DE GRUYTER
OPEN

Vol. 11, Issue 1/2015, 38-44 DOI: 10.1515/cee-2015-0005

EVALUATION OF DYNAMIC METHODS FOR EARTHWORK ASSESSMENT

Jozef VLČEK[1,*], Dominika ĎUREKOVÁ[2], Katarína ZGÚTOVÁ[2]

[1] Department of Geotechnics, Faculty of Civil Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina.
[2] Department of Construction Management, Faculty of Civil Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina.
[*] corresponding author: j.vlcek@fstav.uniza.sk.

Abstract

Rapid development of road construction imposes requests on fast and quality methods for earthwork quality evaluation. Dynamic methods are now adopted in numerous civil engineering sections. Especially evaluation of the earthwork quality can be sped up using dynamic equipment. This paper presents the results of the parallel measurements of chosen devices for determining the level of compaction of soils. Measurements were used to develop the correlations between values obtained from various apparatuses. Correlations show that examined apparatuses are suitable for examination of compaction level of fine-grained soils with consideration of boundary conditions of used equipment. Presented methods are quick and results can be obtained immediately after measurement, and they are thus suitable in cases when construction works have to be performed in a short period of time.

Keywords:

Clegg Impact Soil Tester;
Compaction;
Correlation;
Lightweight reflectometer;
Humboldt GeoGauge™.

1. Introduction

Evaluation of the earthworks quality is one of the most important tasks during the construction of traffic structures. The effort led into development of accurate evaluation methods such as hole test or plate load test but these methods are time consuming. Quick methods such as radiometric gauge or compactionmeter are less accurate. Light dynamic plate test was adopted as a quick and equally accurate method. Series of correlations were derived to determine the relations between static and dynamic deformation modulus. Static plate load test can then be substituted by the light dynamic plate test which is a quick and accurate method.

Our effort was aimed on the possibility of using a small dynamic equipment for earthwork quality controlling. Light dynamic plate or light weight deflectometer is still quite heavy equipment weighing about 30 kg [1]. Humboldt GeoGauge™ and Clegg Impact Soil Tester were chosen for the in-situ measurements and the results were compared to the outputs obtained from light dynamic plate test. Both gauges are based on the dynamic method of compaction level determination of soil layers and both are lighter than light dynamic plate. Humboldt GeoGauge™ weighs about 10 kg and chosen Clegg Impact Soil Tester weighs about 7 kg [2], [3].

Purpose of performed measurements was to prove the ability of selected small dynamic equipment in determining the desired quantities describing the quality of the earthworks with comparable accuracy to the generally accepted light dynamic plate test [1]. Methods have been tested in conditions of soft subsoil when precision of controlling is not so restricted in comparison to the new constructed soil layers. Especially in cases of improper geological conditions in the subsoil layers, it is difficult to achieve the requested stiffness parameters.

2. Test field and used equipment

Test field for in-situ measurements represented the soft subsoil of traffic structure such as road or rail embankment. Geological profile of normally consolidated soil and the basic stiffness properties were determined by the two CPT probes (Cone Penetration Test) and a core borehole. Survey showed the occurrence of clay of immediate plasticity 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, so the tested soil can be considered homogeneous and isotropic in terms of soil stiffness. Overall dimensions of the test field were 5 x 3.5 m. Test field was divided into 70 sections (10 x 7), one for each measurement, with dimensions 0.5 x 0.5 m. Measurements were carried out within 13 testing days and the test procedure was done using 3 selected testing instruments which acted in each of 70 sections. In total, 70 values for each apparatus and each testing day were obtained. Laboratory tests for soil classification were performed and moisture content 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 measurement results.

Following equipment was selected for the measurements:

- light weight dynamic plate LDD 100,
- Humboldt GeoGauge™ H-4140,
- Clegg Impact Soil Tester CIST/882.

LDD apparatus is based on impact loading of falling weight with weight of 10 kg falling from height of 0.755 m on the damping pad on the circular plate of diameter d = 0.3 m. Total contact stress during impact with length of 17.9 ms is 100 kPa. This stress imposes the deflection of the surface of the tested soil layer. According to the equation (1), the dynamic deformation modulus E_{vd} can be expressed as:

$$E_{vd} = \frac{F}{d \cdot y}(1-\mu^2), \tag{1}$$

where: E_{vd} - dynamic deformation modulus of soil (MPa),
F - applied impact force (= 7.07 kN for LDD 100),
D - diameter of the loading plate (= 0.3 m for LDD 100),
Y - overall deflection of the soil layer surface after the impact (mm),
μ - Poisson's ratio of tested soil (= 0.35 for subsoil layers).

