Settlement Characteristics and Prediction of Weak Expansive Soil Subgrade Based on Track Geometry Measurements

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Abstract. The weak expansive soil subgrade of the railway in operation is prone to settlement in a high-temperature climate, which results in a rapid deterioration in the geometric dimensions of the track, and affecting the safety of the train operation. This paper uses Track Geometry Measurements (TGM) to analyze the deterioration characteristics of track geometry parameters in the subgrade settlement of weak expansive soil. Also establishes a Settlement Prediction Model (SPM) to identify the settlement time of subgrade and predict the value of track geometry parameters before track maintenance. SPM applies to the mileage k285+000~k300+000 of the weakly expansive soil subgrade section of the Han-Dan Railway. It was verified by the TGM of the 20 subgrade settlement positions of this section. The results show that SPM has a high application value.

1. Introduction

Expansive soils are a special kind of soil with swelling–shrinkage characteristics[1] and widely distributed throughout China. Some areas will use improved micro-expansive soil as railway subgrade filling in the railway construction period[2]. In recent years, due to the emergence of continuous high-temperature weather, some railways in China (such as Han-Dan Railway, Jiao-Liu Railway, Xiang-Yu Railway, Beijing-Shanghai Railway) have experienced sudden and violent subgrade settlement, which has caused rapid deterioration in track geometry. Traffic safety has been affected.

Many researchers have carried out studies on the prediction of subgrade settlement. The general settlement prediction methods are: Asaoka method, Poisson curve method, three-point method, hyperbolic method, and artificial neural network method[3]. Wang et al[4], analyzed the cumulative subgrade settlement of Yu-Wan Railway from February to December in 2015 and have found that NpGM (1, 1) and UQGM (1, 1) are suitable for the prediction of the post-construction settlement of mountain railway subgrade. At present, the research on subgrade settlement prediction during the railway construction period has achieved good results. However, few scholars have studied the subgrade settlement diseases that often occur during the railway operation period. The settlement of the weak expansive soil subgrade during the operation period will cause a rapid deterioration in the track geometry, which will affect the safety of train operation. The railway works department uses the track inspection car to periodically check the track geometry parameters, car body acceleration, and other indicators. There have been a large number of studies using TGM to make short-term predictions[5] and long-term predictions[6].

As mentioned above, the deterioration of track geometry caused by the settlement of weak expansive soil subgrade is sudden and drastic. It is urgent to find the mileage of the subgrade settlement and grasp the development trend of the subgrade settlement. This paper will use the TGM to analyze the...
deterioration characteristics of the track geometry when the weak expansive soil subgrade subside
cence providing a theoretical basis for identifying the weak expansive soil subgrade settlement
position. Based on TGM, this paper will establish SPM to identify the settlement time of the
subgrade and predict the state of the track situation of post-settlement of the weak expansive
soil subgrade during the operation period. These provide data support for the railway department
to take timely measures for ensuring the safety of trains.

2. Deterioration characteristics of track geometry

In this paper, Han-Dan Railway is used as an example to analyze the deterioration characteristics
of the track geometry size of the weak expansive soil subgrade settlement. The Han-Dan
Railway is a double-track ballasted general-speed railway with a design speed of 200km/h. It
opened to traffic in 1966, and the total length is 412km. It is located in central China, as shown in
Figure 1. The mileage range of weak expansive soil roadbed section is k285+000~k300+000.

![Figure 1. Location map of Han-Dan railway.](image)

2.1. Deterioration project of track geometry

Figure 2 shows the waveform diagram of the Han-Dan railway mileage from k298+160 to k298+260.
On the 100-meter-long section, only the track geometry at mileage k298+249 deteriorated, and the
rest did not deteriorate. At the mileage k298+249, the surface becomes smaller, the alignment
becomes larger, the gauge does not change. Therefore, the settlement disease of weak expansive
soil subgrade should be mainly concerned with the surface and alignment of the diseased point.

![Figure 2. TGM of mileage k283+800 to k283+900.](image)
2.2. Deterioration characteristics

Figure 3 shows the time series of surface and alignment at mileage k298+249 in 2018. The surface and alignment suddenly start to deteriorate after a certain detection, where the surface becomes smaller, the left side decreases more than the right side, and the alignment becomes larger.

In this paper, 20 subgrade settlement diseases are found from the weak expansive soil subgrade section of the Han-Dan Railway with a mileage of k285+000~k300+000. The deterioration of surface and alignment of these diseases are similar to the mileage k298+249. The characteristics of track geometry dimension deterioration in the settlement of weak expansive soil subgrade of Han-Dan Railway are as follows:

- The surface and alignment suddenly deteriorate after a period of stability.
- The surface becomes smaller, the left side decreases more than the right side.
- The alignment becomes larger.

3. Settlement prediction

The surface and alignment suddenly deteriorate after a period of stability. Therefore, it is necessary to find valid data for prediction. This article takes the left surface as an example, and divides it into two parts before and after the subgrade settlement, as shown in Figure 4:

\[ y_1 = b_1 \]
\[ y_2 = kx + b_2 \]

Before the settlement of the subgrade, the track geometry parameters would hardly deteriorate. Therefore, the track geometry parameters during this period can be showed by equation (1).
Expansive soil shrinks in summer \cite{7}, and after the weakly expansive soil shrinks, the subgrade will settle under the continuous action of the dynamic train load. Generally speaking, the track will be repaired during the period of rapid settlement. At the settlement of the roadbed, the number of trains passing every day is the same. Before the track maintenance, the daily settlement rate of the subgrade should be the same. Therefore, the track geometry parameters during this period can be showed by equation (2).

