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Settlement Control Standards of Construction and Expansion for Mountainous Highway Roadbeds

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Abstract: This article analyzes the differential settlement of new and old roadbeds after widening and its characteristics based on a highway reconstruction and expansion project case study. The research proposes a subgrade settlement control standard that states that the maximum differential settlement value should be less than 5 cm when the embankment fill height exceeds 20 m. Similarly, the maximum differential settlement value should be less than 10 cm when the embankment fill height does not exceed 20 m. The findings of the study can provide a useful reference for the design of roadbed widening in highway reconstruction and expansion projects.

Keywords: Mountainous highway; Reconstruction and expansion; Roadbed widening; Settlement control

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1. Introduction

With the continuous increase in traffic volume and transportation demand, the mileage of highways in China has exceeded 35,000 km. It is difficult to meet the growing traffic demand for highways so there is an urgent need to carry out highway reconstruction and expansion projects [1]. Roadbed widening is a key technical problem in highway reconstruction and expansion projects, as it is difficult to treat the joint surface of the new and old roadbed after widening, and the settlement control standards are unclear [2]. Therefore, clarifying the control standards for settling new and old roadbeds after widening is significant to the project.

2. Formulation of settlement control standards

2.1. Comparison of domestic and foreign settlement control standards

The requirements and standards for settlement control are constantly changing with the accumulation of engineering practice on the technical level. Domestic settlement control standards are usually revised and improved regularly to ensure the timeliness and accuracy of the standards to adapt to this change [3]. In contrast, the update frequency of foreign settlement control standards is relatively low, since they will only be revised and updated appropriately according to actual conditions as shown in **Table 1**. This is mainly because professional standardization organizations usually formulate and publish these foreign settlement control standards. These organizations will make appropriate revisions and updates to the standards based on the development of engineering practice and academic research to ensure the standards are scientific [4].

Table 1. Comparison of domestic and foreign settlement control standards

Project	Control target	Control indicators	Monitoring methods	Restriction requirements	Design principles	Standard update frequency
Foreign	Underground	Settlement amount, sedimentation rate	Settlement plate, inclinometer, etc.	Settlement difference, slope rate	Safe, economical, and reasonable	Regular revisions
Domestic	Foundation, pile foundation, soil	Cumulative settlement and slope rate	Displacement meter, inclinometer, etc.	Maximum settlement, allowable inclination	Safe, structurally complete, and environmentally friendly	Regular updates and revisions

2.2. Impact of settlement on highway safety

(1) Pavement damage: Subsidence will cause cracks, potholes, wavy deformation, and other damages on the highway pavement. These damages will seriously affect the safety of drivers [5].

(2) Poor drainage: The occurrence of settlement may change the design of the highway drainage system, leading to poor drainage and serious water accumulation problems. Water accumulation will reduce the friction coefficient of the road surface and increase the risk of traffic accidents.

(3) Unstable vehicle driving: The vehicle may experience bumps, swings, and other unstable phenomena during driving due to uneven road surface settlement. These phenomena will affect the driver's judgment and vehicle control which increases the risk of traffic accidents.

(4) Roadbed damage: Long-term settlement may cause damage to the roadbed structure, such as foundation collapse, embankment landslides, and so on. These phenomena will directly lead to highway subsidence or collapse, seriously threatening traffic safety.

3. Problems with the existing roadbed widening project

In the highway reconstruction and expansion project studied, the roadbed is a first-class highway that is 28 m wide and uses a two-way four-lane highway standard with a design speed of 120 km/h and a roadbed height of around 10 m. The large rocks in the roadbed have weathered into gravel soil and have weakened. The geological conditions of the project are good except that it is a hilly area. There are many karst caves, troughs, ditches, sinkholes, and other undesirable geological phenomena along the proposed road. Based on past engineering experience and on-site surveys, problems such as the difficulty in handling the joint surface of the new and old roadbeds in the highway reconstruction and expansion project, unclear differential settlement control standards, and undetermined settlement patterns of the joint surfaces of the roadbeds need to be solved urgently.

3.1. Main issues during the construction process

3.1.1. Difficulty in the joint connection between the new and old roadbeds

There are many unfavorable geological phenomena along the project area, such as multiple caves and large karst troughs, ravines, and sinkholes, which are all located 2 m below the surface. This causes a large differential settlement at the joint surface of the new and old roadbeds that can lead to uneven surface settlement and affect the overall stability of the roadbed.

