Analysis of Track Bend Limit and Settlement Deformation Affecting the Transition Section of Highway and Bridge of High-speed Railway

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Abstract. In recent years, with the rapid development of high-speed railways, the problem of differential settlement of road-bridge transition sections has become increasingly prominent. The uneven settlement of the road-bridge transition has a great impact on the driving safety and comfort of high-speed vehicles, especially for high-speed railway projects under special ground conditions such as soft stop. And with the continuous increase in train speed and axle weight, the differential settlement requirements at the over-bands are becoming more stringent. The problem of "jump at the bridgehead" has become one of the important factors affecting the safety of high-speed trains. In view of the current situation, theoretical analysis and numerical calculation are used as research methods in this paper. The factors of uneven settlement and deformation of the road-bridge transition section are systematically analyzed and corresponding methods for foundation treatment are proposed.

Keywords: High-speed railway; road-bridge transition track; corner limit value; settlement deformation; influencing factors.

1. Introduction

The emergence and development of high-speed railway, referred to as "high-speed railway", is a milestone in the history of human transportation. Its high speed, high passenger capacity, strong transportation capacity, better safety and comfort meet the growing demand for human transportation. The increase in speed has brought many problems and challenges to the development and research of the railway. The high requirements of high-speed railways for speed, safety and comfort need to be guaranteed by the stability of the lines and foundations. Each part of the circuit structure has its own strength stiffness, deformation, and material characteristics [1]. To optimize the overall structure, it is necessary to optimize the mechanical parameters of each part. The dynamic stability of the subgrade in the high-speed railway and the later settlement deformation have a controlling effect on the safety and durability of the trackless track and its superstructure [2]. A special part of the subgrade structure is the transition section between the soil subgrade and the rigid structure. In China's high-speed railway construction, transition sections inevitably occur, mainly in several common forms, such as road-bridge transition sections, road-transition transition sections, road-culvert transition sections, bridge-transition transition sections, embankments and temporary transition sections [3]. Due to the difference in the
structural form and material stiffness of the rigid structure foundation and the subgrade structure foundation, the geometric smoothness of the line will be reduced, thereby reducing the stability of the line, especially the long-term stability. Therefore, the dynamic characteristics research and optimized design at the transition section will become an important aspect to achieve high smoothness, high stability, durability, and safety of the entire line.

High-speed railways have high requirements for the smoothness of the lines, and high-speed trains must be guaranteed by high smoothness and stable under-rail foundations. Because the stiffness of the roadbed and bridge is very different, it causes the difference of settlement, which leads to the irregularity of the line. The excessive settlement difference will affect the speed, safety, smoothness and comfort of the train. Therefore, reasonable estimation of the settlement of the foundation of the transition section is an important issue in the construction of high-speed rail. This paper analysed the factors of uneven settlement and deformation of the road-bridge transition section and proposes corresponding methods for foundation treatment.

2. Analysis of causes of road settlement in road-bridge transition

When the road-bridge transition is subjected to the dynamic load of high-speed vehicles, a bumping phenomenon with a large vibration often occurs at the bridge head. In the transition section, this kind of bridgehead jump is the most common and most people feel. The direct reason for this is the difference in rigidity between the rigid abutment structure and the flexible embankment, and the repeated action of the driving load at the transition section of the connecting section at the end of the abutment [4]. The problem of poor stiffness and settlement in the transition area is the root cause of line irregularities. The main reasons for this phenomenon are the following.

2.1. Reasons for foundation conditions

Many existing lines are now built on weak foundation soils that are in poor condition and not treated well. On soft ground, the settlement between the road and the bridge after the construction is different, so there must be a settlement difference at the transition between the road and the bridge. Due to the structural reasons of the road-bridge transition section, the filling height of the bridgehead subgrade is large, and the resulting base stress is also high. Therefore, the settlement at the road-bridge transition section is greater than other road sections. Different foundation soils have different properties and structures, and the resulting settlement and the time required for the settlement to reach stability are also different [5]. For silty soil foundation and medium and low compression load-bearing soil foundation, it takes several years to complete the settlement. For high compression salary foundation and saturated salary foundation, it takes more than ten years or even decades to complete the settlement. Therefore, the settlement of the foundation after construction is the cause of the bridgehead jumping caused by the foundation.

