Application of density corrections in case of dynamic falling weight deflectometers

(Background of BC-theory Part 2)

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1 Introduction, antecedents

The application of dynamic measurement methods has spread all over the world very quickly. The method does not require any counterweight, and the measurement is much quicker in comparison to the earlier static method. It has enabled a measurement of the same modelling impact as the effective dynamic traffic loading, on the one hand, and the application of a more accurate and reliable (i.e. more just and economical) qualification mode, on the other hand. Furthermore, it has increased the efficiency and the reliability of the quality control of earthworks and other granular substance layers.

In 2003 the development of a new instrument using a dynamic method started in Hungary, which has been suitable for the simultaneous measurement of the two most important characteristics. The B&C small-plate light falling weight deflectometer SP-LFWD measures the dynamic modulus, as *bearing capacity*, on the one hand, and *the compactness rate* from the compaction curve generated by drops, on the other hand at the same time. The theory and the method of the measurement of the dynamic compactness rate was developed by Andreas Ltd in Europe. The new method became a European standard, and has won several awards and recognition. In 2008 the CWA 15846 European standard was completed, and this enabled the application of the B&C dynamic compactness and bearing capacity deflectometer in Europe and in all countries of the world.

Experiences gained through the application of B&C brought up also such problems which have not emerged so far, or were not known enough. The method of dynamic compactness measurement has been used by fourty deflectometers yet in 28 accredited laboratories of Hungary. Deflectometers are calibrated by the Institute for Transport Sciences, in its calibrating laboratory which was approved by the National Accrediting Agency. Experience from abroad has also been favourable, there has been high interest. The B&C modified light falling weight deflectometer uses, similarly to the static bearing capacity measurement, an underplate loading of p=0.35 MPa, in contrary to the German-type big-plate LFWD (Zorn, HMP) deflectometer, which uses a lower underplate loading of p=0.1 MPa for the determination of the dynamic modulus.

There have been several scientific publications and essays about the application and the analysis of the new method of dynamic compactness measurement. We deemed it necessary and relevant to do an analysis in order to know what kind of impact materials with different densities, the water content and the compactness of the layer might have on the measured compactness and bearing capacity data.

It is of special importance to do the test as regards materials of extreme densities, such as slag, cinder stone, fly-ash, which have to be used as secondary source materials but the qualification (the measurement) of which has not been resolved, yet. These materials are well-known for their badly difficult or imposibly qualification by traditional methods of compactness measurement, and particularly not by an isotopic compactness measurement.

2 Principle of the dynamic light falling weight measurement

The principle of the measurements by LFWD (**L**ight **F**alling **W**eight **D**eflectometer) loading system has been specified in a number of European journals and literature. It is important that the falling weight creates a loading power of 7070 N ± 2% on the power-transmission ball of the plate.

Depending on the type, the size of the plate is D=300 mm or, in case of B&C, D=163 mm, which generates an underplate loading of 0.1 MPa in case of big-plate deflectometers, and of 0.35 MPa in case of the small-plate B&C deflectometer, on the surface of the tested layer. (Hereinafter we refer to the big-plate deflectometer as BP-LFWD, and to the small-plate deflectometer as SP-LFWD.) The dynamic modulus should be calculated from the deformation, i.e. the deflection to be measured under the plate, by the Boussinesq-formula. Thereto, the big-plate German-LFWD applies a fixed Poisson's ratio and a flexible plate multiplier, by indicating a constant value:

$$C_{\mu}=22.5 \qquad E_{vd}= 22.5/\, s_{1a}$$

It is usual to convert the thusly calculated value of E_{vd} into E_2, to which a number of formulas - near unknown regression - are known.

Only the Hungarian solution the B&C modified SP-LFWD is, that works with an alternative Poisson's ratio (μ =0.3-0.4-0.5), which is closer to the measured type of material, as well as with an optional plate mutiplier (c=2 or $\pi/2$) (because of that: $C\mu$ = is not constant):

$$E_d = \frac{(1-\mu^2)\cdot c\cdot p_{din}\cdot r}{s_a} \qquad (1)$$

This calculated values of the E_{d} dynamic modulus fall in a similar measurement range as values of the E_2 static bearing capacity measurement, in which the use of a final loading of p=0.3 MPa under the plate, in case of a static plate measurement, plays an important role. In practice, the E_d limit value is usually raised by a multiplier of 1.2 in comparison to the value of E_2 (despite their conformity).