3.1.2. Unclear standard for differential settlement control

By summarizing the past highway construction experience, it is concluded that the splicing treatment of the new and old roadbeds in highway reconstruction and expansion projects is difficult. The uneven settlement of the joint surface of the new and old roadbeds results in differential settlement. The design specification stipulates that when the settlement difference between the new and old roadbed is within ±5 cm, it can meet the requirements of the expressway. However, the settlement control standards of this road project are unclear due to the complex geological conditions in the area.

3.1.3. Unclear settlement standards of the roadbed joint surface

According to the design data, the maximum settlement of the joint surface of the new and old roadbeds in the highway reconstruction and expansion project is generally 5–8 cm, and the post-construction settlement generally does not exceed 5 cm. However, the actual settlement pattern of the joint surfaces is difficult to determine.

3.2. Specific manifestations of settlement problems

If the settlement difference between the roadbeds is large after the widening project, cracks will appear on the road surface. Cracks usually appear distributed horizontally or vertically at the junction of the new and old roadbeds or on the shoulders of the widened part [6]. This uneven settlement between new and old roadbeds after widening will decrease the smoothness of the road surface and cause issues such as potholes and waves. Additionally, the uneven settlement can affect the road water drainage. If the accumulated water cannot be discharged in time, the structural layer of the road surface can erode, causing damage to the road surface and reducing its structural strength. Hence, the structural stability of the road will be affected if the roadbed treatment is not handled properly.

3.3. Analysis of problem causes

3.3.1. Complex geological conditions

There may be differences in the geological conditions between the roadbed and the widened part of the highway, such as soil type, moisture content, density, and so on. These differences in geological conditions will lead to settlement problems of the new and old roadbeds [7]. Comprehensive geological exploration and detailed analysis and evaluation are required when widening the roadbed in areas with complex geological conditions so that effective foundation treatment measures are taken to reduce settlement problems caused by different geological conditions.

3.3.2. Improper handling when connecting new and old roadbeds

The connecting of new and old roadbeds is one of the key steps in the widening project. Improper road connections will lead to settlement problems between the new and old roads [8]. Thus, effective measures must be taken to properly connect the new and old roadbeds to ensure their overall stability and load-bearing capacity.

3.3.3. Unstrict construction quality control

The construction quality of roadbed widening projects is crucial in managing settlement problems. Poor construction quality control includes situations such as filler quality that does not meet requirements, insufficient compaction, improper construction techniques, and so on [9]. This will lead to the settlement problems of the new and old roadbeds. Therefore, it is necessary to improve quality control and strictly follow relevant construction specifications and requirements during the construction process to ensure that the construction quality meets the design standards.

3.3.4. Influence of natural environmental factors

Natural environmental factors such as climate change, rainfall, groundwater levels, and so on can affect the settlement of highway roadbed widening projects [10]. So, it is necessary to emphasize the monitoring and early warning detection of natural environmental factors and take corresponding measures to deal with these changes to reduce their impact on roadbed settlement.

4. Specific contents of settlement control standards

4.1. Design and construction standards for new roadbeds

4.1.1. Roadbed widening design

When designing the roadbed widening of the project, the actual conditions of the roadbed such as the width, structural form, and geological conditions need to be considered. The final highway grade, traffic volume, service life, and other factors should be comprehensively considered to ensure that the design of the new roadbed is reasonable, economical, and safe [12].

4.1.2. Construction standards

The settlement data of the highway reconstruction and expansion section were analyzed in the project. Two types of points were taken for analysis. The first points include points A, C, and D which were the joints of the new and old roadbeds. The second is point B which was the edge of the roadbed. Points A and B were used to calculate the differential settlement value between points A and C, which is 0.12 cm, and the differential settlement value between points A and D which is 0.07 cm. According to the above data analysis, it is shown that there is a large differential settlement between the new and old roadbeds. The differential settlement value should not exceed 5 cm when the roadbed filling height does not exceed 20 m, whereas the differential settlement value should not exceed 10 cm when the filling height exceeds 20 m. Therefore, the construction method involved installing geosynthetic materials on the road joint surface and laying geogrids on the top of the old roadbed and the bottom of the new roadbed.

