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THE APPLICATION OF THE MODERN METHOD OF EMBANKMENT COMPACTION CONTROL

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Abstract. Light drop-weight tester is a device for field tests and it is used for quick control of bearing capacity and compaction quality of built-in soils in different types of embankments. It is a modern device which is commonly used in Germany and now in Poland. The examples of calibration of the light drop-weight tester in laboratory and in-situ, and its application in real embankment are presented.

Keywords: embankments, compaction control, light drop-weight tester, dynamic modulus of soil deformation.

1. Introduction

Increase of demands concerning the quality of different types of earth structures has been observed recently. Special stress is also put on the short duration of construction. That is why the interest in quick methods of control of ground compaction has increased recently. Application of quick and not complicated method of current control is especially important. Falling-weight deflectometers FWD of different structure and parameters are used in many countries for control tests of achieved compaction of subsoil and made ground [1– 4].

Falling-weight deflectometers mounted on automotive vehicles has been introduced recently in highway engineering. They are used for measurement of bearing capacity of road surface based on deflection bowl [3]. Force impulse in the range of 7 kN to 250 kN is transmitted on the surface of tested medium through thrust plate of radius 300 mm. A scheme of measurement of deflection bowl on road surface using FWD is presented in Fig 1.

On the theoretical basis of considered problem [5, 6] it is assumed that loading of soil with the lightweight dynamic deflectometer can be treated as a problem of short duration quasi-statical pressure of the plate on the elastic half-space.

This paper describes a light drop-weight tester used in Germany [4, 7] and Czech Republic [2]. There are also companies in Poland which apply this device.

The measure of quality of controlled compaction of soil built in embankments is the value of soil degree of compaction $I_s = \rho_d/\rho_{ds}$ (where ρ_d – dry density of solid particles, ρ_{ds} – maximum dry density of solid particles tested with Proctor method) or the value of deformation index $I_o = E_2/E_1$ (where E_1 and E_2 – primary and secondary moduli of soil deformation tested with VSS plate) or secondary modulus of deformation E_2 [8].

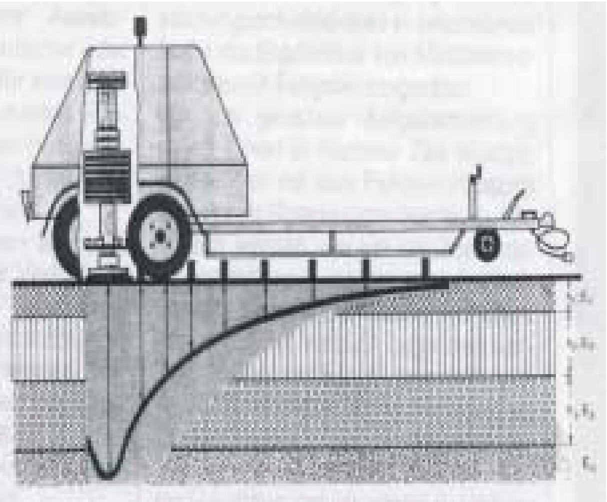

Fig 1. Scheme of measurement of bowl of deflections on road surface using FWD [3]

These types of tests are labour-consuming and long-lasting and they cannot be conducted in all field conditions.

Light drop-weight tester has many advantages comparing with traditional control tests. These are:

- elimination of heavy equipment, which is used as counterweight in the method of tentative static loads with VSS plate,

- possibility to conduct the tests in case of limited surface and difficult access, eg dykes, backfills of narrow excavations,
- small dimensions (1,5 m high) and light weight (20 kg),
- short time for a test (about 3 min) enables to make many tests and to densify tested points and find "weak" areas,
- possibility to obtain results immediately shortens the duration of construction and does not cause shutdowns during earth works.

The paper presents examples of calibrations of the light drop-weight tester which were made prior to its application in compaction control of real embankments. Correlations between dynamic modulus of soil deformation E_D and other geotechnical parameters (I_S, E_1, E_2), which are normally tested for evaluation of compaction quality, were determined on the basis of our own laboratory examinations of medium sand. Dependency $E_D = f(I_S)$ was determined basing on examinations of all-in aggregate on the test field.

2. The description of the test method

2.1. Light drop-weight tester

The light drop-weight tester consists of steel thrust plate (1) diameter of 300 mm with holders (2) and the detector for settlement measurement (3). Guide bar (4) with shock absorber (5) and 10 kg weight (6) hanging in snap fastener (7) is placed on the thrust plate. Detector is connected with the electronic settlement meter (8). The settlement meter shows and registers deflection of subsoil under the thrust plate after each of three impacts and then the average deflection out of the three measurements, the value of dynamic modulus of soil deformation E_D and the "time of acceleration" u_D/v (where u_D – deflection of soil under the thrust plate, v – the deflection rate). The diagram of the light drop-weight tester is presented in Fig 2.

