

# Comparative experimental research on falling ball test method and K30 plate load method on foundation of different structures

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**Abstract.** In highway and railway foundation projects, the mechanical properties of foundation materials are one of the main indicators of construction process control. The elastic modulus of foundation directly affects road surface deflection and must be tested. The falling ball test method and the K30 plate load method are widely used in engineering. In order to explore the relationship between the two methods and guide the engineering application, the falling ball test method and the K30 plate load method are applied to homogeneous materials (homogeneous fine-grained material layers) and layered materials (Old foundation). Through comparative test, we found that there is a strong correlation between the falling ball test method and the K30 plate load method in some scenarios, which can be used for mutual reference in engineering experiments.

## 1 Introduction

In roadbed projects such as expressways and railways, the mechanical properties of roadbed materials (including the modulus of deformation and modulus of resilience, etc.) are one of the main indicators during the construction process. The modulus of resilience is one of the most sensitive parameters that affect the thickness of the pavement structure, and it is also the main factor which affects the deflection of the road surface. If the construction quality cannot reach the required modulus of resilience, the pavement will be damaged prematurely due to excessive deflection. When the subgrade construction is completed according to the design requirements, the test of subgrade's modulus of resilience should be carried out according to the requirements of the test specifications, so as to provide a reference for the construction of the pavement structure, and ensure the quality of the road<sup>[1-2]</sup>.

According to the current technical specifications for subgrade construction in China, the test methods for the quality of on-site subgrade filling engineering mainly includes K30 plate load method, California bearing ratio method (CBR), digging and filling sand, and falling weight deflection tester method (FWD) and so on. The falling ball test method and the K30 plate load method have been widely used in engineering due to their respective advantages. However, due to the differences in the direct measurement indicators between the two methods, in order to standardize the development of the industry, it is necessary to unify the relevant indicators. According to the past experience, comparative test is the best way to establish interrelationships<sup>[3]</sup>. Because the conclusions drawn under different foundation structures are also inconsistent, the typical foundation structure:

homogeneous materials and layered materials are selected for research. Specifically, we select a homogenized fine material layer and the old foundation to test<sup>[4]</sup>.

## 2 Technology Introduction

### 2.1 Falling ball test method

Falling ball detection technology through metal rigid sphere's falling, following Hertz collision theory (also known as Hertz elastic contact theory) and undergoing plastic correction of geotechnical materials to directly measure the deformation modulus and elastic modulus of the material. At the same time, according to the elastic theory and related empirical formulas, the foundation bed coefficient (also called foundation coefficient), Beckman deflection and other physical indicators (dry density, compaction, relative density, etc.) can also be calculated<sup>[5]</sup>. According to the Hertz impact theory, when a sphere with known rigidity collides with an object with unknown rigidity, the greater the rigidity of the object will lead to the shorter the contact time ( $T_c$ ) during the collision<sup>[6]</sup>. However, Hertz impact contact theory is only applicable to linear elastic materials, while geomaterials are typical elastoplastic materials. So this theory needs to be modified to apply to the geomaterials. The specific test method is as follows:

- (1) Raise the rigid sphere to a certain height, such as 0.5m;
- (2) Let the rigid sphere fall freely and collide with the rock and soil materials, and test the acceleration in the process;

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(3) Through the analysis of the acceleration of the impact process, various indexes of the soil material can be obtained at the same time.

For road engineering, the test depth range of falling ball detection is approximately within the thickness of a standard filling layer. In other words, the test result only reflect the mechanical properties of the appropriate layer, and are not affected by the substructure and filling layer.

## 2.2 Principles of the K30 plate load method

The plate load test is the earliest and most widely used in-site test method. It is an in-site test in which loads are applied in stages on a rigid bearing plate of a certain size to observe the pressure and deformation of natural foundation soil under various loads.

The K30 plate load method uses a carrying board with a diameter of 0.30m to increase and reduce loads on soil bases<sup>[7]</sup>, in order to measure the deformation value of the corresponding soil base rebound under each stage load, and the unusually deviated rebound deformation point is eliminated. Plot the  $P \sim L$  curve of the load  $P$  and the deformation value  $L$ , If the initial part of the curve is bent back, the origin should be corrected. Finally, take the deformation values before the end of the test and calculate the deformed modulus from equation (1).

$$E_{ur} = \frac{\pi D}{4} \cdot \frac{\sum P_i}{\sum L_i} (1 - \mu^2) \quad (1)$$

Where  $L_i$  represents the measured rebound deformation value at all levels,  $P_i$  corresponds to the pressure value of  $L_i$  at all levels (MPa).

Sometimes, the slope of the unloading ~ load curve is also used as deformed modulus. The K30 plate load test is suitable for all kinds of soil and rock mixed fillers whose particle size is not larger than 1/4 of the diameter of the load plate, and the effective depth range of the test is 400mm~500mm. Although the K30 plate load method is time-consuming and labor-intensive, it is the main verification method due to its high test accuracy.