The construction steps involved are as follows, earth excavation and backfill, drainage system design, slope protection and reinforcement, compaction, and settlement control. During excavation, measures must be taken to prevent excessive disturbance and damage to the roadbed. It is necessary to select appropriate fillers and control the thickness and compaction of the filling when backfilling to ensure the stability and load-bearing capacity of the new roadbed [13]. The drainage system needs to be reasonably planned so that the road surface water and groundwater can be drained in time to prevent flooding and causing damage to the roadbed. The new original drainage system should be properly coordinated to avoid mutual interference and disruption. Moreover, it is necessary to protect the slopes of the roadbeds during widening. Grass protection, retaining walls, anchor cables, and other reinforcement measures can be used to prevent slope landslides, collapses, and other problems. The slopes also need to be inspected and maintained regularly to ensure their stability and safety. Insufficient firmness will decrease the load-bearing capacity of the roadbed, while excessive settlement will cause problems such as road cracks. Hence, it is necessary to strictly control the compaction degree and settlement amount by taking effective measures that reduce the settlement difference to ensure the quality and stability of the new roadbed.

4.2. Evaluation and treatment standards for existing roadbed

A numerical simulation analysis was conducted on the differential settlement of the new and old roadbeds of the project. The calculations were the average settlement (**Equation 1**) and the differential settlement (**Equation 2**). According to the settlement point data statistics, the differential settlement between the new and old roadbeds is substantial, with the minimum and maximum differential settlement reaching 0.59 cm and 1.36 cm, respectively. The differential settlement value at the joint of the new and old roadbed is smaller than the differential settlement value when the steps are excavated. The differential settlement value at the joint of the new and old roadbed increases as the excavation step width increases [14].

The average settlement refers to the overall average settlement of new and old roadbeds, which is expressed in **Equation 1** below.

$$S = \frac{1}{n}\sum_{i=1}^{n}(s_i - s_0) \qquad (1)$$

Among them, S represents the average settlement, n represents the number of observation points, S_i represents the settlement of the i^{th} observation point, and S_0 represents the settlement of the reference point.

Differential settlement refers to the difference between the settlement of each observation point of the new and old roadbed and the average settlement, which is expressed in **Equation 2** below.

$$\Delta s_i = s_i - S \qquad (2)$$

Among them, ΔS_i represents the differential settlement of the i^{th} observation point.

4.3. Processing standards for the connection between new and old roadbeds

Adding an asphalt concrete surface layer at the junction of the new and old roadbeds can significantly reduce the differential settlement. When the thickness of the pavement structural layer is 10 cm, the differential settlement value between the new and old roadbeds should not exceed 0.4 cm. The differential settlement between the old and new subgrades can be reduced by treating the joints with geogrids.

5. Conclusion

Through the above analysis with actual cases, the following conclusions can be drawn.

(1) The embankment filling height has the most significant impact on differential settlement. The differential settlement becomes larger as the filling height increases. When the embankment filling height is below 20 m, the maximum differential settlement value of the new and old barrier is the same as that of the embankment filling, showing a positive correlation with the construction height.

(2) The influence of foundation conditions on differential settlement is small. When the ground conditions are the same, the maximum differential settlement value of the new and old roadbeds is positively correlated with the embankment filling height.

(3) If The embankment filling height is below 20 m, the differential settlement decreases significantly. When the embankment filling height is above 20 m, the maximum differential settlement value of the new and old roadbed decreases as the filling height increases. Therefore, embankment filling with a height exceeding 20 m should be adjusted, while layered and replacement filling can be used on embankment filling with a height not exceeding 20 m.

Future research should focus on dynamic monitoring technology during the roadbed widening process. The deformation of the roadbed can be grasped promptly and provide a scientific basis for construction through real-time monitoring of the roadbed's settlement, displacement, and other data. At the same time, developing an early warning system can provide timely warnings when the monitored data exceeds control standards or has abnormalities. New mountainous highway road foundation treatment technology should be developed by combining both local and global advanced construction methods to improve the bearing capacity and stability of the foundation while reducing settlement issues. The long-term prediction model of roadbed widening settlement can be improved by analyzing a large number of engineering practices and data on settlement patterns to establish a more accurate prediction model.

Disclosure statement

The author declares no conflict of interest.

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