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Analysis of Applicability of Clegg Impact Soil Tester for Clayey Soils

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Abstract. Dynamic test methods are used in numerous civil engineering sections. Evaluation of the earthwork quality can be carried out effectively using these methods. Equipment utilized the dynamic methods, such as Clegg Impact Soil Tester, is portable and usable in cramped areas or difficult accessible places. Another benefit is that these apparatuses can be used for quick controlling of the subsoil layers during the subsoil improvement. Clegg Impact Soil Tester can substitute the common test equipment in terms of the earthworks assessment. However, boundary conditions of apparatus given by the manufacturer need to be taken into account to obtain results with sufficient reliability. Method is based on the impact effect of the test equipment on the ground. Thus, results have to be interpreted carefully considering the type and the physical state of the tested soil.

1 Introduction

Evaluation of the earthwork quality is one of the most important tasks during the construction of the traffic structures. Established methods such as hole test or plate load test are reliable but time consuming and impractical. Quick methods such as radiometric gauge or compactionmeter are less reliable and required verification. Besides, another equipment based on the dynamic or impact methods was developed such as light weight deflectometer, Humboldt GeoGauge or Clegg Impact Soil Tester. These methods are based on the non-destructive indirect measurement of the subsoil stiffness when other quantities such as deceleration are evaluated, [1]. Study based on the Clegg Impact Soil Tester is presented in this paper.

The Clegg Impact Soil Tester (CIST or Clegg hammer) was proposed by dr. Baden Clegg in 1970s as an alternative to CBR test. The hand-operated equipment has good mobility and tests can be quickly performed in situ. Initially, the CIST device was developed rather for the non-cohesive fill materials. Our goal was to analyse the applicability of the CIST apparatus also for earthwork quality controlling in case of clayey soils.

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The Clegg Impact Value (*CIV*) obtained during the test can be used to calculate quantities according to the correlation relations such as modulus of elasticity of the soil layer E or CBR value (California Bearing Ratio) but a limited number of studies had been carried out to obtain correlations between *CIV* and the Young's moduli of soils E, [2].

This paper presents the outputs of the investigation of the relation between obtained *CIV* values, corresponding modulus E and moisture content of the soil.

2 Impact theory

The Clegg Impact Soil Tester (CIST) is based on the impact method of soil testing. It hits the soil surface without damping with a hammer which falls from a certain height depending on the tester model. Deceleration is measured during the hammer drop and the resultant value of *CIV* is calculated as follows:

$$CIV = a / 10 \cdot g, \tag{1}$$

where: CIV Clegg Impact Value (-),
a deceleration measured during the hammer drop (m.s^{-2}),
g gravitational acceleration (= 9.81 m.s^{-2}).

Vertical force acting on the subsoil is expressed as:

$$F = 10 \cdot m \cdot g \cdot CIV, \tag{2}$$

where: F force induced by the falling hammer (N),
m hammer mass (kg).

Vertical stress is the force divided by the cross-section area of the hammer:

$$p = 10 \cdot m \cdot g \cdot CIV / \pi \cdot r^2, \tag{3}$$

where: p pressure induced by the falling hammer (Pa),
r radius of the hammer (m).

Penetration of the hammer is:

$$y = h / 10 \cdot CIV, \tag{4}$$

where: y deformation of the layer induced by the hammer drop (m),
h hammer drop height (m).

From the elastic theory for rigid bearing plate the penetration can also be expressed as:

$$y = [0.5 \cdot \pi \cdot (1 - \mu^2) \cdot p \cdot r] / E, \tag{5}$$

where: μ Poisson's ratio of tested soil (-),
r radius of the hammer (m),
E modulus of elasticity (Pa).

Substituting the equations (4) and (5) the modulus of elasticity is:

$$E = [100 \cdot m \cdot g \cdot CIV^2 \cdot (1 - \mu^2)] / d \cdot h, \tag{6}$$

where: d diameter of the hammer (m).

3 Field testing

Test field for in-situ measurements represents the soft subsoil of the traffic structure such as road or rail embankment, [3, 4]. Test field with the dimensions 5 × 3.5 m was divided into 70 sections (10 × 7) with dimensions 0.5 × 0.5 m, one for each test site. Tests were accomplished in 13 testing days when a total of 70 values for each testing day were obtained. Soil classification was done and moisture content of the soil was determined for each testing day. This allowed us to classify the soil in terms of the consistency limits and to investigate the influence of the physical state of the soil on the test outputs.

3.1 Test equipment

The Clegg Impact Soil Tester CIST/882 was utilized. The specially instrumented 4.5 kg compaction hammer with built-in impact sensor operates within the vertical guide tube. The height of the impact is 0.45 m, diameter of the hammer is 0.050 m. The tester is equipped with the meter with the digital display and calibration ring, [5].

3.2 Testing procedure

When the hammer is released from a fixed height, it falls through the tube and strikes the surface beneath the guide tube, decelerating at a rate determined by the bearing strength and stiffness of the soil within the area of impact. The output from an accelerometer mounted on the hammer is transferred to the digital readout meter which records the peak deceleration of the hammer on impact. The value attained after the fourth drop is recorded as the Impact Value (IV) for the soil being tested.