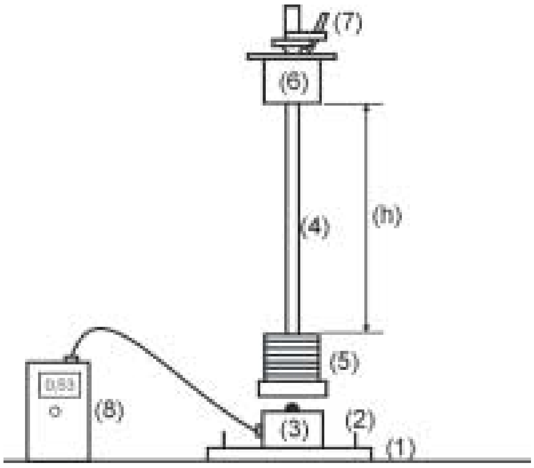

Fig 2. Diagram of light drop-weight tester with electronic settlement meter

The test is based on producing force impulse of short duration (amplitude 7,07 kN) through the weight impact dropping along guide bar from the height (h) on the shock absorber. The impulse is transmitted by the thrust plate to the surface of tested soil and it causes deformation of soil under the plate. The value of dynamic modulus of soil deformation is a result of this test [4]. It is calculated from the following equation:

$$E_D = 1{,}5\frac{r\sigma_D}{\bar{u}_D} = \frac{22.5}{\bar{u}_D}, \quad (1)$$

where r – diameter of the thrust plate, r = 300 mm; σ_D – amplitude of dynamic stress under the thrust plate, σ_D = 0,1 MPa; $\bar{u}_D$ – average settlement of the thrust plate calculated from the results of 3 impacts made after three initial impacts, mm.

2.2. Application of light drop-weight tester

This tester is used for quick examination of dynamic modulus of deformation. The modulus is used for evaluation of bearing capacity and indirectly - for control of compaction quality of subsoil, soil-surfaced roads, layers of embankments or backfills built from mineral soils, soils improved with lime or from waste materials. Light drop-weight tester can be used [4, 7] under the following conditions:

- under the measurement range $15 \le E_D \le 80$ MPa,
- for mineral coarse-grained soil with content of grains $d \ge 63$ mm not exceeding 15 % (and soil with up to 30 % of crushed stone) and fine-grained non-cohesive and cohesive soil in semisolid or low plastic state,
- when thickness of tested uniform soil layer is in the range of 0,3 to 0,5 m [9, 10].

2.3. The way of conducting the test

The thrust plate is set up on the even surface and additionally it is adjusted by shifting and rotating. The surface of coarse grain soil can be even up with the layer of dry fine sand thickness of few millimeters. Then the guide bar is set up on the thrust plate and the deflection meter is connected. The weight is lifted to the height (h) and then dropped on the shock absorber and gripped when it rebounds. Three initial hits should be made in order to get a good contact between the plate and soil. Three test hits are made after turning on the meter.

2.4. Interpretation of test results

Quality control of compaction of soil layers consists in comparison of tested value of degree of compaction I_s (or I_o or E_2) with the minimum required standard value which for road embankments is $I_s \ge 0{,}92 \div 1{,}03$ ($I_o = 2{,}5 \div 2{,}2$ and $E_2 \ge 30 \div 120$ MPa) depending on category of traffic and the depth of the tested soil layer [8].

The above parameters can be determined indirectly on the base of developed correlation with dynamic deformation modulus for the given soil built in embankment.

The general correlations or dependencies determined for many types of soil or for particular groups of soil would be the most useful.

3. Example of calibration of light drop-weight tester

The aim of the test was to determine the dependencies between dynamic modulus of deformation E_D and degree of compaction I_s or primary E_1 and secondary E_2 deformation modulus for medium-grained sand, according to [10]. The sieve-analysis curve is presented in Fig 3.