Humboldt apparatus imparts very small displacements to the ground (< 1.27 x 10^{-6} m) at 25 steady state frequencies between 100 and 196 Hz. Each frequency has duration 3 s and overall length of one measurement is about 75 s. It measures the applied force and the following deflection δ of the surface. Stiffness of the soil K is determined for each steady frequency and the average value is then displayed. Contact dynamic stress reaches about 27.58 kPa and is induced trough the circular ring lying on the surface.

$$K = \frac{F}{\delta}, \tag{2}$$

$$E = \frac{F}{1.77 \cdot R \cdot \delta}(1-\mu^2), \tag{3}$$

where: K - soil stiffness (MN.m^{-3}),
F - applied force (= 0.11 kN for Humboldt H-4140),
Δ - induced deflection of the ground (mm),
E - resilient modulus of the soil (MPa),
R - outer radius of the angular ring of the apparatus (m),
μ - Poisson's ratio of tested soil (= 0.35 for subsoil layers).

Clegg Impact Soil Tester impacts the soil surface with a hammer which is falling from a certain height depending on the tester model. Deceleration is measured during the hammer drop and the resultant value of CIV (Clegg Impact Value) is determined [1]:

$$CIV = \frac{a}{10 \cdot g}, \tag{4}$$

where: CIV - Clegg Impact Value (-),
a - deceleration measured at the hammer drop (m.s^{-2}),

g - gravitational acceleration (= 9.81 m.s^{-2}).

CIV value can be used to calculate other quantities according to the correlation relations:

- resilient modulus of the soil layer *E*,
- CBR value (California Bearing Ratio).

3. Testing procedure and evaluation

All apparatuses were deployed in each measurement sector (0.5 x 0.5 m) in each testing day. Moisture content of the tested soil was determined in each testing stage so obtained results can be linked to the corresponding consistency of the soil. Physical state of the soil has a major influence on the stiffness properties of the subsoil; investigation of this influence was the aim of the results analysis.

Correlation relations were derived for a pair of data sets for each testing day. First pair represents the relation between dynamic deformation modulus from LDD test and resilient modulus from Humboldt GeoGauge™; second pair was the relation between dynamic deformation modulus from LDD test and CIV values from Clegg Impact Soil Tester. Results from LDD test were chosen as a comparative set of data because of the large expansion of this test equipment in the controlling process of earthworks [1].

For each set of data pairs, a standard deviation was determined and the values, which did not fit the standard deviation criterion, were excluded from the data set. Classification of the tested soil was made according to the consistency limits in the Slovak standard STN 72 1001 Classification of soil and rock and international standard ISO 14688-2 Geotechnical investigation and testing [4], [5]. There are some differences in soil consistency determination between both standards, especially in case of hard and stiff consistency when limits of these consistencies have set different values.

4. Analysis of the results

Results of the testing corresponding to the classification of tested soil according to the consistency are shown in the Table 1.

Table 1: Results of the in-situ tests.

Test No.	Moisture content *w* (%)	Consistency index I_c (-)	Consistency STN 72 1001	Consistency ISO 14688-2	Average E_{vd} LDD (MPa)	Average *E* Humboldt (MPa)	Average *CIV* CIST (-)
1	9.40	1.59	hard	hard	18.86	77.26	10.34
2	9.96	1.55			19.81	87.16	19.81
3	10.62	1.52			19.00	79.11	9.69
4	12.72	1.40			11.23	65.67	7.69
5	13.09	1.38			16.65	80.24	8.90
6	14.38	1.31			18.71	94.50	9.75
7	16.06	1.22	stiff		9.32	70.26	8.65
8	16.12	1.22			20.35	72.83	9.76
9	17.01	1.17			10.50	63.78	7.56
10	17.20	1.16			9.42	59.90	5.86
11	18.74	1.07			12.37	68.18	6.77
12	20.50	0.98		stiff	8.93	43.85	5.37
13	23.87	0.79	firm		4.87	25.68	3.99

Dependency of the average test results on the moisture content of the soil is plotted in Figs. 1 – 3. The figures indicate that results strongly depend on the moisture content of the soil. Values of the measured quantities are decreasing with increasing content of the water in the pores. Type of regression curve was chosen according to the highest value of the correlation coefficient *R*.

