Study on the Application of Flat Dilatometer Test in Subway Survey Engineering

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Abstract. Flat dilatometer test (DMT) is a new kind of technology in situ test. This study, through sorting out and analyzing the flat dilatometer test data in subway engineering, obtains the experience of the application of the flat dilatometer test in engineering, and solves practical problems such as soil classification. The results of this study provide an effective basis for the application of flat dilatometer test technology in subway survey and provide sufficient and reliable data for the compilation of regional specifications.

1. Introduction
In recent years, flat dilatometer test (DMT) has been paid much attention in geotechnical engineering. In Western Europe and North America, flat dilatometer test gradually replaced the standard penetration test, and became the two main means of in-situ test together with static contact test, and the American society of civil engineering recommended the use of this in-situ test method[1]. The flat dilatometer test is a new in-situ measurement technique, that is simple, fast, economical, repeatable, and low disturbance[2]. At present, this technology has been included in the technical standards of China’s ministry of railways [3] and geotechnical engineering investigation specifications [4]. Because the geotechnical engineering characteristics have a strong regional, so it is necessary to study the engineering application of flat dilatometer test, put forward the regional experience correction, and provide an effective basis for the flat dilatometer test technology in engineering application.

With the construction of large area of shenyang subway project, the technique of flat lift test is applied in the survey, which provides a lot of test data for the research of this paper. The results show that the flatbed expansion test is an effective in situ test technique and has high accuracy.

2. Principle of flat dilatometer test
Flat dilatometer test is to use static force (or hammer force) to insert the flat shovel probe into a predetermined depth of the soil. The diaphragm on the side of the flat shovel probe expands laterally through the pressure system, causing lateral displacement and deformation of the soil. According to the parameters obtained in the flat dilatometer test, it can be calculated as follows: material index \( I_D \), lateral expansion modulus \( E_D \), horizontal stress index \( K_D \), side bulge pore pressure index \( U_D \).[5]

At present, the DMT-W1 flat dilatometer test produced by nanguang geological instrument factory is widely used in China. The instruments and equipment for the flat dilatometer test are shown in
3. Application of flat dilatometer test

3.1. Conditions of the test site

In this experiment, the flat dilatometer test was carried out on the subway project. The strata along the line were relatively simple. The lower strata are tertiary strata with good engineering geological conditions. The Flat dilatometer test (DMT) was carried out in the upper clay, silt, and fine sand. The author mainly analyzed the collected silty clay and clay data, and at the same time conducted in situ test, geotechnical test and other test methods [6] at the test site, so as to make a comparative analysis of parameters.

3.2. Basic parameters of the flat dilatometer test

The readings A, B and C can be converted to $p_0$, $p_1$ and $p_2$ [7]

$$p_0 = 1.05(A - Z_m + \Delta A) - 0.05(B - Z_m + \Delta B) \quad (1)$$

$$p_1 = B - Z_m + \Delta B \quad (2)$$

$$p_2 = C - Z_m + \Delta A \quad (3)$$

In the formula: $p_0$ - initial pressure; $p_1$ - expansion side pressure at 1.1mm displacement; $p_2$ - the termination pressure when the diaphragm returns to 0.05mm; $Z_m$ - initial reading of pressure gauge before zero setting.

According to $p_0$, $p_1$ and $p_2$, the following four parameters can be calculated:

material index:

$$I_D = (p_1 - p_0) / (p_0 - U_0) \quad (4)$$

horizontal stress index:

$$K_D = (p_0 - U_0) / \sigma_{uv} \quad (5)$$

Lateral expansion modulus:

$$E_D = 34.7(p_1 - p_0) \quad (6)$$
Pore pressure index:

\[ U_D = (p_2 - p_0)/(p_0 - U_0) \]  \hspace{1cm} (7)

In the formula, \( U_0 \) - the static pore water pressure at the test depth; \( \sigma_{vo} \) - the effective overburden earth pressure at the test depth.

According to DMT parameters, the characteristics of soil can be determined. For example, \( I_D \) and \( U_D \) can be classified into soil classes. \( K_D \) reflects the horizontal stress of soil. The larger \( K_D \) is, the better the consolidation and compactness of soil is. \( E_D \) reflects the consolidation characteristics of the soil.