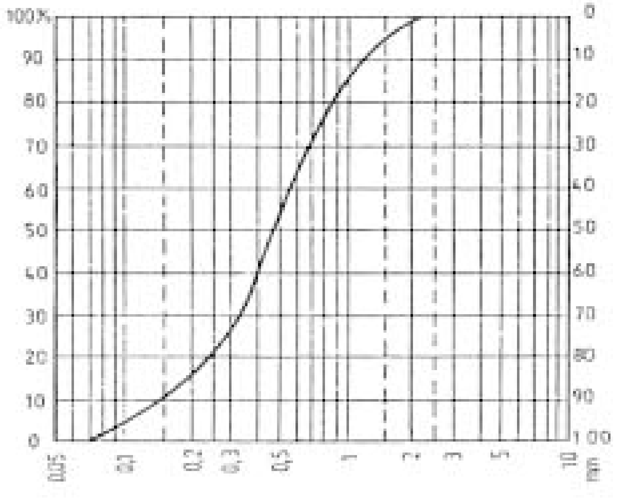

Fig 3. Medium sand sieve-analysis curve

The test was performed on laboratory setup on the model subsoil from medium-grained sand. Soil water content was in the range of 3,5 to 6,7 %. The investigated soil layer thickness $a_1 = 0,3$ m or $a_2 = 0,5$ m was placed on a sublayer thickness 0,3÷0,4 m of $I_s \geq 1,0$ and it was evenly compacted with plate compactor.

Degree of compaction was calculated by the equation

$$I_s = \frac{\rho_d}{\rho_{ds}}, \tag{2}$$

where ρ_d – dry density of solid particles, ρ_{ds} – maximum dry density of solid particles, tested using method I (normal Proctor's method) according to [11].

Dry density of solid particles was calculated by the equation:

$$\rho_d = \frac{100\rho}{100 + w}, \tag{3}$$

where ρ – bulk density of soil tested with sand volumeter according to [12], w – water content tested by drying according to [11].

The tests of dynamic modulus of soil deformation were conducted using light drop-weight tester type ZFG 01 according to [4].

Primary and secondary moduli of soil deformation were determined by means of thrust plate with static load (VSS) according to [8].

The dynamic modulus of deformation was calculated by equation (1).

The values of primary and secondary moduli of deformation were calculated by the equation:

$$E_1 \, or \, E_2 = D\frac{\Delta\sigma}{\Delta u} = \frac{22,5}{\Delta u}, \tag{4}$$

where $\Delta\sigma$ – the range of stress in which modulus E_1 and E_2 were calculated, Δu – measured settlement of the thrust plate for σ_2 and σ_1, mm, correspondingly, $\Delta u = u_2 - u_1$, $\Delta\sigma = \sigma_2 - \sigma_1 = 0,125 - 0,050 = 0,075 MPa$.

A set of variables (I_s, E_D, E_1, E_2) was obtained as a result of examinations of modelled soil. The set consisted of n = 30 results: $n_1 = 14$ for $a_1 = 0,3$ m and $n_2 = 16$ for $a_2 = 0,5$ m. Statistical analysis of the set of variables (Table 1) was made with computer program Statgraphics [13].

Verification of hypothesis of equal average values in groups (using the method of variance analysis with singular classification based on the least significant differences) was conducted in order to determine whether the thickness of tested soil layer influences the value of dynamic modulus of deformation. The level of significance was $\alpha = 0,798$. This conclusion confirmed also the test of homogenous groups. In order to justify the conclusion by the variance analysis, two assumptions were checked [13]: normality of characteristic distribution in groups using Kolmogorov – Smirnov's test of goodness of fit and homogeneity of variance in groups using Chochran's test and Bartlett's test.

The above analysis allowed formulating the following conclusion: the thickness of soil layer (in the range 0,3 m to 0,5 m) does not influence the value of dynamic modulus of soil deformation E_D.

Then correlations between variables in the set of all measurements were determined. The best fitted models of regression between two variables were chosen using simple regression analysis [13, 14].

Table 2 presents matrix of linear correlation coefficients for tested variables.

Analysis of correlation matrix shows significant dependencies between dynamic modulus of deformation and statical moduli of deformation as well as the relationship between degree of compaction.

The dependencies: $E_D=f(I_s)$ and $E_D=f(E_1)$, $E_D=f(E_2)$ are presented in Figs 4 and 5.