2.2. Reasons for embankment filling behind the platform

The embankment filling behind the abutment is generally filled with soil. Due to construction reasons, the working surface is often relatively small, the rolling quality is not easy to control, and its compactness cannot meet the design requirements. Even if the compaction degree meets the design requirements during construction, due to the self-weight and dynamic load of the embankment fill during operation, the embankment fill will be further compressed and deformed, causing a settlement difference at the bridge-road transition. The protection works in front of the abutment will cause a certain horizontal displacement due to the horizontal effect of the earth pressure. This horizontal displacement will cause the settlement of the roadbed at the transition between the road and the bridge. The length of the road bridge transition will produce small expansion cracks. After the surface water or rainwater penetrates, it will cause the subgrade filling soil to appear disease, reduce the intensity and cause settlement. Or due to the infiltration and flow of water, the fine-grained soil in the filler is taken away, causing settlement deformation at the transition between the road and the bridge [6].
2.3. Design and construction reasons
During the design, the construction and rolling process of the excessive sections of roads and bridges is not considered carefully, and the requirements for the filler are not strict. The drainage design behind the abutment is not considered well, which will affect its construction quality. The construction period or process was improperly arranged during construction, so that the filling and compaction work of the road and bridge transition section was arranged at the end of the construction period and forced to rush the construction period [7]. This can not control the compaction quality of the fill well, which causes the settlement of the fill itself. During construction, the backfill of the road and bridge transition section is not filled according to the design requirements, or poor fillers are used, or the rolling thickness exceeds the requirements, or the compactness fails to meet the design requirements, which will cause quality defects. During the construction, the configuration of the rolling equipment is not good, the compaction power is not enough, and the hierarchical quality inspection is not performed, which will make the compaction quality fall short of the control requirements.

2.4. Reasons for the differences between the subgrade and abutment structures
Abutments are generally rigid, while roadbeds are flexible. Due to the difference between these two structures, in the transition zone between road and bridge, there must be a settlement difference between rigid and flexible when subjected to dynamic loads. The road-bridge transition section is a weak link that affects the operation of the line because of its different rigidities, different dead weights, and different strengths. It is also a stress concentration area under external forces. Compared with the bridge pier, the horizontal stability of the abutment of the road-bridge transition section is more disadvantageous [8]. Due to the different load conditions before and after the abutment, there is no load in front of the abutment, and the horizontal earth pressure of the fill behind the abutment causes the bridge head to receive a large horizontal thrust. If there are no corresponding measures during design and construction, accidents will often be caused, such as abutment displacement on soft foundations, shearing of pile foundations, etc.

3. Numerical analysis of uneven settlement of road-bridge transition

3.1. Model establishment and calculation
According to the relevant provisions of the Design Code for High-Speed Railway (TB20621-2014) and the structure of the road-bridge transition section in actual engineering, this paper uses Abaqus software to establish a finite element model of the road-bridge transition section. Because the structure of the transition section is symmetrical about the track center plane, in order to improve the calculation efficiency, a semi-model of the road-bridge transition section is established in this paper, as shown in Figure 1. The key mechanical parameters are listed in Table 1.
In order to accurately consider the situation where the base plate is vacated, this article uses a contact relationship to simulate the interaction of the base plate and the surface of the roadbed. A surface-to-surface flexible contact element is applied to the base plate and the surface of the subgrade. The friction type is Coulomb friction, and the Lagrange algorithm is used to solve the nonlinear solution. In order to make the solution process converge as quickly as possible, this study will encrypt the contact grid to twice the original grid.

3.2. Calculation results

Through calculation, the lateral distribution of the deformation of the roadbed surface is shown in Figure 2. It can be seen from Figure 2 that the vertical deformation on the roadbed under static force is symmetrically distributed at the center of the roadbed. The deformation at the center of the subgrade, that is, the center of the load, is the largest, and the deformation at the edge of the subgrade is the smallest. And the vertical deformation of the roadbed gradually decreases from the center of the roadbed to both sides.

