Field test study on reinforced soil steep slope in subgrade widening of Highways

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Abstract. To study the application effect of the reinforced soil steep slope structure in the subgrade widening project of highways under the condition of limited land occupation, based on the Xinyuan expressway reconstruction and expansion project, this paper conducts field test and research on the structural state of the reinforced soil structure, and selects a natural grading subgrade widening section to compare the widening effect. Through buried sensors to monitor the settlement of the cross-section of the foundation and analyze the change law of the data after the operation. Based on the research on the structural state of reinforced soil steep slope widening subgrade, this paper summarizes the structural deformation law, construction key technology and control method in the construction process and the initial operation stage.

1. Introduction

In recent years, the pressure on highways in my country has been increasing, and some of the existing highways can no longer meet the traffic volume of today's traffic, so it is urgent to widen and expand them\textsuperscript{[1-2]}. At present, the common way of subgrade widening\textsuperscript{[3]} is natural grading, that is, widening both sides of the original subgrade foundation, but it puts forward a greater demand for road land occupation and land acquisition and demolition, which is both difficult and expensive. The widening projects of highways subgrade in China are mainly concentrated in the central plain and the eastern coastal areas. A considerable part of the projects are built on the soft soil foundation due to the foundation conditions and other reasons. If the bad condition foundation cannot be well treated and the new and old subgrade is not properly jointed, the new and old subgrade will have large differential settlement\textsuperscript{[4-5]}, which will undoubtedly greatly affect the performance of the road, thus increasing the maintenance cost in the later period. Although some engineering experience has been accumulated in our country, while the research on the control of the uneven settlement of the new and old subgrade with different subgrade widening structure needs to be improved. Therefore, in-depth study of the different settlement control standards and the deformation characteristics of different forms of widened subgrade in the subgrade widening project has an important theoretical significance and application value for improving the road performance after the widening of highways.

Based on the reconstruction and extension project of Xinyuan high speed project in Hebei Province, this paper used the reinforced soil steep slope\textsuperscript{[6-8]} to widen the original subgrade under the condition of limited land occupation. Under the condition that the occupied area of subgrade was basically unchanged (the position of slope toe is basically unchanged), the slope rate of slope was increased to achieve the purpose of pavement widening. Through a comparative analysis between the field test\textsuperscript{[9]} and the normal filling and grading roadbed widening, the mechanical behavior of the reinforced soil steep slope widening roadbed structure and its effect on uneven settlement control were systematically...
studied. Finally, the quality control technology of the reinforced soil steep slope widening subgrade structure form was proposed.

2. Project overview and monitor plan

2.1. Project overview

The old road before the renewal and expansion of the Xinyuan highway was completed and opened to traffic in December 1994. It is a two-way four-lane road with a roadbed width of 27 m and a height of 4 m–4.4 m. After expansion, the roadbed has a width of 34.5 m and a height of 4.8 m–6.4 m. The slope ratio is 1:0.75 (as shown in Figure 1), the foundation soil is medium-sand-silt-coarse sand from top to bottom, and the groundwater depth is about 22 m. The old subgrade is filled with sand, the reinforced soil slope is filled with gravel soil, and the steep slope with reinforced soil is adopted as the geogrid. The reinforcement is TGDG 65 type HDPE uniaxial geogrid, and the vertical spacing of the reinforcement 0.4 m. A section with a height of 5.6 m was selected for testing.

![Figure 1. Comparison before and after subgrade widening: (a) before subgrade widening; (b) after subgrade widening](image)

2.2. Layout of monitoring points

The layout of monitoring points of observation section is shown in Figure 2. The clamps at both ends of the flexible displacement meter were fixed on the transverse rib of the geogrid to measure the tensile deformation of the geogrid, and the U-shaped section pipe was buried at the bottom of the subgrade to monitor the settlement of the cross section of the foundation. The natural grading structure only embedded U-shaped section pipe at the bottom of subgrade to monitor the settlement of subgrade cross section.

![Figure 2. Layout of experimental observation device for widening subgrade of reinforced soil steep slope](image)
Test monitoring started from the beginning of construction. In the construction process, each layer of geogrid was laid or each vertical load was applied, the data of flexible displacement meter was read once. During the laying period of subgrade, it was monitored every three days. After completion, the data read once a month in the first three months. In each test section, the reinforced soil steep slope subgrade would be opened to traffic about 87 days after completion, and the natural slope widening subgrade will be opened to traffic 60 days after completion.

3. Analysis of monitoring results

3.1. Settlement analysis of cross section
The variation laws of the uneven settlement of the widened subgrade and the maximum settlement point of the section with the filling height time are shown in Figure 3 and Figure 4, respectively.

Based on the analysis of the uneven settlement of the foundation in different periods, it can be seen that:

(1) The accumulated settlement of the new foundation during the construction period was generally at a low level. With the increase of filling height of reinforced soil steep slope subgrade, the increase rate gradually decreased. When the filling height reached 4 m, the growth rate of settlement slowed down obviously. For every 0.4 m of filling, the maximum increase of settlement was 1.4 mm. The
maximum value of foundation settlement during construction was about 72%. 24 days after the road opened to traffic, the foundation settlement gradually decreased, and the maximum monthly average settlement was 1.3 mm/month, which was less than the standard allowable stable value of 3 mm/month. After 112 days of opening to traffic, the maximum settlement of the cross section was 18.3 mm.

Due to the low moisture content of the foundation soil, the foundation soil had higher shear strength, higher bearing capacity and lower overall settlement. With the increase of subgrade filling height, the load on the upper part of the foundation increased, which made the consolidation degree of the foundation soil increased and the settlement rate decreased. After the completion of subgrade filling, there will be a long lay down period. Due to the load of pavement construction on the foundation, the consolidation settlement of the foundation would be accelerated, so the accumulated settlement of the foundation would still increase from the completion of subgrade filling to the initial stage of opening to traffic.

