetration depth and moisture content.](image)

According to the engineering classification of the soil, the soil sample is named high liquid limit clay.

2.2. The Road Properties of Cohesive Soil with High Water Content of Subgrade Widening Section

The relationship between soil dry density, CBR strength and consistency is shown in Figure 3., which shows: 1) The soil density-moisture content curve and strength-moisture content curve are separated from each other for high water content cohesive soil, which has different peak points respectively. This is one of the important characteristics of high-moisture clay soils different from general
fine-grained soils. 2) The maximum strength moisture content is generally 0.2 to 0.3 less than the best moisture content in consistency according to the test statistics, that is, the moisture content is 6% to 10% greater. On-site control of subgrade rolling according to the maximum strength moisture content is beneficial to the long-term stability of the roadbed.

![Figure 3. The relationship between strength, dry density and moisture content.](image)

2.3. Freeze-thaw Characteristics of Cohesive Soil with High Water Content

For the resilient modulus of soil under different compaction degrees, as shown in Figure 4.

![Figure 4. The relationship between the number of freeze-thaw cycles and the modulus of resilience at different degrees of compaction.](image)

It can be seen that ash dosing follows that the resilience modulus at each degree of compaction decays with the increase in the number of freeze-thaw cycles.

3. The Moisture Content Characteristics of High Water Content Cohesive Soil Subgrade

After a complete year of subgrade water content monitoring, the results are summarized in figure 5.

![Figure 5. Monitoring of subgrade moisture content in different depth from slope.](image)

Analysis of monitoring results shows that:

(1) The water content of each point in the subgrade basically keeps the same change cycle. From the
distribution of water content, the closer the distance to the outside of the slope, the greater the water content, indicating the greater the degree of influence by the external climate.

(2) According to the statistics of the annual water content fluctuation of monitoring points, it can be seen that the range of water content fluctuation increases with the decrease of the distance from the outside of the slope.

(3) S1 and S2 points are more than 3m away from the outside of the slope, and less than 1.5m away from the top of the road, but the change range of moisture content is not large, which shows that the impact of atmospheric precipitation on the humidity of the road bed through the pavement structure layer is very small.

4. Control Standard of Frost Heave Deformation and Freeze-thaw Strength of Cohesive Soil Subgrade

4.1. Frost Heave Deformation Control Standard of Cohesive Soil Subgrade

Based on design service life (15 years), the calculation results of differential deformation rate of subgrade are shown in Table 1. From the calculation results, in order to ensure the service life of 15 years, the differential deformation rate of subgrade should be less than 2.61 ‰; and in the reverse bending deformation model of subgrade uplift, the maximum bending tensile stress is located in the subbase. Therefore, considering the standard driving load, the differential deformation rate of subgrade should be less than 3.07 ‰, so as to ensure the service safety within the design life. Considering the overload load, the subgrade's differential deformation rate should be less than 3.07 ‰ and the differential deformation rate must be less than 2.27 ‰.

Table 1. Calculation results of differential deformation rate of subgrade.

| Computational model                | Position of maximum bending tensile stress | Allowable bending tensile stress /MPa | Bending tensile stress under standard axle load /Mpa | Bending tensile stress under overload axle load /Mpa | Differential deformation rate /% |
|-----------------------------------|--------------------------------------------|--------------------------------------|-------------------------------------------------------|---------------------------------------------------|---------------------------------|
| Positive deflection of middle uplift | Upper layer                                | 0.424                                | No consideration                                      | No consideration                                  | 0.261                           |
| Shoulder uplift reverse deflection | Subbase                                    | 0.284                                | 0.096                                                 | 0.144                                             | 0.307                           | 0.227                           |

According to the fatigue equation of semi-rigid material and asphalt surface layer obtained from the split fatigue experiment of domestic asphalt and semi-rigid material, the service life of cohesive soil subgrade with high moisture content in the seasonal frozen area can be calculated from the different deformation rate of subgrade. The relationship between differential deformation rate of subgrade top and service life is shown in Table 2.

