Research on a Rapid Evaluation Method Based on Relative Settlement Measurement

Ziyao Wang¹, XiuShao Zhao¹*, Jiang long Rao¹, Zixi Chen¹

¹Engineering Research & Development Centre for Underground Technology of Jiangxi Province, East China Jiao Tong University, Nanchang 330013, China.

*Corresponding Author’s E-mail: 2504@ecjtu.jx.cn

Abstract. When the bearing capacity of the transition section of the subgrade is insufficient, reinforcement is needed to ensure the normal operation of the railway. The traditional method of judging whether the bearing capacity of the subgrade meets the requirements is time-consuming, laborious and inefficient. Therefore, a rapid assessment method of whether the transition section needs reinforcement is proposed based on settlement measurement. Through the comparison between the exploration test of the subgrade bearing capacity of the transition section and the settlement value of the subgrade, the correlation between the bearing capacity and the bearing capacity of the subgrade is established. According to the characteristics of the transition section of the subgrade, the relative settlement method, the track bed height method and the roadbed reverse slope method are proposed, and the standards for the determination of reinforcement are also obtained. This method is faster than the traditional method and saves investigation funds.

1. Introduction

After years of operation of the existing railway, the properties of the subgrade transition section have changed, some transition sections have compaction under the action of load, and the other part is caused by excessive settlement of subgrade due to the low compaction coefficient [1], resulting in a variety of subgrade diseases. In order to increase the speed of the existing railway, it is necessary to investigate the subgrade of the transition section.

At present, many scholars have studied the subgrade of transition section of railway subgrade, using rapid reinforcement method to reduce the impact on the operation of railway line or using new reinforcement method, which can effectively improve the safety strength reserve and service life of the structure. Xiao [2] carried out electrochemical treatment method for subgrade. Xiao [3] analyzed through experiments that sleeve valve pipe grouting technology can effectively improve the filling density of transition section. Wang [4] used ground penetrating radar to carry out non-destructive detection test for subgrade diseases in transition section. Cao [5] introduced the detection of subgrade diseases and studied the strengthening technology.

The traditional methods to master the bearing behavior of subgrade are light dynamic penetration method and dynamic deformation modulus test method. It is necessary to declare the "skylight" time to the Railway Administration for exploration at the specified night, which seriously affects the operation of the existing railway. The light dynamic sounding needs to explore all the subgrade beds below the subgrade surface, so it has the character of high exploration costs and low exploration efficiency.

In the above studies, most of them are carried out by rapid reinforcement method or new
reinforcement method. To improve the operation efficiency, reduce the "skylight" time and reduce the detection cost, the apparent measurement method can also be used to quickly determine whether the transition section subgrade needs to be reinforced. This paper introduces the concept of quantitative parameters and classification standards, and introduces and analyzes the advantages of three kinds of apparent measurement methods combined with the inspection examples of Ning-Qi railway.

2. Subgrade bearing capacity test and settlement measurement

In order to study the evaluation method of rapid apparent measurement whether the subgrade in the transition section needs reinforcement or not, lightweight dynamic penetration test and relative settlement test were carried out in the bridge-subgrade transition section. The light dynamic penetration test measures the number of hammer strokes of the penetrating head into the subgrade 30cm, and then calculates the bearing capacity of the subgrade by equation (1).

\[ f = 8 \times N - 20 \]  

(1)

Where \( f \) is the bearing capacity of the subgrade, and \( N \) is the number of hammers in lightweight dynamic penetration test.

In Figure 1, \( h_1 \) is the original design elevation of the subgrade, \( h_2 \) is the elevation of the subgrade after operation, so \( S_2 = h_1 - h_2 \) is the settlement of the subgrade. \( S_2 \) does not have a reference, so it is not easy to measure. According to Figure 1, it can be seen that the settlement of the subgrade will cause the settlement of the steps, so \( S_1 \) is the settlement of the subgrade.

In Figure 1, the distance between the top step of the subgrade in the transition section and the bridge deck is measured with a tape measure. It is assumed that the distance is the settlement of the central point of the transition section, and the apparent characteristic changes after the settlement occurs.