In order to obtain a reliable reading of Impact Value it is necessary to carry out five test drops at each location. The first two or three drops should effectively take up the surface irregularities and loose material beneath the hammer. The readings thereafter should get progressively higher. The third, fourth and fifth readings should level out and register the stiffness of the compacted layer under test. The fourth reading is the critical reading; it represents the degree of compaction being measured.

After the test, the deflection made by the drop hammer should be investigated. Typical indentation values on fine fill range from 20 mm at 10 IV to 2 mm at road base with 30 IV. Values outside of these interval usually indicate a problem. If the indentation is greater than 20 mm deep with fine fill or 2 mm deep for coarse or dry materials, the test at that location has failed regardless of the IV recorded, [5].

3.3 Soil characteristics

The test field consists of clayey soil. Grain-size distribution curve and consistency limits were determined for the specimen taken from the top 2 m layer of the profile (Figure 1 and Table 1). Natural moisture content of the soil was 21.70% during the survey which means stiff consistency in accordance with the ISO 14688-2, [6].

Table 1. Consistency limits of the tested soil.

Name	%
Plasticity limit w_P	19.23
Liquid limit w_L	42.19
Index of plasticity I_P	22.96

Geological profile of normally consolidated soil and the stiffness properties were determined by the two CPT probes (Cone Penetration Test) and a survey shaft (Figure 2), [7].

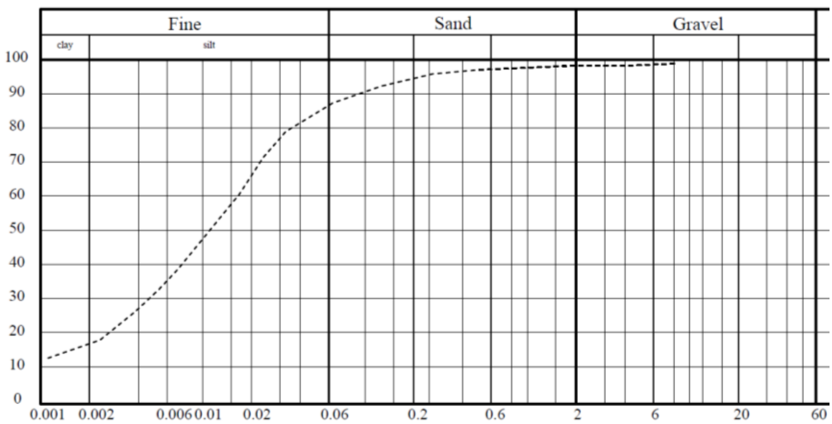

Fig. 1. Grain-size distribution curve of tested soil.

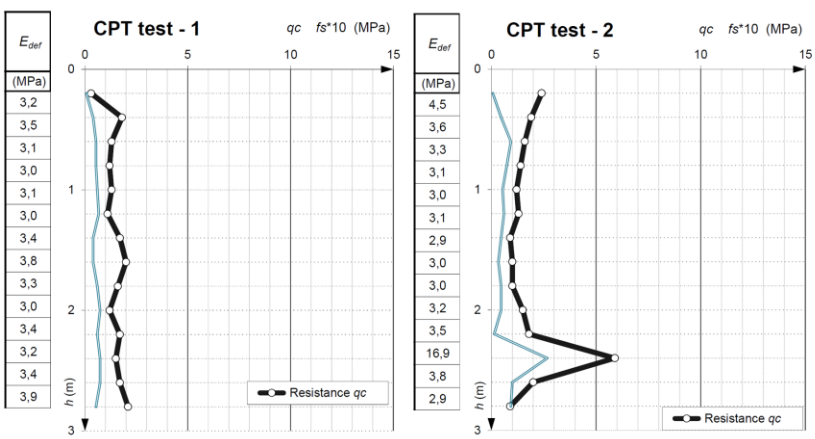

Fig. 2. CPT profile of tested soil.

Survey showed the occurrence of clay of immediate plasticity F6/CI with overall thickness from 2.2 to 2.8 m. Static deformation modulus E_{def} was determined via correlation with the cone tip resistance of the CPT test machine during the penetration of the testing rod. The values of the modulus varied from 2.9 to 4.5 MPa along the plotted profile.

4 Results and discussion

Average *CIV* values calculated from 70 tests in each test day are listed in the table 1. Data are arranged according to the actual moisture content of the soil during the particular test day. At known consistency limits, the index of consistency I_c was determined. Most of the values lie in the hard consistency interval in accordance with the standard ISO 14688-2.