All dynamic (falling weight) measurements use the act of impulse in order to create a loading on the surface of the earthwork. The links and the weights thereof are known. The purpose of this essay is to make statements as regards possible consequences of the density variation of soil, by looking at and analysing these links, and by revealing the potential correlations thereof.

Mechanism of the falling weight on the basis of the act of impulse

In order to make the term 'falling weight' more clear, it is important to emphasize in advance, about which part of the deflectometer we are talking. We let the weight fall on the plate, that has been positioned on the granular layer, in such a way that it is lead by the quide rod. It follows from this, that the impulse affecting the centralizing ball comes from *the joint mass of the quide rod and the falling weight*, i.e. it moves with a different speed as the falling weight would do in free fall. Before the power-transmission-centralizing ball, the building-up and the decay of the power is regulated by an intermediary spring, the time-demand thereof being regulated in 18msec for both the big-plate BP-LFWD and the small-plate SP-LFWD deflectometer.

By the help of the accelerometer, which is positioned in the loading plate, and the quartz clock with a precision of 0.001 sec, the covered distance and the deflection amplitude can be calculated from the measured acceleration of the plate and the measured time. This contains both the flexible and the remaining deformation. The correlation between the speed of the plate and the impression is obvious, since, in case of LFWD deflectometers, deformation can be determined from the speed of the plate and a constant time (18 ms). If we know the speed of the plate then the impulse can be calculated as the product of weight and speed.

By pulling the release lever, the mass of the falling weight strikes the power-transmission structure of the buffer spring after a free fall of a distance of 65-75cm (depending on the calibration). The impulse, which is transmitted to the centralizing ball, can be calculated from mass and by observing the reduced speed. Although prevailing standards understand the mass of the falling weight under the term ’falling weight’ (it is supposed to be unequivocal), it is after all the joint mass of the weight and the bar + spring that generate an impulse together on the power-transmission ball (Zorn, HMP and B&C), i.e. the loading of 7070 N is generated in this way.

According to the act of impulse, the product of mass and speed is constant (I=m·v), and therefrom, powers arising on some parts of the LFWD deflectometer can be calculated. If we put aside the small friction of the bar then the series of impulses is simple and can be reviewed easily.

Table Nr. 1. Mass of the main parts of the LFWD deflectometer

Mass [kg]	Instrument	
	German-LFWD	B&C SP-LFWD
Falling weight	11.0	11.0
Falling weight + quide rod	15.4	15.4
Loading plate	15.2	14.8

If the masses of the falling weight plus the quide rod, which get onto the power-transmission ball, and the mass of the loading plate are equal then the speed of the plate will be the same, and if they are different then the speed will change in reciprocal proportion to the mass. The B&C dynamic compactness and bearing capacity deflectometer measures and records the deflection speed of the plate by the use of an accelerometer. These data as regards the speed of the plate are recorded in the data logger of the instrument, and can be used afterwards, too. The value of the applied impulse can be calculated precisely at all times from the recorded speed data and the mass of the plate.

Impulse transmitted to the soil, or a granular layer

The final side of the impulse is the soil layer which compacts by the impulse transmitted by the plate; it moves downwards. The soil, depending on its flexibility, generates a recoil motion towards the plate which is reduced by the energy put on the deformation. One part of the energy will be consumed by the remaining deformation, and this is the reason why the recoil motion can never reach the typical value of the infinite rigid modulus, i.e. $h=v^2/2g$. The difference in height, measured in comparison to this, is at the same time proportional to the absorbed energy, and the latter is proportional to the deflection (settlement) under the plate.

Deformation under the plate results in volume contraction and the increase of density. The subplate area and the effective depth are constant, the thusly determined volume can be considered as standard. The mass thereof is what the act of impulse can reckon with.