![Figure 1](image_url)

(a) Measuring principle  (b) Measurement method

3. The relationship between bearing capacity and subgrade settlement

According to the survey results of Yangzhou section of Ning-Qi line (see Table 1), when the relative settlement is less than 8 cm, the transition section is basically free from disease, and the subgrade compaction coefficient is high. In the E-Mei River middle bridge, the settlement difference is only 2.8 cm, and the bearing capacity of light dynamic penetration survey reaches 260 kPa. When the relative settlement is 8-15cm, there are some diseases in the transition section, but the main diseases are small scour cavities, and the diameter of cavities is generally within 20cm. When the relative settlement is greater than 15cm, there are larger diseases, mainly landslide and large-scale cavity. According to the results of practice surveys, the differential settlement subgrade bridge transaction (No.91) is 21.5cm, and the average bearing capacity is only 86kPa. The subgrade slope collapses, which is a serious disease and must be treated.

| Name of transition section of bridge | Differential settlement/cm | Average bearing capacity /kPa |
|--------------------------------------|-----------------------------|------------------------------|
| E-Meihe Bridge                       | 2.8                         | 260.0                        |

Table 1 Comparison of average settlement and average bearing capacity of each transition section
The relationship between bearing capacity and settlement can be obtained through the analysis in Table 1, which can be described by equation (2).

\[ f = -0.031s^3 + 1.6787s^2 - 32.804s + 327.94 \]  \hspace{1cm} (2)

Where \( f \) is the average bearing capacity of the transition section subgrade, kPa; \( s \) is the settlement of the transition section subgrade center point, cm.

4. Discussion on the rapid measurement method

4.1. Bridge step relative settlement measurement

Judgment basis of settlement difference method between steps and bridge deck

In the existing Ning-Qi railway, most of the bridges adopt the subgrade and bridge structure (see Figure 1). When the construction is completed, the top surface of the lower bridge steps is flush with the bridge deck. Since the abutment and bridge deck are on pile foundation and the abutment body is of concrete structure, the settlement of bridge deck can be ignored. The step is located on the subgrade of transition section, and the settlement of the step is composed of foundation settlement and subgrade settlement. Due to the large settlement of subgrade andfoundation, there is a settlement difference between the steps and the bridge deck. The larger the settlement difference is, the greater the settlement of the transition section subgrade is. The settlement reason of transition section is closely related to the compaction coefficient of subgrade soil, so the disease of subgrade transition section is more where the relative settlement is large.

Determination of relative settlement

The bearing capacity of the speed-increasing subgrade is required to be 150kPa. According to the equation (2) and the characteristics of subgrade diseases, the following discrimination method can be obtained. If the step settlement is less than 8.6 cm, the transition section subgrade does not need to be reinforced; if the step settlement is greater than or equal to 17 cm, the transition section subgrade needs to be reinforced; if the step settlement is between 8.6 and 17 cm, the transition section subgrade needs to be reinforced, otherwise, reinforcement is not needed.

4.2. Judgment method for apparent height of track bed in transition section

Judgment basis of track bed apparent height method

The original Subgrade of Ning Qi existing railway is non-permeable soil, and the design thickness of track bed is \( h_3 = 50 \) cm. In the transition section, because the bridge deck settlement can be ignored, and the subgrade settlement \( (S_t) \) in Figure 2 (a) in the transition section is large, the track bed thickness must be increased to maintain the rail surface elevation under the condition of keeping the track elevation unchanged. Therefore, when the actual thickness of the measured track bed is far greater than the design thickness, it indicates that there is a large settlement of the subgrade in the transition section.

Judgment method of ballast bed apparent height

In Figure 2 (b), a 2 m long horizontal ruler is used to set one end on the top of the sleeper, and the other end is manually adjusted to measure the height from the top of the shoulder to the level. According to the geometric relationship of settlement, the criterion for the height of the track bed can be obtained. If the step relative settlement is 8.6 cm, the corresponding apparent height \((h_3 + S_t)\) of the

| Bridge       | Step Settlement | Subgrade Settlement |
|--------------|-----------------|---------------------|
| ShengGang Bridge | 6.7             | 148.7               |
| Ci-Liangang Bridge | 5.4              | 190.7               |
| No.89 Bridge  | 18              | 97                   |
| No.90 Bridge  | 22              | 94                   |
| No.91 Bridge  | 21.5            | 86                   |
| No.92 Bridge  | 13              | 158                  |
| No.93 Bridge  | 18              | 62                   |
track bed is 88.6 cm. If the step relative settlement is 17 cm, the corresponding apparent height \((h_3 + S_3)\) of the track bed is 97.6 cm. If the apparent height of the track bed is greater than or equal to 97.6 cm, the subgrade in the transition section needs to be strengthened.