4. Control of soil compaction using light drop-weight tester according to German instructions

In German recommendations regarding road earth works [15, 16] light drop-weight tester is allowed to be

Table 1. Statistical parameters of variables (I_s, E_D, E_1, E_2)

Geotechnical parameter	Number of observations	Minimum value	Maximum value	Average value	Standard deviation	Coefficient of variation	Skewness ratio	Kurtosis
I_s [–]	15	0,907	0,993	0,962	0,024	2,5	–1,02	0,17
E_D [MPa]	30	11,0	38,8	29,0	7,1	24,6	–0,96	0,10
E_1 [MPa]	15	11,2	39,5	28,0	8,1	29,1	–0,72	–0,21
E_2 [MPa]	15	38,1	112,5	91,8	22,9	25,0	–1,47	1,03

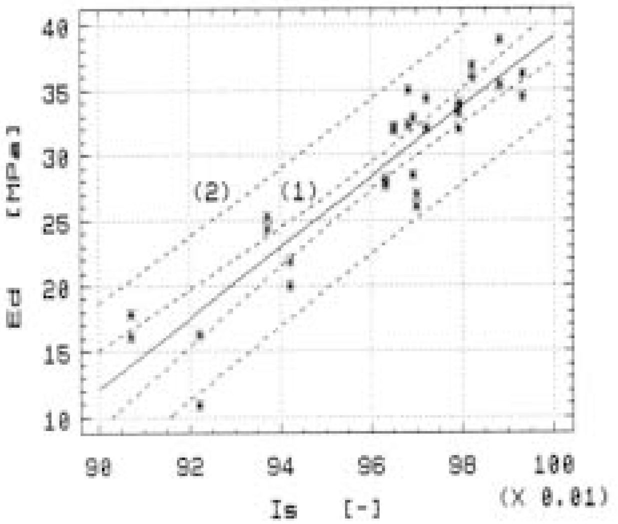

Fig 4. Dependency $E_D = f(I_s)$ for medium grained sand: $E_D = 270{,}51 I_s - 231{,}34$; $r = 0{,}920$; $S_{yx} = 2{,}85$ MPa, r-correlation ratio; S_{yx} – standard estimation error; (1), (2) – ranges of confidence limits for regression line and predicted values calculated for probability 95 %

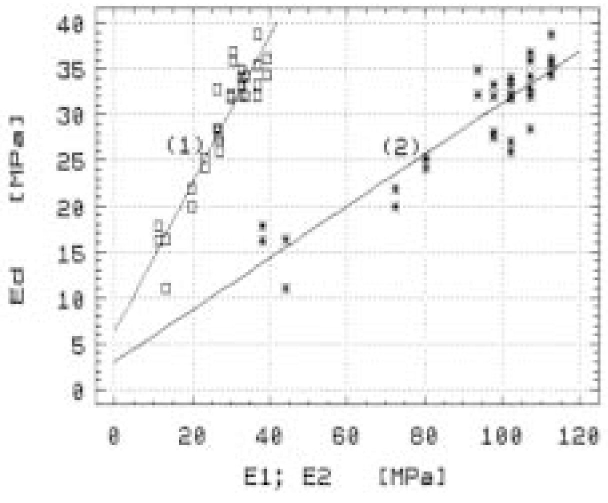

Fig 5. Dependency $E_D = f(E_1)$ and $E_D = f(E_2)$ for medium grained sand: (1) $E_D = 6{,}32 + 0{,}81 E_1$; $r = –0{,}926$; $S_{yx} = 2{,}74$ MPa, (2) $E_D = 2{,}98 + 0{,}28 E_2$; $r = –0{,}911$; $S_{yx} = 3{,}00$ MPa

Table 2. Matrix of linear correlation coefficients for tested variables

	I_s	E_D	E_1	E_2
I_s	1,000			
E_D	0,920	1,000		
E_1	0,951	0,926	1,000	
E_2	0,954	0,911	0,902	1,000

used for control of embankments compaction (as an independent or additional test to static plate load). It is recommended to determine limit values of moduli E_D in comparison with secondary moduli of deformation E_2 tested in the given soil condition. In the case of lack of own correlation dependencies, the values in Table 3 can be used for orientation [16].

Table 3. Values of secondary modulus of deformation E_2 (according to [17]) and dynamic modulus of deformation E_D [16]

E_2 [MPa]	120	100	80	45
E_D [MPa]	60	50	40	25

Comparative examinations has been conducted for many years in order to develop correlation dependencies for different groups of mineral and anthropogenic soils and in order to determine obligatory limit values of modulus E_D in comparison with minimum required values of modulus E_2.

Weingart [18] suggested to consider the following observations:

a) the value of "time of acceleration" u_D/v ratio, where u_D – settlement of thrust under impact, v – speed of settlement, gives additional information on soil compaction,

b) at proper compaction (when $E_2/E_1 \le 2{,}5$ [15]) the condition $2{,}2 \le E_2/E_D \le 2{,}6$ should be satisfied; at not sufficient compaction (when $E_2/E_1 > 2{,}5$) it is observed that $E_2/E_D < 2{,}2$.

On the base of examinations of road load-bearing layers Weingart proposed the following limit values and additional conditions (they do not refer to fine-grained soils sensitive to water) (Table 4).

