Foundation model testing of the second deformation modulus $E_{v2}$

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Abstract: The bearing capacity of the soil foundation can be reflected by its second deformation modulus $E_{v2}$, and the construction quality of the soil foundation can be evaluated by this deformation modulus. At present, the detection method of $E_{v2}$ has been applied in construction quality control of soil foundation in applications such as the foundations of airports, railways, and highways. In order to show the feasibility and reliability of the laboratory test method of calculating $E_{v2}$, the field test method is simulated to test the value of $E_{v2}$ of the fill foundation model and compare it with the laboratory test method. The results show that the results of field testing and laboratory testing were in good agreement. This provides a new method for testing the value of $E_{v2}$.

1. Introduction

The second deformation modulus $E_{v2}$ is a strength index for field testing of fill foundation, which is obtained with a loading experiment$^{[1]}$. The subgrade compaction quality of railway is controlled by the second deformation modulus $E_{v2}$.$^{[2,3]}$ Before 2006, there was no equipment for field testing of $E_{v2}$ in this country, and the relevant technical standards were imitations of foreign standards. Some years later, based on the test equipment of foreign country, Qingming Li proposed a new test equipment by the test principle of the second deformation modulus that meets China’s requirements. As it has become more popular, the monopoly that foreign countries had over this expensive equipment has been avoiding, saving costs for construction, supervision, and detection units$^{[4-6]}$. Although the foundation coefficient $K_{30}$ and the compaction degree index can be obtained with laboratory testing, the second deformation modulus can only be obtained by field testing, and the requirements of the test site and the environmental conditions are high. For example, when conducting a field test, the test point needs to be far away from the vibroseis in order to ensure the accuracy of the test, and testing is forbidden in bad weather. For this reason, this paper proposes an experimental laboratory test for the second deformation modulus $E_{v2}$. The effectiveness of this experimental method is evaluated with a comparison of its results to field experimentation.

In reference [9], the physical parameters of roadbed fillings were analyzed, and one of the parameters was the second deformation modulus $E_{v2}$. The present paper follows the field testing regulations of $E_{v2}$, while refitting the mechanics equipment to do evaluate $E_{v2}$, which is related to the settlement of the roadbed. The value of $E_{v2}$ is only calculated with the laboratory experiment. Because of the high cost of field testing, a foundation model is used to simulate field testing and prove the reliability of the laboratory testing method.
2. Model experiment for simulating the field test of $E_{v_2}$

2.1 Design and manufacture of the model
The test site is located in Key Laboratory of Civil Engineering in Chongqing Jiaotong University. The model experiment is finished in a structure tank with an existing reaction frame for loading. Figure 1 shows the experimental structure. The size of the structure is 1.2m×2.2m×1.4m, and the model size is shown in Figure 2.

![Figure 1. Model test site](image1)

![Figure 2. Model size (cm)](image2)

2.2 Model-making
The experiment uses weathered mudstone soil. The height of the structure tank is 0.8 meters. According to the criterion of the density of the compaction specimen which is made by the laboratory test method, the quality of the soil sample is calculated. The soil sample is put into the structure tank layer by layer. The thickness of each layer is controlled, and water is sprinkled onto the surface after each layer is paved. Finally, a tamping machine is used to compact the coil uniformly. This process is shown in Figure 3.

![Figure 3. Model making](image3)

2.3 Test equipment and installation
After the construction of the foundation model is complete, the loading place is placed in the center of the model. Then, the loading equipment is installed in accordance with the test requirements. Multi-stage loading is carried out, and the deformation of the foundation under the bearing place is recorded after each stage. The main equipment needed for the experiment is as follows: reaction frame,
hydraulic jack, DH - 3818 high speed static strain gauge and sensor.

2.3.1 Loading equipment of experiment. The experimental setup of the loading equipment is shown in Figure 4.

2.3.2 Loading and measurement instrument of settlement. The load can be measured by the loading sensor in the center of the foundation, and the deformation of the foundation can be measured by a DH - 3818 high speed static strain gauge that is directly connected to the foundation. The measuring equipment is shown in Figure 5.

2.4 Loading control
According to the field test principle, the main procedures of controlling the model loading are as follows:

- Lay up a loading plate in the middle of the foundation model, and adjust the position of the bearing plate to keep it level.
- Pre-pressure: First, pressurize to 0.05MPa, maintaining close contact between the dowel steel and the fill foundation model, and maintain this pressure for 2 min. Then, unload and read the beginning of the dial gauge.
- First loading: Load in 6 steps, with the following values: 0.08Mpa, 0.16Mpa, 0.24Mpa, 0.32Mpa, 0.4Mpa and 0.5Mpa. After each step, record the reading of dial gauge.
• Unloading: After the 6 steps of loading are complete, unload in three steps as follows: 0.25 Mpa, 0.125Mpa and 0MPa. After each step, record the reading of dial gauge.