(2) The settlement of the foundation at the foot of the new subgrade slope was small. The settlement of reinforced soil widened structure section gradually increased along the length direction of reinforcement from the new subgrade toe to the old subgrade toe. From the lower part of the shoulder (about 4m) to the lower end of the profile pipe (6m), the foundation settlement first increased to the peak value and then decreases, and the maximum value appeared at 5m or 5.5m of the profile pipe length. After opening to traffic, the accumulated settlement difference at the toe of new and old subgrade was relatively large, and the maximum settlement point occurred near the toe of old subgrade. During construction, the maximum settlement rate of observation point was 3.9mm/3d; after opening to traffic, the maximum settlement rate of observation point was 1.2mm/month.

3.2. Analysis of widening structure results of natural grading Subgrade

The variation laws of the uneven settlement of the widened subgrade and the maximum settlement point of the section with the filling height time are shown in Figure 5 and Figure 6, respectively.

(1) With the increase of filling height, the cumulative settlement of each observation point in the widened cross section of the foundation increased gradually, but the settlement rate decreased gradually. During the subgrade construction, from the old subgrade toe to the new subgrade toe, the accumulated settlement of each observation point gradually increased first and then decreased (except for the observation outdoor at the toe). The maximum settlement point occurred at the 8m position of the section pipe, with the accumulated settlement of 13.6mm and the daily average settlement of 0.32mm/d. The uneven settlement of the new and old subgrade of the natural slope widening subgrade was small.

Figure 5. Settlement curve of cross section of natural slope widening subgrade
Figure 6. Settlement filling height time curve of the maximum settlement point of the natural slope widening subgrade

(2) After the completion of subgrade construction, with the passage of time, the accumulated settlement of the foundation gradually increased, and the settlement rate first increased, then decreased and then increased. After 110 days of operation, the accumulated settlement of the maximum settlement point was 33.9 mm, and the average settlement rate was 3mm/30d. The rate of consolidation and compression settlement decreased with time. After opening to traffic, the settlement rate increased gradually due to the increase of load, and the settlement tended to be stable after opening to traffic for 110 days.

(3) Due to the influence of traffic load and other factors, the natural sloping structure has a large settlement at the foot of the slope, and the minimum settlement was 23mm at 2m from the foot of the slope. Therefore, in the construction process, it is necessary to ensure the compaction quality of the foundation and subgrade near the slope surface, and appropriately increase the slope brushing depth of the soft soil on the slope surface, so as to reduce the settlement impact caused by consolidation compression after completion.

3.3. Comparative analysis of settlement between reinforced soil steep slope and natural grading structure

Comparing and analyzing the foundation settlement of the two types of roadbed widening sections after completion and 112 days after opening to traffic, as shown in Figure 7 and Figure 8, respectively.

(1) It can be seen from Figure 7 and Figure 8 that, the cross-sections of the two structural forms had basically the same trend in settlement changes, and the natural grading structure cross-sections had large fluctuations at the foot of the new subgrade after completion. Compared with the reinforced soil structure, the settlement value of the natural grading structure was larger as a whole. In the direction of cross section, the reinforced soil structure had better control over the uneven settlement than the natural grading structure.

Figure 7. Settlement curve of foundation cross section after completion
Figure 8. Settlement curve of foundation cross section after 112 days of operation

(2) After 112 days of opening to traffic, the settlement values of the two widened subgrade cross sections changed obviously, and increased with the increase of height. The settlement and deformation trend along the cross-section was gradually obvious, the reinforced soil structure changed gently along the transverse direction, while the natural grading structure fluctuates greatly in the cross-section direction.

(3) Compared with the settlement at the foot of reinforced soil steep slope structure, the settlement of natural grading structure was very large, so it can be concluded that reinforced soil steep slope had better coordination in controlling subgrade deformation. Due to the pull-out effect of reinforcement material in reinforced soil structure, the structure integrity was stronger, the larger local stress can be dissipated, and the deformation of subgrade structure was more uniform, while the natural grading structure adopted the loose plain soil filler, so the deformation fluctuation was larger. It can be seen from the monitoring data that the strain of the reinforced soil structure reinforcement near the subgrade lap was large, which indicated that the relative displacement of the new and old subgrade occurs. The geogrid can enhance the shear strength of the filler at the lap joint, so as to improve the connection performance between the widened subgrade and the old subgrade.

4. Conclusion
Based on the analysis of the settlement of the cross section of the reinforced soil structure and the settlement of the natural slope, the following conclusions are obtained:

During the construction period, the accumulated settlement of subgrade basically increased first and then decreased, reaching the maximum value at about 1m of the slope toe of the old subgrade. The reinforcement had a good effect on coordinating the uneven deformation of subgrade. After the operation, due to the traffic load, the settlement at the slope angle of the widened subgrade increased greatly. Therefore, in the process of construction, it is necessary to control the compaction quality of subgrade and foundation to ensure the uniformity of compaction.

The total settlement of subgrade widening structure with natural grading was small. With the increase of filling height, the settlement amount increased gradually, and the settlement rate decreased when it reaches a certain height.

Compared with the natural grading structure, the reinforced soil steep slope had a better integrity, which can better coordinate the subgrade deformation, dissipate the vertical stress, and make the subgrade settlement more uniform.

In conclusion, based on the analysis of the measured data, it should be noted that the reinforced soil steep slope structure had good application performance in the subgrade widening project, but the compaction quality of the subgrade and the construction quality of the overlap should be mainly controlled.

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