Modulus of elasticity E and deflection of the surface after hammer drop y were calculated following the equations (4) and (6). Calculated modulus E for stiff consistency reached 2.6 and 4.8 MPa what is in good agreement with results obtain during the survey when modulus E_{def} reached 2.9 to 4.5 MPa. It should be mentioned that calculated modulus E is referred as an elasticity modulus while E_{def} is strain modulus. This difference is linked to the soil behaviour under load. In some tests, the deflection was larger than allowed 20 mm mentioned in the manual. Larger permanent deflection indicates that the calculated modulus E should be rather referred to strain modulus, especially in case of softer consistency. The equation (5) is common for calculation both elastic and strain modulus, the only difference is input deflection.

Table 2. Measured moisture content and *CIV* values, and calculated modulus of elasticity and deflection

Test No.	w (%)	I_c (-)	Consistency ISO 14688-2	*CIV* (-)	E (MPa)	y (mm)
1	9.40	1.59		10.3	17.5	4.4
2	9.96	1.55		10.9	19.6	4.1
3	10.62	1.52		9.7	15.5	4.6
4	12.72	1.40		7.7	9.8	5.8
5	13.09	1.38		8.9	13.1	5.1
6	14.38	1.31	hard	9.7	15.5	4.6
7	16.06	1.22		8.6	12.2	5.2
8	16.12	1.22		9.8	15.8	4.6
9	17.01	1.17		7.6	9.5	5.9
10	17.20	1.16		5.9	5.7	7.6
11	18.74	1.07		6.8	7.6	6.6
12	20.50	0.98	stiff	5.4	4.8	8.3
13	23.87	0.79		4.0	2.6	11.3

The moisture content – calculated modulus E dependency shows some correlation relation but with decreasing amount of water in pores results became more dispersed (Figure 3). Dehydrating of the clay causes the creation of the thin stiffer top layer which can influence obtained data.

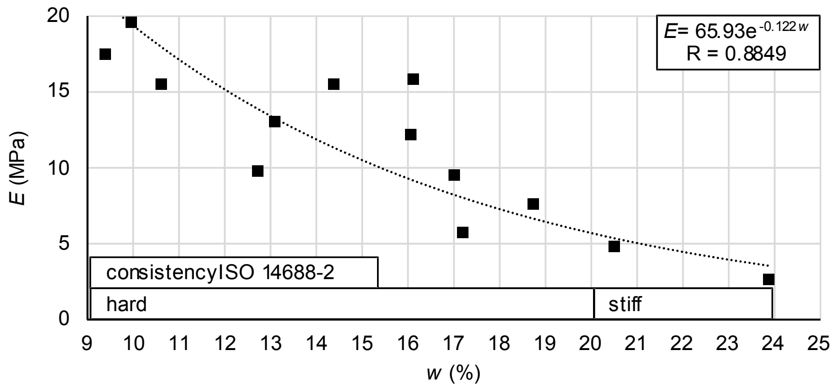

Fig. 3. Moisture content – calculated modulus E dependency.

Common approach is to remove this layer to achieve reliable results. Generally, very soft and very hard consistency can be potentially a cause of larger irregularities of measured values. Statistical evaluation of laboratory tests carried out in former Czechoslovakia was done and this data were part of the cancelled standard STN 73 1001 for shallow foundations. For stiff consistency of the clay of intermediate plasticity, the typical strain modulus E_{def} is 8 to 20 MPa, [8]. Calculated modulus for stiff consistency is in interval from 5.86 to 19.81 MPa what is in good agreement with the typical values.

Assuming that the calculated modulus E is a strain modulus, the CIV – E modulus dependency for clay of immediate plasticity can be expressed as plotted in the Figure 4.

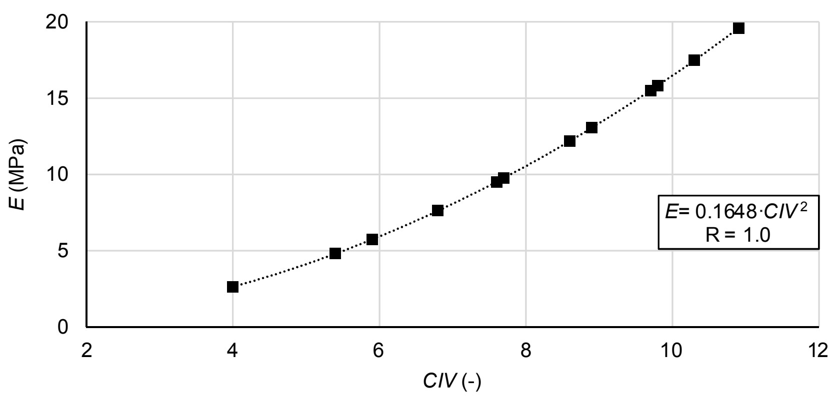

Fig. 4. CIV value – modulus E dependency for tested clay.

5 Conclusions

Generally, Clegg Impact Soil Tester can substitute the common test equipment in terms of the earthworks assessment for clayey soils. However, boundary conditions of apparatus need to be taken into account to achieve results with sufficient reliability.

We recommend to interpret the results of CIST testing as a strain modulus E_{def} instead of elasticity modulus for clays of hard and stiff consistency. Usability for soils of firm and soft consistency was not investigated and need to verify.

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