Table 4. Values of secondary modulus of deformation E_2 depending on the value of dynamic modulus of deformation E_D [18]

E_2 [MPa]	150	120	100	80	60	45	Additional conditions: $E_2/E_1<2,2$, $u_D/v<3,5$ms
E_D [MPa]	70	55	45	40	30	25	

5. Example of light drop-weight tester application on the building site

Light drop-weight tester was used to control the quality of compaction of layers built in road embankments (parking platforms) of considerable area and the thickness up to 5 m. The embankments were built of glacial sand-gravel mix from local deposit.

The embankments were formed with layers compacted using vibrating tamping rollers and smooth rollers. Control of soil compaction was conducted currently for each compacted layer of thickness of 0,30÷0,50 m. The test points were located in square grid, side length about 25 m.

The tests of dynamic modulus of soil deformation were conducted using light drop-weight tester type ZFG 01 according to [4].

Comparative tests in 28 points were made in order to calibrate the light drop-weight tester for the most commonly built-in soils. The following geotechnical parameters were determined according to [11]:

- maximum dry density of solid particles ρ_{ds} and optimum water content w_{opt} (using I Proctor's method) (ρ_{ds}= 1,922÷2,179 g/cm^3, w_{opt}= 6,7÷11,1 %),
- bulk density of soil ρ, using sand volumeter (ρ = 1,995÷2,311 g/cm^3),
- water content w, using drying method (w = 2,4÷7,4 %),
- degree of compaction I_s (I_s=0,90÷1,05).

Soils were qualified as sand-gravel mix (P_o) according to [11].

Chi-square test and Kolmogorov-Smirnov test (at significance level α = 0,05) were conducted at the beginning and it was accepted that tested variables had a distribution consistent with normal distribution. Then, based on analysis of matrix coefficients of linear correlation of variables and stepwise regression analysis, it was found that soil water content (in the tested range) did not influence significantly the value of modulus E_D.

The best fitted model was found based on the method of simple regression. The dependency E_D=f(I_S) and the confidence limits of regression line (1) and predicted values (2) for probability 95 % are shown in Fig 6.

The values of dynamic modulus of deformation depend on soil compaction – they increase with increase of the value of compaction degree.

The developed correlation curve was used to current control of compaction quality of built-in soil layers.

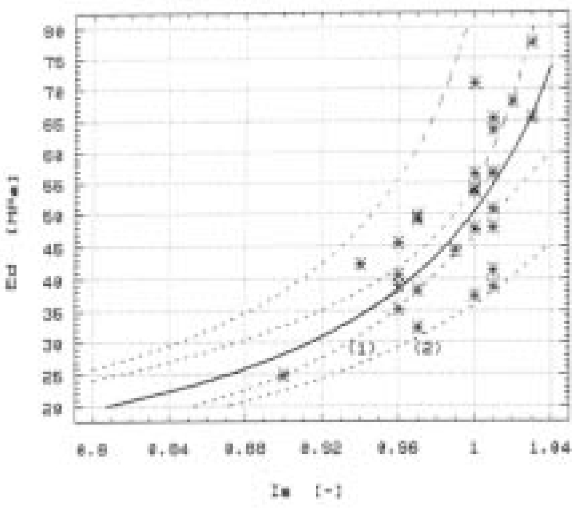

Fig 6. Dependency E_D= f(I_s) for sand-gravel mix: $1/E_D = 0,176–0,156I_s$; r = –0,778; S_{yx} = 0,004

It was decided to accept the following limiting values of modulus E_D:

– when I_s< 0,97 → E_{Dmin} < 40 MPa,
– when 0,97 ≤ I_s< 1,00 → 40 ≤E_{Dmin}< 50 MPa,
– when 1,00 ≤ I_s< 1,03 → 50 ≤E_{Dmin}< 65 MPa,
– when I_s ≥ 1,03 → E_{Dmin} ≥ 65 MPa.

6. Conclusions

Preliminary examinations (calibration of the device) were made prior to application of the light drop-weight tester in field for compaction quality control of embankments. Correlations E_D=f(I_S) and E_D=f(E_1), E_D=f(E_2) were determined for medium sand, and correlation E_D=f(I_S) was determined for all-in aggregate.

Examinations performed by the author showed that there exist dependencies between values of dynamic modulus of soil deformation and values of soil degree of compaction and values of moduli of deformation E_1 or E_2. These correlations can be used during compaction control of embankments under construction. The light drop-weight tester can be applied for quick current control of the quality and uniformity of compaction. This may considerably promote earth works.

Acknowledgements

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