Table 2. Prediction of highway service life under different deformation rates.

| Differential deformation rate | Maximum bending tensile stress /MPa | Splitting strength/MPa | Number of fatigue actions / Ten thousand times | Service life /years |
|-------------------------------|-------------------------------------|------------------------|-----------------------------------------------|---------------------|
|                               |                                     |                        | Standard axle load                             | Overload axle load  |
|                               |                                     |                        | Standard axle load                             | Overload axle load  |
| 1‰                            | 0.064                               | 0.6                    | 1.43E+06                                       | 3.32E+04           | 86.1                            | 46.7                            |
| 2‰                            | 0.121                               | 0.6                    | 1.81E+04                                       | 1.03E+03           | 40.5                            | 13.5                            |
| 3‰                            | 0.223                               | 0.6                    | 71.85                                          | 9.62               | 1.8                             | 0.3                             |
| 4‰                            | 0.278                               | 0.6                    | 7.34                                           | 1.30               | 0.2                             | 0.0                             |

From the calculation results, the subgrade differential deformation rate is 1 ‰ only considering the frost heave factor. Under the standard driving load and the overload effect, the service life of highway can reach 86 years and 46 years respectively, while when the differential deformation rate of subgrade
is 4‰, the service life of both loads is less than 1 year. From the relationship between service life and differential deformation rate, it can be seen that when the deformation rate is more than 3‰, the relationship between the two is linear decreasing; when the deformation rate is more than 3‰, the service life changes little to zero. Considering the allowable bending tensile stress and the pavement structure service life, the differential deformation rate of the top surface of the subgrade under the effect of frost heaving of the high water content cohesive soil subgrade in the seasonal frost zone should be controlled within 2‰.

4.2. Control Standard for Freeze-thaw Strength of Cohesive Soil Subgrade

The prediction results of highway service life under different subgrade strength ratios are shown in Table 3.

| Strength ratio | Load condition | Maximum bending tensile stress /MPa | Splitting strength /MPa | Number of fatigue actions / Ten thousand times | Service life /years |
|---------------|----------------|----------------------------------|------------------------|---------------------------------------------|--------------------|
| 0.5           | Standard axle load | 0.30                              | 0.6                    | 1.82E+02                                    | 4.0                |
|               | Overload axle load   | 0.34                              | 0.6                    | 2.98E+01                                    | 0.8                |
| 0.75          | Standard axle load | 0.25                              | 0.6                    | 2.24E+03                                    | 20.0               |
|               | Overload axle load   | 0.29                              | 0.6                    | 3.55E+02                                    | 6.8                |
| 1             | Standard axle load | 0.22                              | 0.6                    | 1.48E+04                                    | 38.5               |
|               | Overload axle load   | 0.25                              | 0.6                    | 2.37E+03                                    | 20.5               |
| 1.5           | Standard axle load | 0.18                              | 0.6                    | 2.64E+05                                    | 68.4               |
|               | Overload axle load   | 0.20                              | 0.6                    | 5.82E+04                                    | 52.6               |

From the calculation results, only considering the influence of freeze-thaw, the service life of the road can reach 38.5 years under the standard driving load and 20.5 years under the overload effect when the strength is not attenuated, and the service life of the road under the overload effect is less than 1 year under the strength ratio of 0.5. From the relationship between subgrade strength ratio and service life, we can see that under standard axle load, the relationship between the two is basically linear decreasing, while under overload axle load, the relationship between the two is quadratic polynomial. Considering the allowable flexural stress and service life of the pavement structure, the subgrade-soil strength ratio of the high water content cohesive soil subgrade in the seasonal frost zone should be controlled within 0.75 under the standard load and within 1 under the overload load.

5. Conclusions

Through analysis of control standard of frost heave deformation of cohesive soil of expressway widening subgrade in seasonal frozen region, the following conclusions can be drawn:

(1) The water content of each point in the subgrade basically keeps the same change cycle. From the distribution of water content, the closer the distance to the outside of the slope, the greater the water content, indicating the greater the degree of influence by the external climate. According to the statistics of the annual water content fluctuation of monitoring points, it can be seen that the range of water content fluctuation increases with the decrease of the distance from the outside of the slope.

(2) Considering the overload load, the subgrade's differential deformation rate should be less than 3.07‰ and the differential deformation rate must be less than 2.27‰.

(3) Considering the allowable bending tensile stress and the pavement structure service life, the differential deformation rate of the top surface of the subgrade under the effect of frost heaving of the high water content cohesive soil subgrade in the seasonal frost zone should be controlled within 2‰.
(4) Considering the allowable flexural stress and service life of the pavement structure, the subgrade-soil strength ratio of the high water content cohesive soil subgrade in the seasonal frost zone should be controlled within 0.75 under the standard load and within 1 under the overload load.

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