## 3 Comparison test

During the test, both K30 plate load method and the falling ball test method will affect the original soil foundation. For example, K30 plate load test will have a compaction effect, while the falling ball test may loosen or compact the soil foundation. Therefore, the test positions of the two methods cannot be exactly the same. Generally speaking, the K30 plate load test is performed first, and then the falling ball test is performed at about 400mm outside the

adjacent test area. Due to the difference between the two methods' test areas, it is inevitable that a certain discrete error will be brought about.

We choose to conduct related comparative tests under homogeneous materials and layered materials. Part of the test site diagrams are shown in Figure.1 and Figure.2.



Figure 1. Falling ball test



Figure 2. K30 plate load test

### 3.1 Comparison test under homogeneous fine-grained materials

For three homogeneous fine-grained materials with different water contents, K30 plate load test and falling ball tests were carried out in different compaction states respectively, and the K30 plate test result were converted into elastic modulus, and the falling ball result were taken as the original value without correction. By summarizing a large amount of test data, the typical comparative data is shown in Table.1.

**Table1.** Comparison result of falling ball test and K30 plate load test under homogeneous fine-grained material

Water content	Compacted state	Structural form	K30 test value/MPa	Falling ball test value /MPa	proportion	Proportional average
Optimal	Medium density	Silt foundation	2.1	3.53	0.59	0.85
	Medium density		3.8	4.18	0.91	
	Medium density		2.7	2.60	1.04	
general	high density	Clay foundation	24.3	15.80	1.54	1.11
	Medium density		9.1	12.92	0.70	
	Medium density		7.8	7.17	1.09	
dry	high density	Loess foundation	100	105	0.95	0.95
average						0.97

It can be seen from Table.1:

(1) In the optimal water content state, the K30 plate load test result is about 0.85 times of the falling ball test result;

(2) In the general water content state, the K30 plate load test result is about 1.11 times the falling ball test result;

(3) In the dry state, the K30 plate load test result is 0.95 times the falling ball test result.

The average value of the test result under three different water contents is about 0.97.

The test result show that the typical test result of the falling ball test method and K30 plate load test method for homogeneous fine-grained materials are similar on the whole, evenly distributed between 0.85 and 1.11, which can be used for mutual reference, but we should pay attention to the difference in the structural state, because there are differences in the relationship between the two methods under different states such as water content, structural form and compaction state.

### 3.2 Comparison test under layered old foundation

In a section of the national road reconstruction site in Shanxi, the testers used K30 plate load test and falling ball test to conduct a comparative test on the old foundation (gravel foundation). Due to the long-term rolling and compaction of large vehicles, the surface is very hard.

The testers selected 4 road section points for testing, corresponding to pile numbers k644+650 ~k644+680, of which k644+650~k644+670 are common road section points, and there is a protrusion at the position of the k644+680 measuring point. When the vehicle is driving to the point, a large impact load will be repeated. It is guessed that the elastic modulus of the foundation here will be much higher than that of ordinary road sections. Later, we will study this conjecture through a series of experiments.

Follow the same test procedure, and convert the K30 plate load test result into elastic modulus, the falling ball test result is the original value without correction. The test result of the two methods are shown in Table.2.

**Table2.** The comparison result of the falling ball test and K30 plate load test under the gravel foundation

Stake	K30 test value/MPa	falling ball test value/MPa	proportion
K644+680	555	526.75	1.05
K644+670	17.3	68	0.25
K644+660	66.0	233.5	0.28
K644+650	67.8	259.5	0.26

It can be seen from Table.2 that the test result of the elastic modulus of the foundation at the pile number position k644+680 between K30 plate load test and the falling ball test are much higher than that of the ordinary

road section point, which is consistent with the previous conjecture. The large elastic modulus extends to a greater depth of the foundation, which is similar to the elastic modulus of the foundation surface represented by the

falling ball test result. Judging from the test result of pile numbers k644+650~k644+670, the falling ball test result are all greater than the K30 plate load test result. It can be seen that the compaction effect of ordinary road sections due to vehicle rolling is mainly concentrated on the surface of the foundation. From the test result of the two methods can be obtained:

$$E_{FBT} = k \cdot E_{K30} \quad (2)$$

Among them,  $k=0.26\sim 0.28$ , which is relatively stable and can be used as a reference for engineering practice.

## 4 Conclusions

From the comparative test result of the falling ball test and K30 plate load test on homogeneous materials and layered materials, we can see that there is a clear correlation between the two methods, especially on layered foundations, the relationship between the two method is approximately proportional, and the conclusion of this article can be used for reference in this engineering application scenario.

The relationship between the two methods is different under different foundations and different foundation conditions such as water content, Engineering reference needs to clarify the specific application scenarios, and pay attention to distinguishing the foundation structure and the foundation state; At the same time, it can be seen that the relationship between the two methods is not obviously, the dispersion is relatively large, which reason may be that the test conditions are not consistent, and the influencing factors of the test are not well considered, and further systematic tests are needed to be studied.

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