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Evaluating Compactness of CSGR by Falling-Ball Test

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ABSTRACT: Cemented Sand, Gravel and Rock (CSGR) is a new dam-building material produced by mixing a small amount of cementitious materials, sands and gravels without screening or washing on site, paving and vibrating compaction. CSGR dams are economical, fast and safe. In recent years, CSGR dams have been used as permanent buildings in China, Japan, Turkey, Greece, France, Philippines and other countries. Compactness of CSGR is the key factor in construction quality control. The conventional density test method to evaluate the compactness of CSGR has a low efficiency, and cannot be carried out in a large area. Also the testing data are often inaccurate. Based on the Hertz contact theory, a new method to evaluate the compactness of CSGR called the falling-ball test (FBT) is proposed to measure the deformation modulus of CSGR after compacting. The study results showed as a non-destructive method, FBT could measure the compactness of CSGR in a specified range and specified thickness by the mesh points method. The impact depth of falling ball is generally below 20~30cm, therefore, FBT is not suitable for CSGR with a placing layer thicker than 30cm.The correction coefficient is available between 0.85 and 0.90 for CSGR materials before the initial setting. It should be noted that the ball should not fall directly on coarse aggregates or where coarse aggregates are particularly enriched. Distribution of the deformation modulus of CSGR in the compacting layer could be easily obtained by FBT. Combined with the conventional density tests, the compactness of CSGR on the entire layers can be better evaluated.

Key words: Falling-ball test (FBT); Cemented sand, gravel and rock (CSGR); Compactness；

Deformation Modulus

1 INTRODUCTION

The cemented sand, gravel and rock (CSGR) dam construction reflects the new concept of appropriate materials and optimum dam structure, which has advantages of making use of locally available materials and abandoned materials, simple construction, economical utility and safety. The research and application of such a new dam technology are significant for the construction of a lot of small and medium-sized water conservancy and hydropower projects in China(Jia et al.2016).The construction quality of the CSGR mainly relies on testing the density of the material after roller compactness. The specific implementation steps are as follows: digging a pit on the layer after rolling compaction, measuring the mass and volume of the materials in the pit and then calculating the density of compacted CSGR. The greatest advantage of this method can directly reflect the CSGR density at one point. However, the shortcomings are also very obvious. Firstly, the test rate is slow, and that will damage the pouring layer surface to some extent, so it is difficult to carry out within a wide range. Secondly, sampling inspection is only done at a certain area, namely, the rest result has poor representation and sometimes it may even cause great errors (Feng et al. 2013).

FBT is a non-destructive testing method for the large-scale and can rapidly evaluate the density of soil and rock. When combined with the conventional density tests, FBT can better judge the compactness of CSGR on entire layers.

2 FUNDAMENTALS OF FBT

The FBT (fall ball technology) method used to test the deformation properties of geotechnical materials is derived from the Hertz Collision Theory (Gugan 2000).When a known rigid sphere A hits an unknown rigid object B, when collision, the greater the rigidity of B is, the shorter the contact time is (Figure 1).

For a collision of a spherical body with a semi-infinite plane body, the contact time can be calculated by

$$T_c = 4.53\left[\frac{(\delta_1 + \delta_2)m_1}{\sqrt{R_1 v_0}}\right]^{2/5} \tag{1}$$

Where:T_c is the contact time, s； $\delta = \frac{1-\mu^2}{E\pi}$, the parameters of the material are that E is deformation modulus, Pa (N/m^2).$\mu$is the Poisson's ratio of material; subscript 1 is the falling sphere, and subscript 2 is the semi-infinite plate body to be tested;m_1 is the mass of the falling ball, kg;R_1 is the radius of the falling sphere, m;V_0 is the velocity when the falling ball collides with the semi-infinite plane body , m/s; $v_0 = \sqrt{2gH}$, H is the sphere falling, m. Formula (1) is solved by the contact time T_c to get the deformation modulus E of the material under test; wherein the impact of Poisson's ratio μ is small.However, the Hertz Collision Theory is only applicable tolinear elastomeric materials, but geotechnical materials (such as uncured CSG)are typical elasto-plastic materials.Therefore, some amendments have been made to the Hertz Collision Theory. Forelastic materials, the deformation after collision can be completely restored and the maximum deformation occurs at half of the contact time. The pratical geotechnical materials have a certain elasticity and the value of the springback deformation coefficient is greater than that of compression. The elastic coefficient of compression is the most important parameter for geotechnical materials. The contact time of the compression part and rebound part should be separated. As shown in Figure 2,the collision process was divided into two parts,the compression and the rebound.

