Research on Settlement Control of New and Old Highway Roadbed Based on Different Bench Excavation Dimensions

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Abstract. The reconstruction and expansion of expressways is an important means, and how to control the settlement deformation of the subgrade width is an urgent problem to be solved. Step splicing is an effective means to control settlement. Therefore, it is very important to study the size of the steps. Expansion is based on engineering. Through literature research, numerical simulation and other research methods, combined with theoretical knowledge of soil mechanics, the settlement control of widened roadbed in highway reconstruction and expansion is studied, and the following conclusions are obtained: (1) Three different types are studied. The deformation law of subgrade and foundation top surface of step size; (2) A combined subgrade step excavation method is proposed, which provides a reference for similar projects. (3) The method of excavation and splicing of combined subgrade steps was verified, and the correctness of combined subgrade excavation and splicing was verified.

Keywords: Expressway, new and old subgrade, subgrade splicing, step size; subgrade settlement.
1. Introduction
The road network with vertical and horizontal thoroughfare is an important context for promoting communication and economic development between regions. Driven by the vigorous development of the national economy, the investment and construction of highways in China has increased rapidly. With the increase in traffic pressure, the reconstruction and expansion of highways has become an important means, and how to control the settlement and deformation of roadbed width is an urgent problem to be solved. Step splicing is an effective means to control settlement, so it is very important to study the step size.

Teng Ai [1] used the finite element method to analyze the deformation law of the new and old subgrade, and analyzed the factors affecting the settlement of the new and old subgrade. Walid El Kamasha et al. [2] used the finite element method to establish a two-dimensional model, studied the effect of different reinforcement schemes for the foundation under the new subgrade, and explored the law of the stability of the new subgrade affected by different reconstruction methods. Wang Zhichao [3] established the new and old subgrade widening model, from the height of the embankment, the width of the widening, the weight of the subgrade filling and the size of the splicing steps between the new and old subgrades, the four single factors explained the impact on the difference in subgrade settlement; Wu Wenming [4] took Zhangpu Take the main road reconstruction and expansion project in the county city as an example, in-depth study of the construction technology of the connection treatment of the new and old subgrades; Long Lianghui [5] discussed the construction technology of subgrade splicing from the original subgrade treatment and splicing section construction plan, and analyzed the subgrade splicing construction Key points: Fang Yuanwei [6] analyzed the effect of geogrid laying and old roadbed excavation steps on the differential settlement of subgrade; Hante [7] studied the loess area highway through field investigation, theoretical analysis, model test, and numerical analysis The problem of differential settlement of new and old roadbeds and stability of joints in highway reconstruction and expansion. Wang Ke [8] used a combination of theoretical analysis, numerical simulation and field tests to study the differential settlement characteristics and control standards of the old and new subgrades in the reconstruction and expansion project. Wang Jianghong [9] analyzed different bench excavation size combinations, different geocell laying schemes, and foundation replacement compaction treatment effects through numerical calculations, and selected bench excavation size, geocell laying scheme, roadbed filler selection and compaction; Provide suggestions in four aspects of the foundation treatment plan. Zeng Yang [10] focused on how to reduce the differential settlement of the old and new subgrades of the Tangjin Expressway reconstruction and expansion project based on the existing research results and engineering experience of subgrades.

In summary, many experts and scholars at home and abroad have conducted research on uneven settlement of highway reconstruction and expansion roadbeds, and the research system is mature. A large part of the research is reflected in the on-site construction situation and the theoretical analysis of the step size. The research is relatively simple, tending to be one of a certain height, a certain width or a certain slope rate. There is a lack of research on the actual size of the excavation on the site; some experts and scholars use a single project to design the excavation size of the step to increase the width and settlement of the roadbed Conduct research, lack of universality.