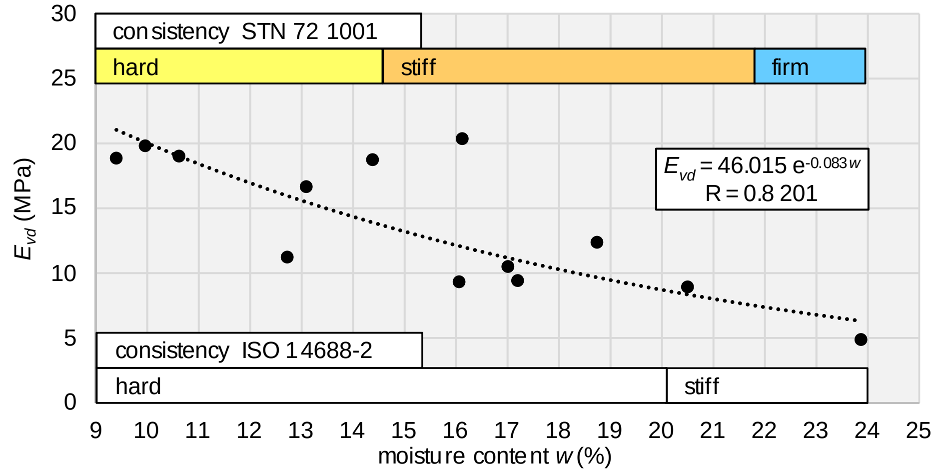

Fig. 1: Dependency of the deformation modulus E_{vd} from LDD test on the soil moisture content.

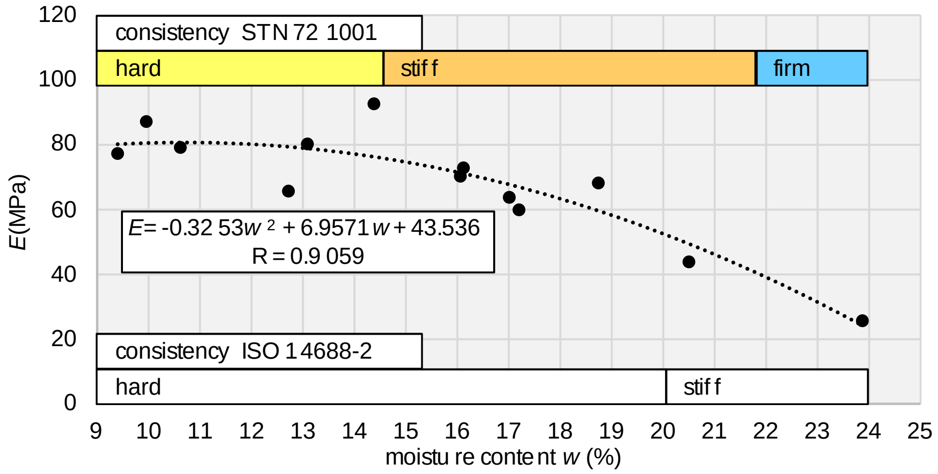

Fig. 2: Dependency of the resilient modulus *E* from Humboldt test on the soil moisture content.

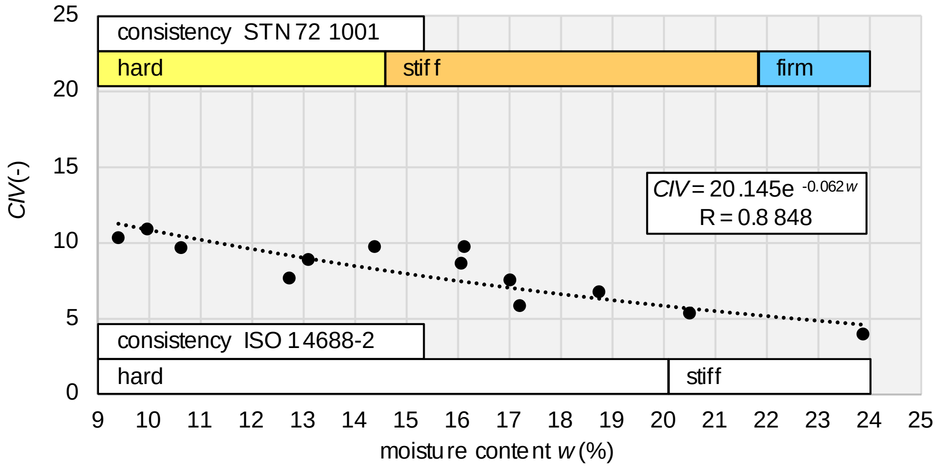

Fig. 3: Dependency of the Clegg Impact Value *CIV* on the soil moisture content.