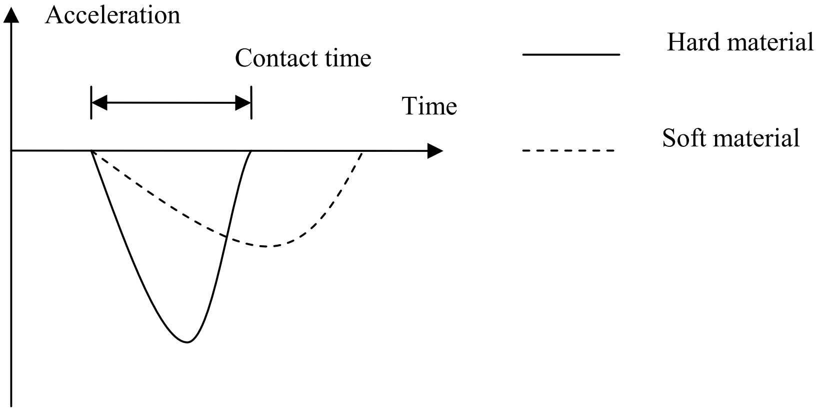

Figure 1: Diagram of FBT Test

For the linear elastomers, the compression coefficient (beside the elasticity coefficient with loading) is consistent with the rebound coefficient, and for geotechnical materials, there is a great difference.This technique separates the process of compression and rebound, and calculates the deformation modulus E by the contact time of the compression part and the rebound modulus E_{ur} is reckoned by the contact time in the rebound part.

1) Deformation modulus E under compression

$$E = \frac{\kappa \cdot (1-\mu_2{}^2) \cdot m_1 E_1}{0.0719 E_1 \cdot \sqrt{R_1 v_0} \cdot T_{cc}{}^{2.5} - m_1(1-\mu_1{}^2)} \tag{2}$$

Where κ is the corresponding correction factor. 0.0719 is an experimental coefficient. T_{cc} is the corresponding contact time, calculated by the following formula:

$$T_{cc} = 2T_{c\_c} \tag{3}$$

T_{c_c} is the compression time when the falling ballcollides with geotechnical materials, the value is the time from the start point to peak, seen from the procedure chart of acceleration and time in Figure 3. Formula(1) provides references for other parameters.

2) Deformation modulus E_{ur} under rebound

The equation of the E_{ur} is the same as deformation modulus E.

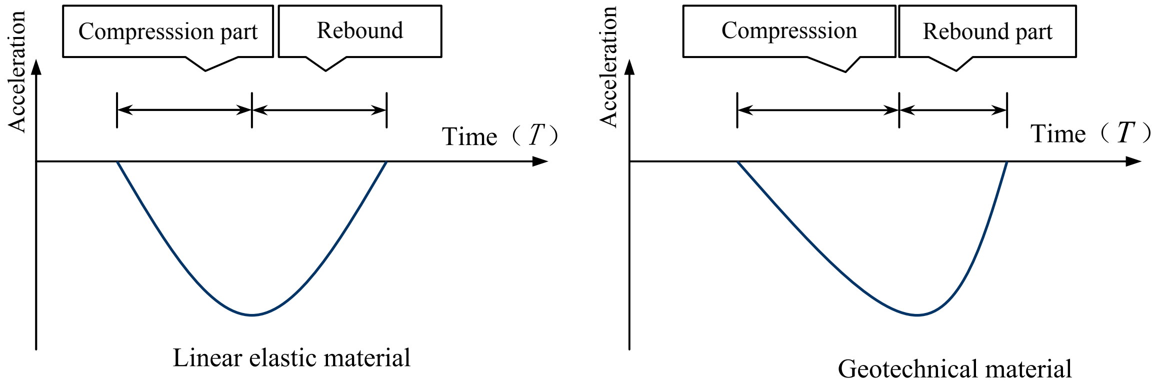

Figure 2: Compression Process and Rebound Process after the Fall Ball Contact

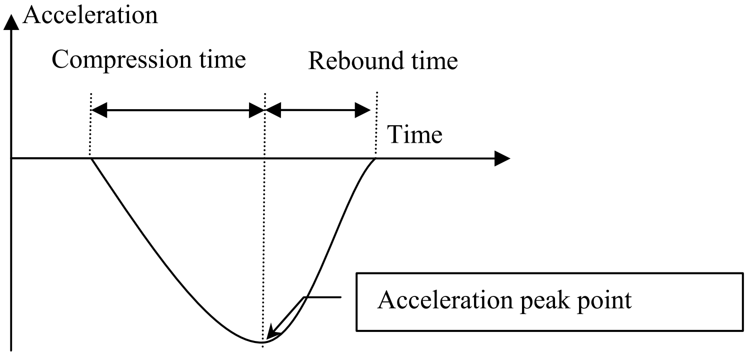

Figure 3: Separations of Compression and Rebound Process

3) Data processing

In FBT test, when encountering large-size aggregates, the test values are often too large (deformation modulus in particular). Therefore, rocks should be avoided in the method, but that has an effect on the tests’ objectivity. For this reason, the unique "equivalent deformation method" has been developed in our research to replace the simple average data processing method.

