Correlation analysis of quality testing indexes of coarse grained soil subgrade of high-speed railway

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Abstract. The compaction quality of subgrade is controlled by such indexes as high speed railway coarse soil subgrade adopts foundation coefficient K, second deformation modulus E'v2, and dynamic deformation modulus E'dE, but the three detection principles are similar. For the purpose of reducing the detection workload and improving the detection efficiency, based on a brief analysis of the test principles of the three indicators, this paper carries out the filling and testing of coarse grained soil subgrade, obtains the values of 10 groups of K30, E'v2 and E'dE, and analyzes the correlation of K30, E'v2 and E'dE. The results shows that both K30 and E'v2 have a good linear relationship with E'dE and establish a corresponding functional relationship. The quality inspection scheme for coarse grained soil subgrade filling indirectly judged by the dynamic deformation modulus E'dE and the secondary deformation modulus E'v2 is proposed.

1. Introduction
Code for Design of Railway Earth Structure(TB 10001-2016)[1] divides subgrade fillings into three categories: macrograined soil, coarse grained soil and fine grained soil, among which coarse grained soil refers to soil and rock mixture with particle content (mass ratio) greater than 50% with particle diameter of 0.075~60mm. According to the fine grain content and fine grain gradation, coarse soil can be divided into three categories: A, B, C. Coarse soil is widely used as subgrade filler in the construction of high-speed railway because of its excellent engineering characteristics. As an important part of high-speed railway, subgrade directly bears the weight of track structure and the running load of train. The quality of compaction determines the safety and comfort of high-speed railway, especially the high-speed railway. If the compaction quality of roadbed needs to be overhauled, it may lead to the shutdown of high-speed railway [2]. In order to strengthen the high speed railway embankment quality control, various countries have adopted more index control system, Code for design of High Speed Railway(TB 10621-2009) [3] in our country to used for high speed railway subgrade filling in coarse grained soil compaction coefficient K, foundation coefficient K30, dynamic deformation modulus E'd, secondary E'v2 static modulus of deformation, etc, are made clear rules.

The engineering practice shows that the test process of E'dE is relatively simple, the speed is fast, the test conditions are relatively simple, it is convenient to carry out the multi-point test, it is helpful to eliminate the influence of packing dispersion on the test results, and has little influence on the
construction progress, so it is suitable for wide application in the construction site. Compared with the $E_{vd}$ test, the $K_{30}$ and $E_{2\nu}$ tests are relatively complex, requiring the cooperation of large construction machines and tools. The test time is long, has certain influence on the construction. For this reason, the correlation of foundation coefficient $K_{30}$, deformation modulus $E_{2\nu}$ and dynamic deformation modulus $E_{vd}$ was studied for coarse grained soil filler, and the relationship between $E_{2\nu}$, $K_{30}$ and $E_{vd}$ was found out, so as to indirectly judge the compliance of $E_{2\nu}$ and $K_{30}$ by $E_{vd}$, which is conducive to the improvement of detection efficiency of coarse grained soil subgrade filling effect. A large number of existing field experiments show that $K_{30}$, $E_{2\nu}$ and $E_{vd}$ have a high linear correlation[4-6]. However, at present, most studies on $K_{30}$, $E_{2\nu}$ and $E_{vd}$ are focused on homogeneous soils such as silty clay and silty soil, with relatively few studies on coarse grained soil. For this reason, laboratory filling and testing tests were carried out on coarse soil subgrade of high-speed railway. The values of $K_{30}$, $E_{2\nu}$ and $E_{vd}$ in 10 groups were obtained, and the correlation between $K_{30}$, $E_{2\nu}$ and $E_{vd}$ of coarse soil subgrade was studied. The research conclusions can provide technical references for quality testing of coarse soil subgrade of high-speed railway.

2. The Testing Principle Of Roadbed Testing Index

2.1. The foundation coefficient $K_{30}$
The foundation coefficient $K_{30}$ is a plate load test method that uses a plate with a diameter of 30 cm to carry out a plate load test and measure the subsidence of a plate with a foundation coefficient of 1.25 mm, so as to measure the bearing capacity of soil under static load. Under pressure, the load is applied one step at a time. Under the action of each load, the load strength and settlement value are read after the settlement is stable. When the total settlement exceeds 1.25mm or the load strength reaches the yield point of the foundation, the load can be terminated. Finally, according to the relationship curve between the vertical settlement of the load plate and the applied load, the load size when the settlement is 1.25mm can be obtained, and the value of $K_{30}$ can be calculated [8-9]. Namely:

$$K_{30} = \frac{\sigma}{S_s}$$  \hspace{1cm} (1)

In the formula, $\sigma$ is the load intensity (MPa) corresponding to the reference value of subsidence in the relation curve between load intensity $\sigma$ and subsidence $S$. $S_s$ is the fiducial value of subsidence(1.25mm). $K_{30}$ is the characteristic value that measures the compressibility of soil surface under the action of plane pressure, and simulates the static load response of roadbed in use. In fact, it is a concept of foundation stiffness coefficient, and it has a certain relationship with deformation modulus.