In this paper, based on the size of the roadbed steps, the control of the width and settlement of the highway reconstruction and expansion is studied. Based on the reconstruction and expansion of the Jiqing highway, the certain steps are analyzed through literature research, numerical simulation and other research methods, combined with theoretical knowledge of soil mechanics the changing law of widened subgrade under the three conditions of height, width and slope rate. Based on the site conditions and construction conditions, a method of excavation and splicing of composite subgrade benches was proposed, and the composite bench was carried out by numerical simulation. Verify, verify its correctness.
2. Project Overview

2.1. Project overview

The Jiqing Expressway is a two-way four-lane road. It was opened to traffic in November 1993. It is the first expressway in Shandong Province with a design life of 15 years. The total thickness of the road surface structure is between 63-71cm. The new structure layer is 82cm (4cmSMA-13+6cmAC-20+8cmAC-25+10cmATB-25+18cm water-stable upper base+18cm water-stable lower base+18cm water-stable base base), the thickness of the old road side is 10cm (4cmSMA-13+6cmAC-20). Reconstruction and expansion of Jiqing Expressway, the original roadbed width is 23m, and the expanded roadbed width is 42m (two-way eight lanes). The main technical indicators are shown in Table 1.

![Table 1. Main technical index table](image)

2.2. Engineering geological and hydrological conditions

2.2.1. Topography and landform. This section belongs to the quasi-plain landform of Jiaozhou and Jimo. The accumulation quasi-plain landform is distributed in the Jiaolai River, Dagu River, Taoyuan River in the middle and on both sides of Moshui River and Hongjiang River in the west and east. It is mainly composed of silty clay and the terrain is flat. The denuded quasi-plain landforms are distributed in the west and east of this area, with weakly undulating topography, the surface is mainly composed of silty clay, and the underlying bedrock is mainly siltstone and mudstone. Located in the northern temperate zone, the climate is mild and suitable. The annual average temperature of the area is 12℃~14℃, and the summer is relatively cool. The annual average precipitation is 500mm-700mm, and precipitation is concentrated in July and August. Winter is dry and less rainy, spring is windier, autumn is foggy, and the freezing period is about 40 days.

2.2.2. Engineering Geology. The route passes through the Gaomi and Haiyang depression areas, which belong to the local subsidence zone of the second uplift zone of the Neocathaysian System. In the local depression section where the crust is in the ascending stage, the ascending activity is relatively stable. The geological structure of Jiaozhou belongs to the North China Block, located on the east side of the Tanlu Fault Zone, spanning the northern edge of the Jiaonan Uplift and the southern edge of the Jiaolai Depression. It is mainly composed of faulted structures and fold structures. Jimo geology is a hilly valley subregion composed of clastic rocks and extruded rocks, with simple structure and relatively stable crust. There are liquefied soil layers and slightly expansive soil in some sections along the project.

2.2.3. Hydrogeology. The route passes through a well-developed river network in the area with numerous rivers, which are rain-sourced rivers in the monsoon area, mainly Taoyuan River, Dagu
River, Nanjiaolai River, and Mosi River, all of which are not navigable. There is pore water in loose rock formations, carbonate karst fissure water, clastic weathered fissure water, and basalt pore fissure water.

3. Analysis of differential settlement of new and old roadbed

3.1. Settlement and deformation characteristics of new and old roadbeds

For the existing old subgrade after years of operation, under the action of dead weight load and traffic load, the consolidation settlement deformation has been basically completed, and the settlement of the cross section at the bottom of the subgrade is shown as a basin with "small on both sides and large in the middle" as shown in the figure. As shown in Figure 2, the maximum settlement point is located below the center line of the old road subgrade.

3.2. Calculation method of differential settlement of new and old roadbed

The final settlement value mainly includes instantaneous settlement, consolidation settlement and secondary consolidation settlement, namely \( S = S_d + S_c + S_s \). Where \( S_d \) represents instantaneous settlement, \( S_c \) represents consolidation settlement, \( S_s \) represents secondary consolidation settlement. Generally, for the convenience of calculation, simplified calculation is adopted to determine the final settlement, \( S = mS_c \), generally speaking, \( 1.1 \leq m \leq 1.7 \). \( S_c \) is generally calculated by the layered sum method, namely

\[
S_c = \sum_{i=1}^{n} \frac{e_{oi} - e_{li}}{1 + e_{oi}} \Delta h_i
\]