\[ y_2 = kx + b_2 \]  

(2)

This paper establishes the settlement prediction model (SPM). SPM uses a piecewise function to fit the track inspection parameters and takes the minimum error as the objective function to find the time of subgrade settlement. The objective function of the settlement prediction model is:

\[ z = \min_{1 \leq c \leq d} \left( \frac{1}{d-c+1} \left( \sum_{i=c}^{d} \left( p_i - (kx_i + b_2) \right) \right)^2 \right)^{1/2} + \frac{1}{d-c+1} \left( \sum_{i=c}^{d} \left( p_i - (kx_i + b_2) \right) \right)^2 \]  

(3)

Where c means that the c-th inspection is regarded as the settlement time of the subgrade, d means that the track is repaired after the d-th inspection, \( p_i \) is TGM of the i-th inspection, \( x_i \) is the date of the i-th track inspection. \( k, b_1, b_2 \) are the parameters of equation (1) and (2), the calculation methods of these three parameters are as follows:

\[ b_1 = \frac{1}{c} \sum_{i=c}^{d} p_i \]  

(4)

\[ k = \left( \frac{\sum_{i=c}^{d} (p_i x_i)}{\sum_{i=c}^{d} x_i} \right) - \frac{1}{d-c+1} \sum_{i=c}^{d} p_i \sum_{i=c}^{d} x_i \left( \sum_{i=c}^{d} x_i \right)^{-1} - \frac{1}{d-c+1} \left( \sum_{i=c}^{d} \right)^2 \]  

(5)

\[ b_2 = \frac{1}{d-c+1} \sum_{i=c}^{d} p_i - \frac{k}{d-c+1} \sum_{i=c}^{d} x_i \]  

(6)

This paper takes the left surface at mileage k298+249 in 2018 as an example to verify the SPM. The track was maintained after the 21st inspection. Before maintenance, the objective function under different values of \( c \) is shown in Figure 5. The 15th detection is the time when the subgrade begins to settle. The left surface at mileage k298+249 are fitted by equation (1) and (2), and the result is shown in Figure 6. After the subgrade settlement, the fitted correlation coefficient is 0.9142. The result is excellent.
Table 1. The correlation coefficients of the surface and alignment of 20 positions

| Settlement position number | Correlation coefficient of left surface | Correlation coefficient of right surface | Correlation coefficient of left alignment | Correlation coefficient of right alignment |
|---------------------------|--------------------------------------|----------------------------------------|-----------------------------------------|-------------------------------------------|
| 1                         | 0.92                                 | 0.92                                   | 0.91                                    | 0.90                                      |
| 2                         | 0.91                                 | 0.90                                   | 0.92                                    | 0.91                                      |
| 3                         | 0.87                                 | 0.92                                   | 0.93                                    | 0.88                                      |
| 4                         | 0.92                                 | 0.88                                   | 0.90                                    | 0.92                                      |
| 5                         | 0.94                                 | 0.90                                   | 0.90                                    | 0.91                                      |
| 6                         | 0.93                                 | 0.87                                   | 0.94                                    | 0.90                                      |
| 7                         | 0.92                                 | 0.93                                   | 0.91                                    | 0.96                                      |
| 8                         | 0.95                                 | 0.89                                   | 0.94                                    | 0.97                                      |
| 9                         | 0.89                                 | 0.88                                   | 0.93                                    | 0.88                                      |
| 10                        | 0.91                                 | 0.89                                   | 0.94                                    | 0.92                                      |
| 11                        | 0.91                                 | 0.92                                   | 0.88                                    | 0.94                                      |
| 12                        | 0.88                                 | 0.96                                   | 0.90                                    | 0.92                                      |
| 13                        | 0.92                                 | 0.91                                   | 0.89                                    | 0.93                                      |
| 14                        | 0.91                                 | 0.89                                   | 0.94                                    | 0.89                                      |
| 15                        | 0.91                                 | 0.95                                   | 0.94                                    | 0.91                                      |
| 16                        | 0.87                                 | 0.92                                   | 0.94                                    | 0.93                                      |
| 17                        | 0.91                                 | 0.93                                   | 0.90                                    | 0.92                                      |
| 18                        | 0.91                                 | 0.92                                   | 0.92                                    | 0.91                                      |
| 19                        | 0.88                                 | 0.91                                   | 0.89                                    | 0.93                                      |
| 20                        | 0.91                                 | 0.93                                   | 0.92                                    | 0.89                                      |

4. Conclusion
The weak expansive soil subgrade of the railway in operation will settle in a high-temperature climate, which will cause a rapid deterioration in the geometric dimensions of the track and affect the safety of train operation. Based on the track geometry measurements, this paper finds that the settlement of weak expansive soil subgrade will be accompanied by deterioration of surface and alignment, and further analyzes the deterioration characteristics of surface and alignment, and provides a theoretical basis for identifying the settlement position of weak expansive soil subgrade. Based on the characteristics of the sudden deterioration of surface and alignment, this paper establishes the Settlement Prediction Model (SPM) that divides the Track Geometry Measurements (TGM) into two parts, pre- and post-settlement of the subgrade, and uses different functions to fit these two parts to identify the time of the subgrade settlement with the minimum fitting error. Then, predicting the track situation of post-settlement of the subgrade. The model was applied to the Han-Dan Railway mileage k285+000~k300+000 to fit the track inspection parameters of 20 subgrade settlement positions in the section, and the correlation coefficient was high. The results show that the settlement prediction model has a high application value.

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Conflict of interest
This paper is originally completed by the author alone. My tutor doesn't know the content of this paper.

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