Table 1 Comparison of Different Data Processing Methods

Terms	Concept of simple average method	Concept of equivalent deformation method
Mechanical meaning	The deformations at different point of the surface are the same	The forces at different point of the surface are the same
Processing method	Simple average of the modulus under test	Average and process after the test modulus’ deformation
Effects of large size gravel	Great	Small
Effects of part weak zone	Small	Great

It can be seen that the characteristics of the"equivalent deformation method", based on the concept of flexible deformation, were as follows :(1) it was slightly affected by large size gravel (boulder): For example, the average value of nine tests was 1 MPa among ten tests, but that of one test was 10MPa. If the simple average method is used, the test value is 1.9MPa; the value in one test can increase by 90%. While, the test value is 1.09MPa, as the equivalent deformation method is adopted, which could reflect the actual soil conditions. (2) The influence of the part weak zone is huge. For example, the value of nine tests was 1 MPa within ten tests and only the value in one test was 0.1 MPa. If the simple averaging method is used, the test value is 0.91MPa. When the equivalent deformation method is adopted, the test value is 0.53MPa, which could greatly improve the sensitivity of the weak soil texture.(3) The data processing of equivalent deformation method can reasonably reflect the influence of different materials, thus avoiding the excessive impact of large size gravel on test results to ensure the stability.(4) Material correction. Due to the different particle sizes, the deformation modulus measured by FBT will also change at different degrees. According to numerous experiments, the corresponding correction factor has been introduced in our research. According to the types of soil material, the correction coefficient is between 0.67 and 0.90. The larger the particle size is, the smaller the correction coefficient is. In addition, the reference of Poisson's ratio μ is given as the material type.

$$E^{*} = \kappa \cdot E \tag{4}$$

Where, E^{*} is the modified deformation modulus and κ is the correction factor and E is the value of direct test.

Table 2 Poisson's ratios and Correction factors for Different Materials

Material	Gravel	Sandy soil	Silt	Clay	Cement stabilized soil
Poisson's ratio	0.20	0.30	0.35	0.40	0.20
Correction factor	0.85	1.0	1.0	1.0	1.1

The correction coefficient is available between 0.85 and 0.90 for the CSGR material before initial setting. It should be noted that FBT possesses the characteristic of rapid detection and could measure the filler materials of the specified range and thickness of multiple points by the mesh points method, so as to provide basic data for evaluating the uniformity of the filling structure.

3 FIELD TEST

3.1 Test instruments

The falling ball geomechanicstest instrument used in the field test is shown in Figure 4 and Figure 5, and the weight of falling ball is 19.1kg.

Figure 4: Falling Ball Geomechanics Test Instrument (SEH-FBT) Figure 5: Field Test

3.2 Field test arrangement

A CSGR overfall in Southwest China under construction is selected for a site test, wherein No. 8 dam section is used as the test object, the dam length is thirty metres and the width on the top is four metres available for test. FBT is used to measure the distribution state of the deformation modulus of CSGR before initial setting at the whole horizontal layer surface. In Figure 6, five points were set horizontally with separation distance at one metre and sixteen points were arranged longitudinally with an interval of two metres. Finally, the mesh points of five rows and sixteen columns were finally formed.