(1)

\( n \) represents the number of layers; \( h_i \) represents the layer thickness of the \( i \) layer; \( e_{oi} \) represents the midpoint void ratio of the \( i \) th layer under the action of dead weight stress; \( e_{li} \) represents the midpoint void ratio of the \( i \) th layer under the action of dead weight stress and additional stress; Therefore, before widening, the roadbed settlement \( S_{lz} \) is shown in the formula.

\[
S_{lz} = \sum_{i=1}^{n} \frac{e_{ol} - e_{li}}{1 + e_{ol}} \Delta h_i
\]

(2)

Since the reconstruction and expansion of the expressway need to consider the role of the newly widened roadbed and pavement load, the total settlement of the new and old road base surface cannot be solved by the layered sum method, so the settlement is calculated from the perspective of additional
stress changes. Assuming that the calculated depth of the foundation is \( h \) and the average deformation modulus of the foundation soil is \( E_s \), then the total settlement \( S_z \) of the new and old road base surface is shown in the formula.

\[
S_z = \int_0^h \frac{1}{E_s} \sigma_z(z) \, dh = \sum_{i=1}^n \frac{\sigma_{zi} \Delta h_i}{E_{si}}
\]  

(3)

\( \sigma_z \) represents additional stress, \( \sigma_{zi} \) represents the average additional stress of the soil layer, \( E_{si} \) represents the average deformation modulus of the soil layer, and \( \Delta h_i \) represents the thickness of the soil layer.

Solving \( S_z \) and \( \sigma_z \) is a key step.

**Figure 2.** Additional stress coefficient under trapezoidal load

The trapezoidal load can be divided into two triangular loads and one rectangular load, and the two parts of the load can be solved separately, and the stress superimposed to obtain the stress calculation formula at any foundation depth \( z \) :

\[
\sigma_{zi} = k_1 p + k_2 p + k_3 p
\]  

(4)

Among them, \( k_1 \) is the additional stress coefficient under distributed load of \( \Delta AEF \) :

\[
k_1 = m \left[ \arctan \left( \frac{m}{n} \right) - \arctan \left( \frac{m-1}{n} \right) \right] - \frac{(m-1)n}{(m-1)^2 + n^2}
\]  

(5)

among them, \( m = \frac{x + 2a + b}{b}, n = \frac{z}{a} \)

Similarly, \( k_2 \) is the additional stress coefficient under rectangular \( ABDE \) distributed load:

\[
k_2 = \arctan \left( \frac{m}{n} \right) - \arctan \left( \frac{m-1}{n} \right) + \frac{mn}{n^2 + m^2} - \frac{n(m-1)}{n^2 + (m-1)^2}
\]  

(6)

among them, \( m = \frac{x + a + b}{b}, n = \frac{z}{a} \)
\(k_3\) is the additional stress coefficient under the distributed load of \(\Delta BDC\). According to the symmetry, \(k_1 = k_3\).

For the new road embankment, the parallelogram load is distributed, but the parallelogram load is essentially equivalent to the trapezoidal load [11]. In summary, the calculation formula for the additional stress \(\sigma_s\) at any depth of the widened foundation is as follows:

\[
\sigma_s = \sigma_{sl} + \sigma_{sx} = (k_1 + k_2 + k_3) p_i + (k_1^' + k_2^' + k_3^') p_e
\]

(7)

In the formula, \(k_1\), \(k_2\), \(k_3\) are the additional stress coefficients of the old roadbed load, and \(k_1^', k_2^', k_3^'\) are the additional stress coefficients of the new road load. \(p_i\) is the maximum distributed load value of the old road, and \(p_e\) is the maximum distributed load value of the new road.