2.2. Secondary deformation modulus $E_{2\nu}$
The deformation modulus is the deformation modulus of soil measured by two kinds of load tests, in which the diameter of the loaded plate is quite large. When the maximum load is 0.5MPa or the settlement is 5mm, the increment of the first load is 0.5MPa and the unloading load is 0.5MPa. According to the maximum load of 0.5 or 0.25 times, the unloading gradient is carried out step by step, and the residual deformation after all loads are released is recorded. When finished, execute the second load. The load is the same as the first load and is only loaded to a higher level of the maximum load of the first application. Regression analysis using quadratic functions on loading curves [8]:

$$S = a_0 + a_1 \cdot \sigma + a_2 \cdot \sigma^2$$  \hspace{1cm} (2)
Where: $\sigma$ is carrying board under stress (MPa). $S$ is load plate center settlement (mm). $a_0$, $a_1$ and $a_2$ are regression coefficients. The formula can be solved according to specification [10].

Variable modulus $E_{vi}$ by the following formula calculated:

$$E_{vi} = \frac{1}{a_1 + a_2\sigma_{\text{max}}}$$

(3)

Where: $r$ is the radius (mm), $\sigma_{\text{max}}$ is the first time to load the maximum stress (MPa).

2.3. Dynamic deformation modulus $E_{vd}$

Dynamic deformation modulus $E_{vd}$ refers to the load applied by a drop hammer, applying a certain size and action time, so as to determine the parameters of the soil resistance to deformation under the impact of a certain magnitude of vertical impact and impact time. The load plate has a diameter of 30 cm, a hammer weight of 10 kg, a maximum impact force of 7.07 kg, a load pulse width of 18 ms and a maximum dynamic stress of 0.1 MPa. Calculate and determine dynamic deformation modulus:

$$E_{vd} = 1.5r\sigma/s = 22.5/s$$

(4)

Where: $\sigma$ is the radius of the circular carrier plate (mm), $\sigma$ is the maximum dynamic stress under the load plate, $\sigma = 0.1$ MPa, $s$ is the carrier plate sinking value (mm).

3. Filling And Testing Of Coarse-Grained Soil Roadbed

3.1. Filler selection

The filler used in the test is fine, in which the coarse grain is mainly blue-gray sandstone with obvious corner edge, and the maximum particle size is about 60 mm. The packing unevenness coefficient $Cu = 135$, the curvature coefficient $Cc = 0.87$, the gradation is poor, and this category belongs to the group B filler in the specification. The gradation curve of the filler is shown in Figure 1.

![Grain size distribution of fill materials.](image)

Figure 1. Grain size distribution of fill materials.

The specimen was subjected to compaction test using a heavy-duty Z3 compactor. The maximum dry density of the filler was 2.21 g/cm$^3$, and the optimum moisture content was 5.11%. Drainage consolidation test was performed using a large-scale triaxial shear instrument of SZ30-4 type. The test obtained the filler cohesive force $c = 64.1$ kPa and the internal friction angle was 39.7$^\circ$.

3.2. Filling of coarse grained soil subgrade

In the model groove, the filling construction of granular soil roadbed. The length, width and height of the model groove are 16m, 13m and 4m, respectively. After being fully stirred by excavator, the
thickness of packing is 40cm. Using YA18F roller wheels vibratory road roller yielded by Luoyang BaoLu Construction Machinery Limited to roll the subgrade. The weight of the roller is equal, and the width of the rolling is equal. In the rolling process, first use static pressure, then use micro-vibration to crush the filler. Strong vibrations are then performed according to the test requirements. The rolling width of transverse overlapping zone is 0.4m~0.5m and the driving speed of the roller is controlled at 2~4km/h. At the edge of the roadbed that cannot be rolled by a roller, the frog is used for artificial compaction. Compacting standards are the same height elevation and roller. As shown in figure 2.

Figure 2. Filling of granular soil subgrade.