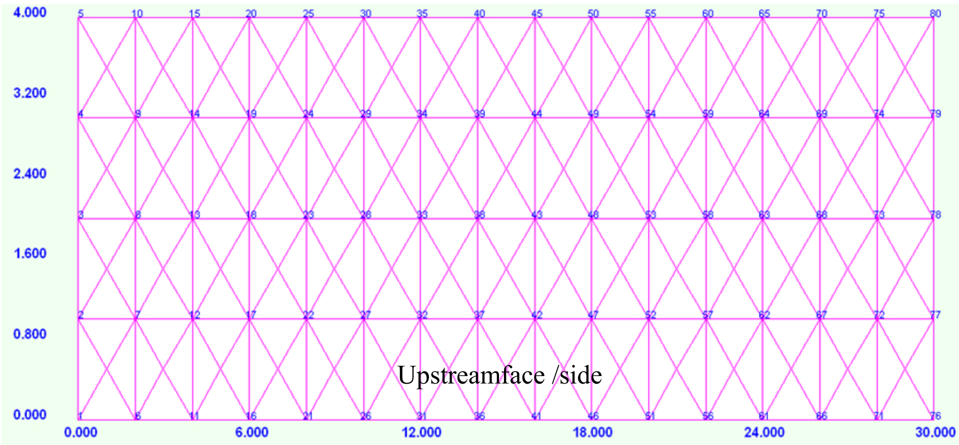

Figure 6: Distribution Figure of Falling Ball Test

3.3 Test results

The deformation modulus of each test point before initial setting could be tested by the falling ball tests, then isopleths distribution diagram of the whole horizontal pouring layer surface was obtained by data inversion and the graphics processing in Figure 7, which reflects the uniformity of the deformation modulus of the whole CSGR dam section after rolling compaction, Therefore, the distribution of compactness could be inferred.

In Figure7, after rolling compaction of the horizontal pouring layer, the deformation modulus of CSGR before initial setting in No. 8 dam section is ranged from 40MPa to 100MPa by FBT. Areas with a low value of deformation modulus focused on the downstream side of the pouring surface, and about 15MPa to the lowest part. Therefore, it could be concluded that the CSGR density of such areas is inferior to other areas after rolling compaction.

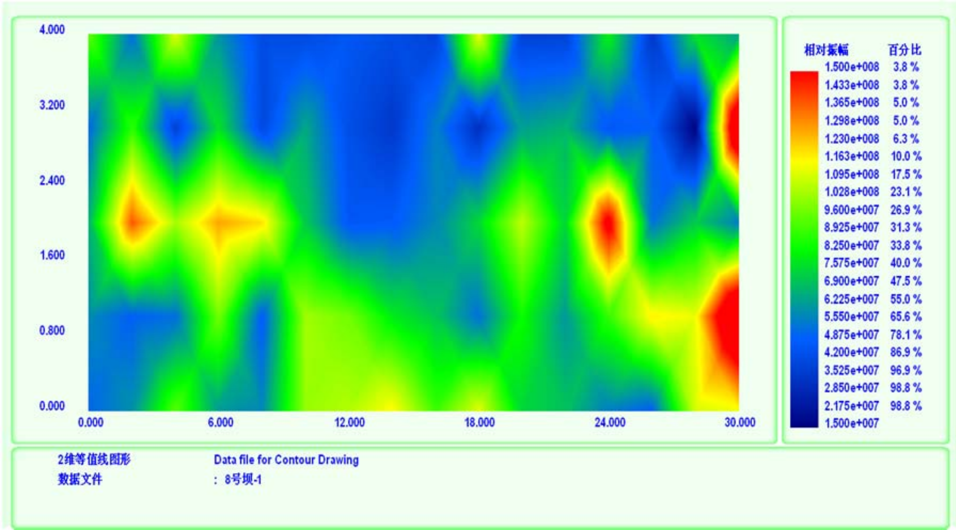

Figure 7 Isopleths Distribution Diagram of FBT Deformation Modulus (15MPa-150MPa)

4 CONCLUSIONS

By FBT, the distribution of CSGR deformation modulus on the pouring layer surface could be quickly achieved. And it could qualitatively estimate the compactibility on the pouring layer surface after rolling compaction. However,the following issues should be taken into account for the CSGR in the application of FBT:

(1) The field test must be carried out rapidly. It is preferably done before the initial setting of CSGR to ensure that surface hardness of the same pouring layer surfaceis not affected by the condensation state of cementing material.

(2)The impact depth of falling ball is generally below 20~30cm, therefore, FBT is not suitable for the measurement of CSGR pouring layer with a larger thickness.

(3)FBT has been primarily used for studying relative uniformity earth material with a small particle size. The CSGR with a larger particle size has many coarse aggregates content, which is easy to separate during the paving process. And such larger sized coarse aggregates can affect the test accuracy. Therefore, it should be avoided falling ball directly hits the coarse aggregates or locates the places where coarse aggregates are particularly concentrated, when detected.

(4) There is no significance to study the result of one measurementpoint by FBT, because the value of FBT just shows the overall and relative datas on the pouring layer surface. With the comparison of the deformation modulus on the whole surface, it could find that the areas where rolling compaction is inadequate, then can be confirmed by the conventional density test.

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REFFERENCES

Jinsheng J.,Michel L.,Feng J., and Cuiying Z.,2016,The cemented material dam: a new, environmentally friendly type of dam. *Engineering*, 2(4), 490-497.

Wei F., Jinsheng J., Fengling M., 2013, Study on design parameters of mix proportion forcemented sand and gravel (CSG). *Water Resources and Hydropoower Engineering*, 44(2), 55-58.

Gugan, D. J. (2000). Inelastic collision and the Hertz theory of impact.*American Journal of Physics*, 68(10): 920-924.