It can be calculated from equations (3) and (7), so the calculation formula for the differential settlement of the new and old roadbed is:

\[
\Delta S = S_{xz} - S_{lz}
\]

(8)

### 3.3. Calculation method of differential settlement of new and old subgrade after construction

According to the calculation formula for the uneven settlement of the subgrade after construction proposed by related documents, the settlement of the new subgrade after construction is predicted \(S_{gh}\):  

\[
S_{gh} = (S_{xz} - U_i 'S_{lz}) (1 - U_i)
\]

(9)

In the formula: \(S_{lz}\) represents the total settlement of the new subgrade; \(S_{lz}\) represents the total settlement of the old subgrade; \(U_i '\) represents the degree of consolidation of the old subgrade before construction; \(U_i\) represents the completion of the consolidation after the completion of the new subgrade; Among them: \(U_i = \frac{2\alpha U_0 + (1 - \alpha) U_i}{1 + \alpha}\), \(\alpha\) is the ratio of the additional stress at the drainage surface to the stress at the non-drainage surface; \(U_0\) is the calculation expression of consolidation degree when the pore pressure distribution map is rectangular and \(\alpha = 1\), \(U_0 = 1 - \frac{8}{\pi^2} e^{\frac{-x^2}{4T}}\), \(U_1\) is the calculation expression of the degree of consolidation when the pore pressure distribution diagram is triangular and \(\alpha = 0\), \(U_1 = 1 - \frac{32}{\pi^2} e^{\frac{-x^2}{4T}}\), \(T\) — time factor, \(T = \frac{C_f}{H^2}\), \(C_f\) — consolidation coefficient, \(m^2 / s\), \(H\) represents the thickness of the soil layer (m), which is also the maximum seepage diameter of pore water; \(e\) is taken as \(e = 2.7182\).

### 4. Analysis of the impact of excavation of new and old roadbed benches on post-construction settlement

#### 4.1. Excavation of old roadbed steps

Take half of the cross section of the embankment for numerical simulation. The width of the old roadbed is 11.5, the width of the new roadbed is 9.5m, and the foundation is 60m wide and 20m high.
During construction, the old road steps are excavated and one layer is filled with new roadbed soil. The material-related parameters are shown in Table 2.

### Table 2. Calculation related parameter table

| Soil layer                  | Old embankment | New embankment | Foundation soil |
|----------------------------|----------------|----------------|-----------------|
| Natural bulk density $\gamma$ (KN/m$^3$) | 18.5           | 18.5           | 16.0            |
| Saturated bulk density $\gamma_{sat}$ (KN/m$^3$) | -              | -              | 18.9            |
| Modulus of resilience $E$ (KN/m$^2$)          | 40000          | 50000          | 8000            |
| Poisson's ratio $\nu$                        | 0.32           | 0.32           | 0.3             |
| Cohesion $c$ (KN/m$^2$)                       | 25             | 25             | 23              |
| Internal friction angle $\phi$ ($^\circ$)     | 30             | 30             | 27              |
| Dilatancy angle $\phi$ ($^\circ$)             | 0              | 0              | 0               |
| Permeability coefficient $m/d$                 | -              | -              | 0.0005          |

According to the engineering experience of the current project and existing research, the excavation width of the steps should be kept between 90~150cm, and the height should be between 60~100cm.[12] Respectively studied the influence of different excavation widths on the deformation characteristics of subgrade when the excavation height was fixed; when the excavation width was fixed, the influence of different excavation heights on the deformation characteristics of the subgrade; and the slope ratio of the subgrade (1:1.5) Under the same condition, the influence of different excavation steps on the deformation characteristics of the roadbed is shown in Table 3.

### Table 3. Step excavation method

| Serial number | Step height(m) | Step width(m) |
|---------------|----------------|---------------|
| 1             | 1              | 0.5. 0.7. 1.0. 1.5 |
| 2             | 0.6. 1. 1.2. 1.5 | 1             |
| 3             | 0.5. 0.6. 1. 1.2 | Gradient 1:1.5 Corresponding width (0.75. 0.9. 1.5. 1.8) |

4.2. Analysis of the control effect of subgrade deformation in different excavation steps

4.2.1. The height of the steps remains unchanged. The height of the steps is constant, and the vertical deformation cloud map of the subgrade under different excavation widths is shown in Figure 3–Figure 6.
**Figure 4.** Vertical cloud map of subgrade with step height of 1.0m and width of 0.7m