**Table 1. Key parameters of high-speed railway road-bridge transition**

| Structure               | Height (m) | Width (m) | Density (kg m$^{-3}$) | Modulus of elasticity (GPa) | Poisson's ratio |
|-------------------------|------------|-----------|-----------------------|----------------------------|-----------------|
| Track board             | 0.21       | 2.5       | 2500                  | 36.5                       | 0.2             |
| Base plate              | 0.3        | 3.1       | 2500                  | 28                         | 0.25            |
| Gravel surface          | 0.4        | -         | 1300                  | 0.4                        | 0.25            |
| Embankment below the bed| 3.3        | -         | 1700                  | 0.06                       | 0.25            |
| Rail                    | -          | -         | 7850                  | 206                        | 0.28            |

**Figure 1. FE-Model**

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Figure 2. Transverse change of vertical displacement of subgrade surface in transition section

4. Settlement measures for road and bridge transition

For the deformation control of the road-bridge transition section, two issues are considered to convert the staggered settlement at the junction of the backfilled roadbed and abutment into a continuous slope settlement. In this study, treatment measures such as inclined filling of crushed stone materials, reinforced earth embankment structure, and reinforced concrete transition slabs were used to solve the strict control of the rail surface bending deformation of the transition section line to meet the requirements of high-speed traffic. At present, the vibration analysis model of road-bridge transition can only be established based on the analysis theory of vehicle line system, and the comprehensive system dynamics calculation can be performed, which can be comprehensively resolved by referring to relevant technical data. According to the design standards for the subgrade bed structure proposed in the "Interim Provisions for the Design of the Beijing-Shanghai High-speed Railway Line Bridge and Tunnel Station", the rate of change in track stiffness between roads and bridges with reinforced concrete track structure is only about 25% [9]. The impact is relatively small. Therefore, the treatment of the transition section should focus on reducing the settlement difference between roads and bridges and strictly controlling the deformation of the track surface.

Smooth transition to ensure the stiffness of the transition section is an important guarantee to reduce its harm. In order to reduce the difference in stiffness and settlement of the transition section of the road and bridge, and achieve the purpose of a smooth transition in the stiffness of the transition section, foreign countries with advanced railway technology have a certain foundation in dealing with the transition section, and have accumulated rich experience, and put forward some technical treatment measures that have been proven to be feasible in practice [10]. In summary, there are three main categories:

1) On the softer side of the transition section, increase the stiffness of the foundation bed and reduce settlement of the embankment;
2) On the softer side of the transition section, increase the vertical stiffness of the track;
3) On the harder side of the transition section, adjust the vertical stiffness of the track by setting rubber pads under the rail, under the pillow, and at the bottom of the heel.
At the same time, in order to control the settlement of the subgrade in the transition section, the foundation must be treated. Ground treatment is an important part of controlling the settlement of the roadbed and has a long history. In subgrade engineering, common ground treatment methods are shown in the figure.

In order to control the settlement and deformation, the use of natural foundation is a more economical method in the selection of the foundation treatment scheme. Therefore, before deciding to treat the foundation, priority should be given to choosing a treatment scheme that can make full use of the natural foundation to reduce the cost. Generally, the replacement method is used to excavate the weak soil within a certain range of the upper part of the foundation, replace the material with greater strength and less compressibility, such as sand, gravel, slag, or soil, and process it into a cushion [11]. As shown in Figure 3.

![Figure 3. Settlement control method](image)

In the roadbed engineering, in addition to strengthening the settlement control of the foundation, the settlement control of the embankment body should also be strengthened. This involves the selection of embankment fillers, and various reinforcement measures can also be adopted. Such as various geotextiles to improve the deformation resistance of the embankment.

5. Conclusion
This paper used Abaqus software analysis to obtain that under static force, the vertical deformation of the lateral subgrade on the transition section is symmetrically distributed at the center of the subgrade, the deformation at the center of the subgrade is the largest at the center of the load. Minimal deformation at the edge of the subgrade, the vertical displacement of the subgrade at different locations along the depth direction is basically the same, subgrade displacement gradually decays in the form of a hyperbola. This paper proposed several solutions to the settlement problem to improve the deformation resistance of the embankment.

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