3.3. Collation and analysis of test data

According to \( p_0 \), \( p_1 \) and \( p_2 \), material index \( I_D \), Lateral expansion modulus \( E_D \) and horizontal stress index \( K_D \) can be determined, and the change curve of \( I_D \), \( E_D \) and \( K_D \) of each station with depth \( H \) can be drawn. Take Zhangshi station of Shenyang subway as an example, see figure 2.

It can be seen from the curve that the shape of \( I_D \) and \( E_D \) curve is similar, and the soil layer can be divided according to the shape of the curve. \( I_D \) index is stable and sensitive to soil property. The \( K_D \) curve reflects the horizontal stress state of different sites.

3.4. Application of horizontal coefficient of subgrade reaction

Horizontal coefficient of subgrade reaction is an important parameter of displacement and internal force of foundation pit engineering and tunnel support design under horizontal load. Flat dilatometer test can reflect the stress state of the soil more truly, and has a unique advantage in solving the parameters related to the lateral basal bed reaction coefficient.

At present, it is mainly applied in solving the reaction coefficient of lateral basal bed by flat dilatometer test in Shenyang area. The test formula is as follows[8]:

\[ K_h = \Delta p / \Delta S \]  \hspace{1cm} (8)

In the formula: \( \Delta p \) - stress increment; \( \Delta S \) - displacement.

Professor Tang Shidong of Tongji University [9] proposed that the calculation of lateral bed reaction coefficient should take into account the properties of the soil, the width of the foundation, the loading rate and other factors, and proposed the following solution:

\[ K_h = \lambda_1 \lambda_2 \lambda_3 K_{h0} \]  \hspace{1cm} (9)
In the formula: \( \lambda_1 \) - width correction coefficient; \( \lambda_2 \) - shape and stiffness correction coefficient; \( \lambda_3 \) - rate correction factor; \( K_{ho} \) - test value of horizontal coefficient of subgrade reaction.

Combined with the flat dilatometer test data of Shenyang metro line 1 project, the calculation was carried out according to formula by using the Tang shidong recommended method, and the results were compared with the empirical formula for the same soil layer, as shown in table 1.

| Layer | Empirical formula method | Recommended the method |
|-------|--------------------------|------------------------|
| ②    | 95.141                   | 61.709                 |
| ②_1  | 93.545                   | 57.067                 |
| ④_1  | 129.102                  | 84.189                 |
| ⑥    | 98.426                   | 65.129                 |
| ⑥_5  | 87.854                   | 53.341                 |
| ②_2  | 99.034                   | 61.239                 |
| ⑥_2  | 71.273                   | 69.952                 |

It can be seen from the table that: horizontal coefficient of subgrade reaction \( K_{ho} \) calculated by the Tang shidong recommendation method is relatively small, but this method is obtained under the condition that the square rigid foundation with a width of 1m is assumed. The calculation formula takes into account the correction of various factors, and the result is more reasonable.

3.5. Application of lateral expansion modulus

The lateral expansion modulus \( E_D \) of soil can be directly determined by flat dilatometer test. While the vertical compression modulus is used to calculate the settlement of foundation soil. At present, it is very difficult to obtain the accurate ES value of the compression modulus in actual engineering. Considering that the vertical compression modulus \( M_{DMT} \) has a good relationship with the lateral expansion modulus \( E_D \), the relationship can be established and the compression modulus can be solved by using the results of flat dilatometer test.

Marchetti proposed to calculate the vertical compression modulus by using the empirical formula of flat dilatometer test[10].

\[
M_{DMT} = R_m \cdot E_D
\]  

(10)

In the formula: \( R_m \) is a function of \( I_D \) and \( K_D \), which generally increases with the increase of \( E_D \), and the value is generally in the range of 1~3.

According to the data of Subway engineering test (DMT), the vertical compression modulus of soil of each soil layer was selected for comparative analysis with the average value of compression modulus of the earth test. It was found that the average value of flat dilatometer test was 14.2% larger than that of the earth test. This is because the soil samples in the laboratory geotechnical test are susceptible to disturbance, resulting in a relatively small measurement value. Since the flat dilatometer test can more truly reflect the stress state of the soil, it is suggested to apply the lateral swelling modulus \( E_D \) of the flat dilatometer test to solve the vertical compression modulus \( M_{DMT} \) of the soil.

3.6. Application of material index

Through mathematical statistical analysis of the 613 group \( I_D \) values collected in the flat dilatometer test, we obtained the following distribution pattern, as shown in table 2. It can be seen that the \( I_D \) value of material index in Shenyang is basically within the classification range of soil layer proposed by
Marchetti. This shows that we can use the material index $I_D$ of the flat dilatometer test to classify the soil.