**Figure 5.** Vertical cloud map of subgrade with a height of 1.0m and a width of 1.0m

**Figure 6.** Vertical cloud map of subgrade with a height of 1.0m and a width of 1.5m

**Figure 7.** Comparative analysis of the settlement of the top surface of the roadbed
It can be seen from Figure 7 that when the height of the excavation steps remains unchanged, the deformation value of the top surface of the new and old roadbed has a negative correlation with the excavation width. When the step width increases from 0.5m to 1.5m, the settlement value at the center of the old road subgrade decreases from 0.041m to 0.037m, a decrease of 9.8%, and the settlement value at the old road shoulder decreases from 0.047m to 0.043m. It is reduced by 8.5%, and the vertical settlement deformation value at the shoulder of the new subgrade is reduced from 0.044 to 0.040m, which is a reduction of 9.1%. That is, when the height of the steps is constant, as the width of the steps increases, the post-construction settlement of the top surface of the new and old subgrades decreases.

It can be seen from Fig. 8 that when the height of the excavation steps is constant, the deformation value of the top surface of the foundation and the width of the excavation are negatively correlated. When the step width is increased from 0.5m to 1.5m, the settlement value at the center of the foundation decreases from 0.042m to 0.038m, a 9.5% reduction, and the vertical deformation value at the junction of the old and new subgrade on the top surface of the foundation decreases from 0.048m to 0.044m, which is a decrease of 8.3%; the settlement value at the foot of the subgrade slope is reduced from 0.031m to 0.027m, which is a decrease of 12.9%, the largest difference. The settlement decreased from 0.017m to 0.016m, a decrease of 5.8%. That is, with a certain step height, as the step width increases, the settlement value of the old and new foundations decreases, and the uneven settlement value also decreases.

4.2.2. The width of the steps remains unchanged. The width of the steps is constant, and the vertical displacement and deformation cloud diagrams of the subgrade under different excavation heights are shown in Figure 9~Figure 12.

![Figure 8. Comparative analysis of the settlement of the top surface of the foundation](image)

![Figure 9. Vertical cloud map of subgrade with step width of 1.0m and height of 0.6m](image)
Figure 10. Vertical cloud map of subgrade with step width of 1.0m and height of 1.0m

Figure 11. Vertical cloud map of subgrade with step width of 1.0m and height of 1.2m

Figure 12. Vertical cloud map of subgrade with step width of 1.0m and height of 1.5m

Figure 13. Comparative analysis of the settlement of the top surface of the roadbed
It can be seen from Figure 13 that when the width of the excavation step remains unchanged, the post-construction deformation value of the top surface of the new and old roadbed has a positive correlation with the excavation height. When the height of the steps is reduced from 1.5m to 0.6m, the settlement value at the center of the old road subgrade is reduced from 0.042m to 0.035m, a 16.7% reduction, and the settlement value at the shoulder of the old road is reduced from 0.048m to 0.040m. It was reduced by 16.7%, and the vertical settlement deformation value at the shoulder of the new subgrade was reduced from 0.045m to 0.040m, a 15.6% reduction. That is, when the step width is constant, with the increase of the step height, the settlement value of the top surface of the old and new subgrade increases.

It can be seen from Figure 14 that when the width of the excavation step remains unchanged, the post-construction deformation value of the top surface of the foundation and the excavation height are positively correlated. When the step height is reduced from 1.5m to 0.6m, the settlement value at the center of the top surface of the foundation is reduced from 0.043m to 0.035m, a decrease of 18.6%, and the vertical deformation value at the junction of the old and new subgrade on the top of the foundation is reduced from 0.048m. It is 0.041m, a decrease of 14.6%; the maximum settlement value of the foundation surface is reduced from 0.048m to 0.041m, a decrease of 14.6%; the settlement value at the foot of the subgrade slope is reduced from 0.031m to 0.025m, a decrease of 19.3%, The maximum differential settlement is reduced from 0.017m to 0.015m, a decrease of 11.7%. That is, with a certain width of the excavated step, as the height of the step increases, the settlement of the top surface of the old and new subgrade increases, and the uneven settlement is also Increase.