![Diagram](image)

\(\text{(a) Measuring principle } \quad \text{(b) Measurement method}\)

*Figure 2. Test method for apparent thickness of track bed in transition section*

### 4.3 Judgment method for reverse slope of road shoulder

**Judgment basis of shoulder reverse slope method**

In the design of non-permeable filling subgrade, the top surface of subgrade has a slope of 4% from the center to both sides, so as to ensure that the rainwater falling to the subgrade surface can be discharged smoothly (Figure 3(a)). When the shoulder is higher than the center of the subgrade, the precipitation cannot be discharged out of the subgrade bed in time, which results in the water soaking the subgrade and softening the subgrade.

**Criterion of shoulder reverse slope method**

If the shoulder is higher than the subgrade at the toe of the slope, and there are water immersion marks, it is necessary to reinforce the road shoulder and regulate the slope at the shoulder, so that the rainfall can smoothly discharge out of the surface range of the subgrade bed [6].

![Diagram](image)

\(\text{(a) Before the operation of the slope } \quad \text{(b) The reverse slope after operation}\)

*Figure 3. Schematic diagram of shoulder reverse slope*

### 5 Conclusions

- According to the relationship between the settlement and the bearing capacity of the subgrade, the bridge-step relative settlement method can be used for whether the transition section of the roadbed needs to be reinforced. When the relative settlement is lowered to 8.6 cm, it does not need to be reinforced. When the relative settlement is greater than 17 cm, it needs to be reinforced. Whether the subgrade needs to be reinforced, there is a transition zone when the bridge-step relative settlement ranges from 8.6 cm to 17 cm. When subgrade diseases occur, it needs to be reinforced; otherwise, it does not need to be reinforced.

- The ballast bed height method can also be used to determine whether the transition section needs reinforcement. When the height of the track bed is lower than 88.6 cm, it does not need...
to be reinforced; when it is higher than 97.6cm, it needs to be reinforced. Whether the subgrade needs to be reinforced, there is a transition zone when the ballast bed height ranges from 88.6cm to 97.6cm. When there is a roadbed disease, it needs to be reinforced; otherwise it does not need to be reinforced.

- The subgrade reverse slope method can be used to assist whether the subgrade transition section needs reinforcement. When the subgrade surface reverses slope, the transition section needs to be reinforced.

Acknowledgments
This work is supported by the National Natural Science Foundation of China (Grant No. 51668018, No. 52068027 and No. 51768021).

References
[1] Sun J.L. Research on Test of the Dense State of Existing Railway Subgrade. Railway Construction Technology. 2015 Jan;(01):1-3+38.
[2] Xiao F.Y, Su Q., Zhang Q., Shao K., Chen C., Huang Z.C.. Experimental Study on Electrochemical Rectification of Railway Muddy. Railway Engineering. 2019 Sep;(08):1-6.
[3] Fu M.C., Chen W.Z., Huang B.C., Chen X.J.. Over-limit Settlement Treatment of Railway Subgrade Transition Section Based on Sleeve-Valve-Pipe Grouting Method. Subgrade Engineering. 2019 May;(05):213-218.
[4] Wang C.L., Bai M.Z., Du Y.Q., Liu X.P., Qin G.D.. Ground penetrating radar nondestructive testing method applied in railway subgrade of existing heavy haul railway. Journal of Beijing Jiaotong University. 2013 Apr;37(04):35-39.
[5] Cao Y.. Study on the Subgrade Disease Test and Strengthening Technology for Baotou-Xi’an Railway. Beijing Jiaotong University. 2014.
[6] Zhao X.S., Zhu J.N., Dai Y.Q., Liu X.P., Wang L.L., Geng D.X., Liu W.. Research on Survey Evaluation and Reinforcement Control Standard for Existing Railway. Journal of Railway Engineering Society. 2011 Mar;28(03):11-15.