Results obtained with Humboldt GeoGauge™ and Clegg Tester show higher dependency on the moisture content in the soil than the results from LDD testing. Extreme values are caused by the conditions during the particular testing day but overall trend of the measured values coincides with the trend curve plotted in the graph. Special attention has to be paid in case of saturated soils when increase of pore pressures during impact of weight on the plate of LDD apparatus can overestimate the stiffness of tested layer. Load impact acting in a very short time interval brings the soil body into undrained stress state when total stresses play major role [6].

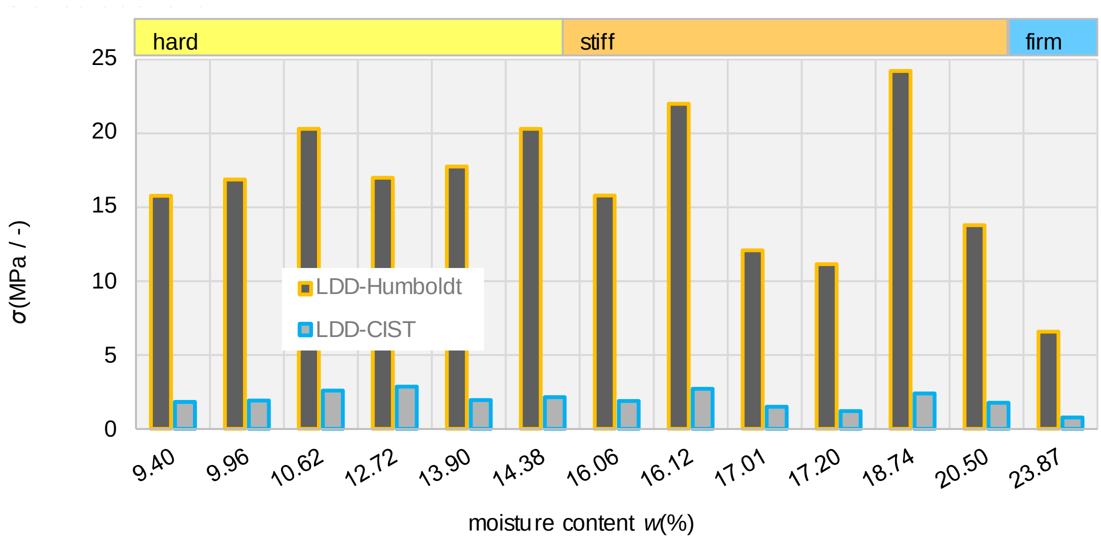

Fig. 4: Standard deviations of data pairs for different moisture content, consistency according to the STN 72 1001.

Table 2: Statistic evaluation of the measured values.

Test No.	Moisture content w (%)	Consistency index I_c	Consistency STN 72 1001	Correlation coefficient R		Number of valid measurements	
				LDD-Humboldt	LDD-CIST	LDD-Humboldt	LDD-CIST
1	9.40	1.59	hard	0.9196	0.8054	61	54
2	9.96	1.55		0.8285	0.7368	60	51
3	10.62	1.52		0.7921	0.8048	57	59
4	12.72	1.40		0.8688	0.8416	62	62
5	13.09	1.38		0.7472	0.8334	59	61
6	14.38	1.31		0.7997	0.8844	56	60
7	16.06	1.22	stiff	0.9042	0.8098	67	53
8	16.12	1.22		0.7732	0.8584	44	52
9	17.01	1.17		0.8577	0.8530	61	64
10	17.20	1.16		0.8187	0.8951	50	54
11	18.74	1.07		0.9037	0.8702	60	63
12	20.50	0.98		0.8988	0.8321	65	64
13	23.87	0.79	firm	0.8171	0.5883	55	50

Data pairs LDD-Humboldt and LDD-CIST were first statistically analysed and values lying beyond the limit defined as a common mean ±σ (standard deviation) were excluded. Common mean was determined as an arithmetic mean from both sets of data pair when LDD values were normalized according to the ratio of the Humboldt or CIST values mean to the LDD values mean (Fig. 4). This allowed us to exclude the extreme values without excessive elimination of members of data pair. Excluding the extreme values in separate data set (LDD, Humboldt or CIST) would cause the excluding of the corresponding value in the second data set of the pair (obtained from the same test section) even if this value satisfies the given limits.

Despite the excluding of extreme values (Table 2), some correlation relations did not fit the minimal value of the correlation coefficient R = 0.8 for supplanting methods for compaction evaluation [7]. These extremes are caused by the conditions during the particular testing days.