4.2.3. Subgrade slope rate remains unchanged. The subgrade slope rate is constant, and the vertical displacement and deformation cloud diagrams of the subgrade under different excavation heights are shown in Figure 15–Figure 18.
Figure 16. Vertical cloud image of roadbed with a height of 0.6m and a width of 0.9m

Figure 17. Vertical cloud map of subgrade with step height of 1.0m and width of 1.5m

Figure 18. Vertical cloud map of subgrade with step height of 1.2m and width of 1.8m

Figure 19. Comparative analysis of the settlement of the top surface of the roadbed
Figure 20. Comparative analysis of the settlement of the top surface of the foundation

It can be seen from Figure 19 that when the subgrade slope rate remains unchanged, the post-construction vertical deformation of the top surface of the new and old subgrade increases with the increase of the excavation step size. When the height of the steps is reduced from 1.2m to 0.5m, the settlement value at the center of the old roadbed decreases from 0.038m to 0.035m, which is a decrease of 10.5%, and the settlement value at the shoulder of the old road decreases from 0.044m to 0.041m. Reduced by 6.8%, the vertical settlement deformation value at the shoulder of the new subgrade is reduced from 0.041m to 0.038m, which is a decrease of 7.3%. That is, with a certain slope of the step, as the size of the step decreases, the construction of the new and old subgrade Afterwards the settlement is decreasing.

It can be seen from Figure 20 that when the subgrade slope rate remains unchanged, the post-construction vertical deformation of the top surface of the foundation increases with the increase in the size of the excavation step. When the step height is reduced from 1.2m to 0.5m, the settlement value at the center of the foundation is reduced from 0.039m to 0.035m, a decrease of 10.2%, and the vertical deformation value at the junction of the old and new subgrade on the top surface of the foundation is reduced from 0.041m to 0.038m, a decrease of 4.9%; the maximum settlement value of the foundation surface decreased from 0.046m to 0.042m, a decrease of 8.7%; the settlement value at the foot of the subgrade slope decreased from 0.028m to 0.026m, a decrease of 7.1%, the largest difference The settlement is reduced from 0.017m to 0.016m, a decrease of 5.9%. That is, with a certain step slope, as the size of the excavated step decreases, the settlement of the old and new foundations is decreasing, and the uneven settlement is also decreasing.

In summary, when the height of the steps is constant, as the width of the steps increases, the post-construction settlement of the top surface of the new and old roadbeds is decreasing, the settlement value of the new and old foundations is decreasing, and the uneven settlement value is also decreasing; In the case of a certain step width, with the increase of the step height, the settlement value of the top surface of the new and old subgrade is increasing, the settlement of the top surface of the new and old subgrade is increasing, and the uneven settlement is also increasing; in the case of a certain slope of the step As the step size decreases, the post-construction settlement of the new and old subgrade is decreasing, the settlement of the new and old foundation is getting smaller, and the uneven settlement is also decreasing.

5. Analysis of post-construction settlement caused by the splicing of new and old roadbeds

5.1. Combined step splicing scheme
In the construction of the first tender section of the Jiqing Expressway Reconstruction and Expansion Project, considering that there is a large amount of silty clay and sand in the subgrade filling of this section, the height of the steps should not be too large. Excavation of 200cm and 133.3cm high, the height of the upper step is adjusted to 100cm wide and 66.7cm high. After excavation, splicing and
filling are carried out in time, and the first step is excavated from bottom to top and the first step is filled in time. When excavating the steps spliced to the bottom of the road bed, the height and width of the steps are determined according to the height of the roadbed. When the step surface is less than 220cm from the top surface of the road bed, 120cm of the road bed will be excavated as a single step, and the rest less than 100cm will be used as a step Excavation and backfilling; when the step surface is more than 220cm from the top surface of the road bed, 120cm of the road bed is treated as a single step excavation, and the remaining portion greater than 100cm should be excavated and backfilled in two steps of 66.7cm and ≥ 33.3 cm.