### Table 2. $I_D$ distribution rule table of Shenyang subway engineering.

| Soil resistance | Probability range(80%) | The average | Overlapping range |
|-----------------|------------------------|-------------|-------------------|
| Clay            | 0.21~0.48              | 0.35        | 0.22~0.48         |
| Silty clay      | 0.22~0.54              | 0.38        |                   |

The data of side heaviness index $I_D$ and side heaviness modulus $E_D$ value in the flat dilatometer test of Shenyang subway were used to estimate the soil weight, and the comparison with the soil weight value obtained in the geotechnical test is shown in Table 3.

### Table 3. Comparison of flat dilatometer test and geotechnical test results.

| Layer | Flat dilatometer test $\gamma (kN/m^3)$ | Geotechnical test $\gamma (kN/m^3)$ | Correction coefficient |
|-------|----------------------------------------|-------------------------------------|------------------------|
| ①    | 16.8                                   | 18.2                                | 1.08                   |
| ②    | 16.7                                   | 18.0                                | 1.08                   |
| ③    | 17.0                                   | 18.5                                | 1.09                   |
| ④    | 16.8                                   | 18.6                                | 1.10                   |
| ⑤    | 16.7                                   | 19.3                                | 1.16                   |
| ⑥    | 16.7                                   | 18.7                                | 1.12                   |
| ⑦    | 16.6                                   | 18.6                                | 1.12                   |

As can be seen from the table, the heavy component value obtained by the flat dilatometer test in Shenyang area is 11.1% smaller than the average result of the geotechnical test, so it needs to be multiplied by 1.11 to make regional empirical correction.

### 4. Conclusion

This paper sorted out and analyzed the data of the flat dilatometer test of subway engineering survey, and studied the engineering application of parameters, and reached the following conclusions:

The material index $I_D$ and Lateral expansion modulus $E_D$ curve are similar in shape, and the soil layer can be divided according to the shape of the curve. The material index $I_D$ in Shenyang area is basically within the classification range of soil layer proposed by Marchetti, which can be used as one of the indicators to classify soil. The heavy index obtained by the flat dilatometer test needs to be multiplied by 1.11 for regional empirical correction.

Horizontal coefficient of subgrade reaction is an important soil parameter. The horizontal coefficient of subgrade reaction $K_s$ of soil layer can be obtained accurately by using the results of the flat dilatometer test. The applicability of Tang shidong’s recommendation method in Shenyang area is verified by combining with the data of the flat dilatometer test.

The vertical compression modulus ($M_{DMT}$) obtained in the flat dilatometer test was slightly larger than that in the geotechnical test ($E_S$). Because the flatbed lateral expansion test can reflect the stress state of soil more truly, it can be used to solve the flat dilatometer test.

### References

[1] Choo H, Lee W, Hong S J, et al. 2016. Application of the dilatometer test for estimating undrained shear strength of Busan New Port clay[J]. Ocean Engineering, 115: 39－47.

[2] Xu yuan et al. Application of the flat dilatometer test in Tianjin [J], China water transport, 2017,17 (2) : 254~256.
[3] National standards of the People's Republic of China. In-situ testing procedures for railway engineering geology (TB10041-2003). Beijing: China railway press, 2003.

[4] National standard of the People's Republic of China. GB 50021-2001 geotechnical investigation specification (2009 edition)[S]. Beijing: China building industry press, 2002.

[5] Engineering geology handbook compilation committee "engineering geology handbook 4th edition" [M]. China building industry press, 2007.

[6] Yi xin, pan ruilin, sun bao-zhong. Application of in-situ test in obtaining geotechnical parameters of subway exploration [J]. Railway survey, 2014(3):34 ~ 37.

[7] Xu chao, shi zhenming, gao yanbin et al. In situ geotechnical engineering test [M]. Shanghai: tongji university press, 2005.

[8] Marchetti S. In-situ tests by flat dilatometer[ J]. Journal of Geotechnical Engineering, ASCE, 1980, 107(3):832-837.

[9] Tang shidong, Lin guohua. Solving the reaction coefficient of lateral basal bed by flat expansion test [J]. Chinese journal of geotechnical engineering, 2003,25 (6) : 692-694.

[10] Marchetti S. The Flat Dilatometer Test (DMT) in Soil Investigations[C]. IN Measurement of Soil Properties, Bali, Indonesia, 2001.