3.3. Compaction quality test

According to the specifications and the actual length of the test subgrade model, determine the compaction coefficient \( K \) to measure 2 points per layer. Test of the influence depth based on the test for foundation coefficient \( K_{30} \), deformation modulus \( E_{v2} \) and dynamic deformation modulus \( E_{vd} \) is 90cm. Therefore, when the third layer is filled, each test is carried out under two strong vibrations. The first layer and the second layer are according to the standard of static once, micro vibration once, strong vibration 10 times comminution packing. In view of the trait of \( E_{vd} \) is faster measurement and higher discreteness of result, 5 groups of parallel tests were performed each time. The test results of compaction quality at the bottom of coarse-grained roadbed can be found in Table 1.

| Measuring point | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-----------------|----|----|----|----|----|----|----|----|----|----|
| \( E_{vd} \)    | 33.6 | 34  | 50.1 | 52.3 | 61.2 | 65.7 | 76.8 | 78.4 | 90.7 | 100.2 |
| \( E_{v2} \)    | 50.1 | 59.3 | 77.4 | 81.1 | 116.5 | 117.1 | 134.8 | 142.4 | 148.2 | 155.3 |
| \( K_{30} \)    | 41.7 | 44  | 56.4 | 61.2 | 89.5 | 90.6 | 109.1 | 111.2 | 112.3 | 115.2 |

4. Correlation Analysis Of Test Indicators

4.1. Correlation analysis between \( E_{vd} \) and \( K_{30} \)

The study with the least square method, analyzing unitary linear correlation based on the measured data of \( E_{vd} \) and \( K_{30} \) in the filler compaction control index of coarse grained soil group B. Then fitting line for correlation reached, as shown in Figure 3 And the functional relation between \( E_{vd} \) and \( K_{30} \), as shown in formula 5.
The correlation coefficient $R^2$ of unitary linear regression between $E_{vd}$ and $K_{30}$ is 0.915, indicating that both $E_{vd}$ and $K_{30}$ have a high linear correlation.

4.2. Correlation analysis between $E_{vd}$ and $E_{v2}$

The study uses the least square method, analyzing unitary linear correlation based on the measured data of $E_{vd}$ and $E_{v2}$ in the filler compaction control index of coarse grained soil group B. Then fit line for correlation reached, as shown in Figure 4 and the functional relation between $E_{vd}$ and $E_{v2}$ is as shown in formula 6.

$K_{30} = 1.258E_{vd} + 2.26$

(5)

The correlation coefficient $R^2$ of unitary linear regression between $E_{vd}$ and $K_{30}$ is 0.915, indicating that both $E_{vd}$ and $K_{30}$ have a high linear correlation.

4.3. Correlation analysis between $K_{30}$ and $E_{v2}$

In this study, the least square method is adopted to carry out a single linear correlation analysis according to the measured data of the filling compaction control index of the coarse-grained soil B,
and the relevant fitting line is obtained, as shown in Figure 5. As shown in formula 7, the functional relationship between the two is.

\[ y = 0.7618x + 0.2377 \quad R^2 = 0.9927 \]

![Figure 5. Fitting line for correlation between \( E_{v2} \) and \( K_{30} \).](image)

The correlation coefficient \( R^2 \) of unitary linear regression between \( K_{30} \) and \( E_{v2} \) is 0.993, indicating that both \( K_{30} \) and \( E_{v2} \) have a high linear correlation.

In view of the relatively complex and time-consuming testing of the foundation coefficient \( K_{30} \) and the deformation modulus \( E_{v2} \), in order to improve the detection efficiency of the roadbed filling quality, this paper proposes to use the improved filler for filling, the filling quality detection to dynamically deform modulus \( E_{vd} \) is dominant, the discrete large data is eliminated, the detection result is representative, and then the deformation modulus \( E_{v2} \) and the ground coefficient \( K_{30} \) are calculated according to formula (5) and (6). Determine whether \( E_{v2} \) and \( K_{30} \) are up to standard, and select test points appropriately for \( E_{v2} \) and \( K_{30} \) tests to verify the test results.

5. Conclusion

(1) The mechanical parameters of the foundation coefficient \( K_{30} \) and \( E_{vd} \) of the coarse grained soil subgrade have a high correlation, and the other index values are estimated by the regression formula.

(2) Because \( K_{30} \) is very well correlated with \( E_{v2} \), and the test difficulty is quite, but the data tested by the former is more realistic and reliable. Therefore, it is suggested to cancel or greatly reduce the detection index.

(3) Because the dynamic deformation modulus \( E_{vd} \) test is convenient and can best reflect the dynamic response characteristics of the subgrade in operation, it is recommended to carry out the \( E_{vd} \), \( E_{v2} \), \( K_{30} \) test on the filler before the same type of filler is used to fill the subgrade, and establish \( E_{vd} \) and The \( E_{v2} \) and \( K_{30} \) relational expressions are mainly based on the dynamic deformation modulus \( E_{vd} \) in engineering practice, and are checked by \( E_{v2} \) and \( K_{30} \) tests to improve the subgrade filling speed and compaction quality.

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