5.2. Numerical simulation of combined steps

Taking the height of 6m of subgrade filling as an example for research, the subgrade slope rate of the combined step excavation method provided by the reconstruction and expansion project of Jiqing Expressway remains unchanged and the aspect ratio is 1:1.5, so section 4.2.3 of the article is taken. The four cases where the height and width dimensions are 0.5×0.75m, 0.6×0.9m, 1.0×1.5m, and 1.2×1.8m are compared and analyzed. The settlement cloud diagrams taken in the four conditions are shown in Figure 15-18, and the deformation data analysis is shown in Figure 19-20. Figure 22 shows the vertical deformation cloud image of combined step splicing. The deformation comparison between the top surface of the combined step splicing subgrade and the top surface of the foundation is shown in Figure 23~Figure 24.

Figure 21. Excavation form of combined bench

Figure 22. Vertical cloud map of combined step subgrade
It can be seen from Figure 23 that with the combined step excavation method, the post-construction settlement of the top surface of the new and old subgrade is compared with the step height of 1.2m and 0.5m. The settlement value at the center of the old subgrade is reduced from 0.038m and 0.035m to 0.031m, a decrease of 18.4% and 11.4%, respectively. The settlement value at the shoulder of the old road was reduced from 0.044m, 0.041m to 0.038m, a decrease of 13.6% and 7.3%. The value of vertical settlement at the shoulder of the new roadbed was reduced from 0.041m and 0.038m are reduced to 0.036m, a decrease of 12.1% and 5.3%. From the analysis, it can be seen that the combined bench excavation method can better control the deformation of the new and old subgrade settlement after construction.

It can be seen from Figure 24 that the post-construction settlement of the top surface of the new and old subgrade is reduced from 0.039m, 0.035m to 0.032m compared to the case of the step height of 1.2m and 0.5m after the combined step excavation method is adopted. Decreased by 17.9% and 8.8%, the vertical deformation value of the joint between the old and new subgrade on the top surface of the foundation was reduced from 0.041m, 0.038m to 0.035m, a decrease of 14.6% and 7.9%; the maximum settlement value of the foundation surface was reduced from 0.046m, 0.042m is reduced to 0.039m, a decrease of 15.2% and 7.1%; the settlement value at the toe of the subgrade slope is reduced from 0.028m, 0.026m to 0.023m, a decrease of 17.9% and 11.5%, the maximum differential settlement is reduced from the largest difference The settlement is reduced from 0.017m and 0.016m to 0.015m, which is a decrease of 13.3% and 6.3%. The analysis shows that the combined bench excavation method can better control the deformation of the new and old foundation settlement after construction.

In summary, the combined step excavation method can effectively control the post-construction settlement of the highway reconstruction and expansion project and ensure the safety of road traffic.
6. Conclusions
Based on the reconstruction and expansion project of Jiqing Expressway, this paper studies and analyzes the influence of step excavation size on subgrade splicing settlement, and the following conclusions are obtained:

(1) Through literature review, combined with numerical simulation techniques, the impact of the three conditions of a certain height of the excavation step, a certain width of the excavation step, and a certain slope rate of the excavation step on the deformation characteristics of the subgrade are studied separately. Under the condition of a certain height, the step width is negatively related to the settlement value of the top surface of the subgrade and the top of the foundation; under the condition of a certain width, the height of the step is positively related to the settlement value of the top surface of the subgrade and the top of the foundation; when the slope rate of the step is constant, the size of the step is related to the top surface of the subgrade, The settlement value of the top surface of the foundation is negatively correlated

(2) Combining on-site construction conditions and geological conditions, a combined subgrade bench excavation method is proposed, which provides a reference for similar projects.

(3) Through the technical means of numerical simulation, the combined subgrade bench excavation and splicing method was verified, compared with the data under a certain step slope rate, and the correctness of combined subgrade bench excavation and splicing was verified.

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