• Second loading: after the first loading and unloading, the dowel steel is kept in close contact with the sample. The second loading proceeds 5 steps as follows: 0.08Mpa, 0.16Mpa, 0.24Mpa, 0.32Mpa and 0.4Mpa. After each step, record the reading of dial gauge.

• Record the test data, and draw the test curve.

2.5 Analysis of test results on model experiment

Figure 6 shows the relation curve between $E_{v2}$ and settlement according to the test data. The data is ordered, and curves are drawn between loading and settling. These curves are expressed by Formula (1), which includes coefficients $a_0$, $a_1$ and $a_2$, which can be solved by the least square method. Then, the $E_{vi}$ can be obtained with Formula (2).

$$s = a_0 + a_1\sigma + a_2\sigma^2 \quad (1)$$

Where, $\sigma$ is the stress under the loading plate; $s$ is the settlement in the center of the loading plate; $a_0$, $a_1$, $a_2$ are the constant terms when using the least square fit.

With the calculation formula of deformation modulus,

$$E_{vi} = 1.58r(1 - \mu^2) \times r \times \frac{1}{a_1 + a_2\sigma_{\text{max}}^2} \quad (2)$$

where $r$ is the radius of the loading plate, here 50 mm, and $a_1$ and $a_2$ are the coefficients that can be obtained from the second loading curve. $\mu$ is the poisson ratio, here 0.21.

$$s = 6.2071 - 0.6222\sigma + 16.603\sigma^2$$

$$E_{v2} = 1.58 \times 5 \times (1 - 0.21^2) \times 5 \times \frac{1}{0.6222 + 16.603 \times 0.5} = 29.5MPa$$

Then, the first and second deformation modulus can be calculated as follows. the value of $E_{v2}$ was 29.50MPa.

3. Comparison analysis between laboratory experiment and model test

3.1 Laboratory experiment of the soil sample of the foundation

According to the requirements of the field test, the specimen was made by the compaction test following the standard of design compaction degree. Then, the specimen was installed. The laboratory setup is shown in Figure 6.

![Experimental setup](image)

Figure 6. Experimental setup

The loading process is shown in Table 1.
| Load options | Load size /MPa | 1st | 2nd | 3rd | 4th | 5th | 6th |
|--------------|----------------|-----|-----|-----|-----|-----|-----|
| **First loading** |                | 0.08 | 0.16 | 0.24 | 0.32 | 0.40 | 0.50 |
| **unloading** |                | 0.25 | 0.125 | 0 | / | / | / |
| **Second loading** |                | 0.08 | 0.16 | 0.24 | 0.32 | 0.40 | / |

The foundation model and the laboratory setup are made with same compaction degree and the same kind of soil. The only difference is that the size of the foundation model is larger than the laboratory samples, and it is nearly identical to field testing.

### 3.2 Analysis of experiment results

According to the test data, a curve was drawn to compare the foundation model test to the laboratory test (Figure 7).

![Figure 7. Relationship curve between stress and settlement](image)

The laboratory sample had the same compaction degree and kind of soil as the field simulation, and the results were calculated with the same formula. The laboratory samples were made with the compaction instruments. The compaction degree of the sample was calculated, and the same compaction degree was used to calculate the amount of soil in the foundation model. This can demonstrate the similarity of the results of the two tests. The key point is to obtain the settlement of each loading, and then draw the relationship curve between the settlement and the load stress.

According to Formula (2) and the curve, the value of $E_{v2}$ can be obtained.

$$\sigma = 6.9082 \cdot 5.2906 \sigma - 8.1194 \sigma^2$$

$$E_{v2} = 1.58 \times 5 \times (1 - 0.21^2) \times 5 \times \frac{1}{5.2906 + (-8.1194 \times 0.5)} = 30.67 MPa$$

Then, the first and second deformation modulus of the laboratory specimen can be obtained. In this case, the value of $E_{v2}$ was 30.67MP. Compared to the foundation model test, the value of first deformation modulus was almost identical between the laboratory experiment and field model test. The value of the second deformation modulus was larger than the field model test because there are many factors that impact the field foundation model test, such as a variety of man-made factors, the environmental impact and so on. Therefore, some error is present. The similarity of the results shows that the laboratory experiment method for the deformation modulus is feasible.
4. Conclusions
By creating a fill foundation model, $E_{v2}$ of the fill foundation was tested by simulation. Then, a specimen with the same compaction degree as the fill foundation was used for a laboratory experiment. The results were compared in order to verify the feasibility of the laboratory experiment method. These results did verify that this new method of testing is feasible. Therefore, the main conclusions of this paper are as follows:

- The $E_{v2}$ of the fill foundation model was 29.5 MPa. This value was obtained by simulating the field test method, and it is nearly identical to the value obtained by the laboratory test. Therefore, the feasibility and reliability of the laboratory experiment method is validated.
- When the laboratory experiment was compared to the field test, the laboratory experiment was found to be more efficient and economical than the field test.

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