Correlation coefficient shows no dependency on the moisture content and is dependent only on the actual conditions during the test and physical regularities of the test procedure (Fig. 5). Dropdown is visible at the LDD-CIST results when coefficient R reached only 0.5883 (Table 2). In the case of firm consistency, hammer of CIST machine penetrated the layer surface with permanent deformation more than 20 mm which is not acceptable according to the equipment manual [3]. The deformation after impact is permanent, so modulus obtained from this method cannot be considered as resilient but as a deformation modulus. On the other hand, LDD apparatus brings undrained stress conditions into the tested soil, so the relation between results from both tests is small due to the different process of test procedure, especially in the case of saturated soils.

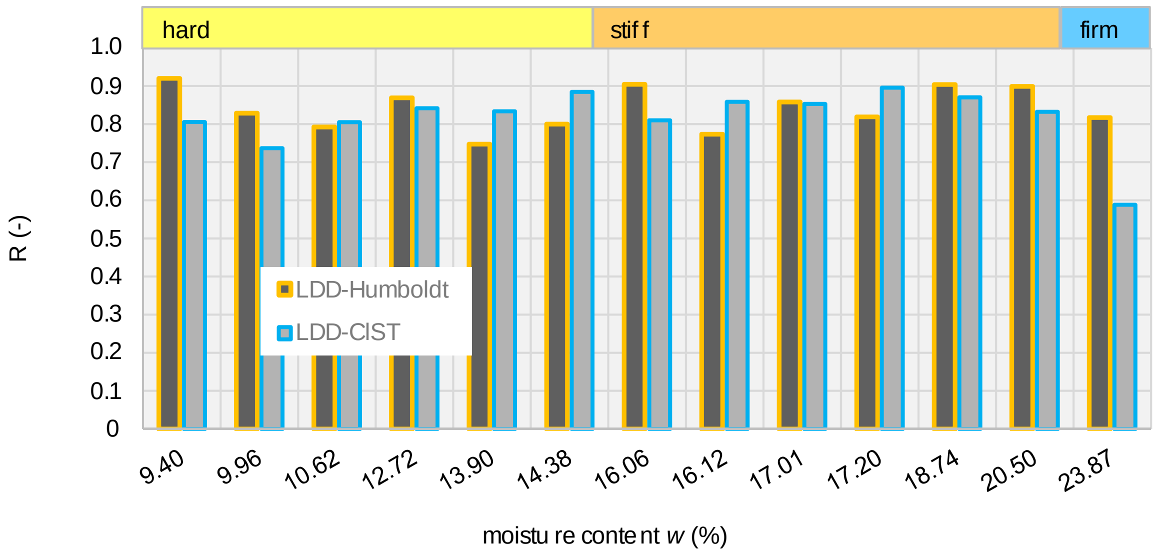

Fig. 5: Correlation coefficients R of data pairs for different moisture content.

5. Conclusions

Presented results of analyses proved that apparatuses Humboldt GeoGauge™ and Clegg Impact Soil Tester are capable of evaluation of the quality of earthworks close to the level of widely used Light Dynamic Deflectometer. These apparatuses are more portable and are more 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 ground improvement.

Generally, both Humboldt GeoGauge™ and Clegg Impact Soil Tester can substitute the LDD test in terms of the earthworks assessment, but boundary conditions of apparatuses given by the manufacturers need to be taken into account to achieve results with a required accuracy level. All mentioned methods are based on the dynamic effect of the testing equipment on the soil layer and results have to be interpreted carefully considering the type and physical state of tested soil.

References

[1] DECKÝ, M. - DRUSA, M., et al.: Designing and control of quality of earth works of engineering structures (In Slovak). Žilina: BTO Print, 2009, ISBN 978-80-970139-1-2.

[2] GeoGauge™ User Guide. Humboldt Mfg. Co., 2007.

[3] CLEGG, B.: Clegg Impact Soil Tester Technical Note. Calculation of Penetration and Elastic Modulus from CIV. Jolimont, 1994.

[4] STN 72 1001:2010: Classification of soil and rock.

[5] STN EN ISO 14688-2: Geotechnical investigation and testing. Identification and classification of soil. Part 2: Principles for a classification.

[6] DRUSA, M.: Improvement in evaluation of neogenous soils by CPT testing. Proceeding of 12th international multidisciplinary scientific geoconference. 17-23, June 2012, Albena, Bulgaria. Sofia: STEF92 Technology, 2012, p. 151-158, ISSN 1314-2704.

[7] DECKÝ, M. - DRUSA, M. - PEPUCHA, Ľ. - ZGÚTOVÁ, K.: Earth Structures of Transport Constructions. Pearson Education Limited 2013, Edinburg Gate, Harlow, Essex CM20 2JE, p. 180, ISBN 978-1-78399-925-5.