The soil density to be observed by the act of impulse can be easily calculated by the measurement theory of B&C. The density is directly proportional to compactness (the smaller the compactness is, the smaller the density will be), and it is directly proportional to water content (the lower the humidity is, the lower the density will be). It follows from this that the soil density under the plate at the time of the measurement is

$$\rho_n = \rho_{\mathrm{Pr}} \cdot \frac{T_{rE}\,\%}{100} \cdot \left(1 + \frac{w\%}{100}\right) \qquad (2)$$

where:

- $w\%$ water content during measurement
- ρ_{Pr} the highest dry density according to the Proctor-test, and according to Section 7.4 of EN 13282-2
- $T_{rE}\%$ the on-site relative compactness of the tested layer at a given water content

Since the subsoil can be of different types and the water content may differ, too, values of the recoiling (and of the deformation measured under the plate) will also depend thereon. Accordingly, the measured deflection amplitude will include the impact thereof.

The principle question is whether this measured value has to reach the qualifying limit values of bearing capacity and compactness, or the measured value has to be fulfilled 'irrespective of the material'. Obviously that a given general qualifying limit values (the actually used value may be general, too), not handle them depending on the material (an example might be the limit values of ÚT 2-1.202 ÚME that depend on the material, and refer to the bearing capacity modulus before laying the granular soil).

This way of thinking is further justified by the fact that the covered soil will, in the course of time, approximate to the optimal water content and to a compactness of 100%. If we consider the prescribed limit values as being in accordance with these, then, consequently, only a bearing capacity which corresponds to this should be reached due to the inadequate compactness and to the water content, which differs from the optimal one.

It became obvious that what *we are measuring is a value that includes compactness and water content, and this has to be corrected in order to get a standard result, which we can then compare with the limit value*. Therefore, it is necessary to analyse what kind of impact density will have on the dynamic modulus, or rather, how much and what impact this factor will have on the dynamic compactness rate, and furthermore, how the measured modulus can be corrected in order to enable a comparison thereof with the specified (general) limit value.

Calculation of soil mass with regard to water content and compactness

The height of the recoiling impulse depends on the mass of the soil fragment included in the mechanism. The impact thereof can be best demonstrated in an example including four chosen materials. We do tests on two materials of very different densities, i.e. fly-ash and slag, and on two substances with close density values, i.e. silty sand and fine sand. At the same time, we chose this latter as basis and reference base (Table Nr. 2).

The modified Proctor density of the sand chosen as a reference base, *basis* is ρ_{Pr} =1.65 g/cm^3, which we consider yet as an acceptable building material for the building of earthworks. The optimal water content for this material is w_{opt}=7%, (the interval specified for building-in is ± 3%). Its wet density at the optimal water content is $1.65 \cdot 1.07 = 1.77$ g/cm^3, and this material has a density of $0.95 \cdot 1.65 \cdot 1.07 = 1.68$ g/cm^3 at a compactness rate of 95%. Accordingly, in general, the density of the tested soil can be calculated with formula (2).

Table Nr. 2. Tested materials and characteristics

Type of material	ρ_{dmax}	$w_{opt}\%$	$w_{opt}\%$-3%	$w_{opt}\%$+3%
Fly-ash	1.00	26	23	29
reference basis =fine sand (F Sa)	1.65	7	4	10
Silty sand (siSa)	1.72	11	8	14
Slag	1.92	6	3	9

We formed density values in Table Nr. 3. similarly for all materials, in case of the three water content and four compactness categories.
Initial data of the materials are summarized in Table Nr. 2.

Since the effective depth can be considered as a constant irrespective of the density, we chose a volume equivalent to an effective depth of 25cm in our example. At a lower density the mass thereof will be smaller, and so, the recoil will be lower and the measured deflection amplitude higher. If we want to know the (standard) value as projected on the reference basis, then it is necessary to calculate the impact thereof and to correct the measured value. The same logic refers to the calculation of the impact of the water content.

By setting a limit value for the dynamic modulus we didn't think that is could depend on the impact of water content or that we would make it depend on the compactness. Therewith we also confirmed that the limit value can not cover the same characteristic (and behaviour) in case of different soil types.

Table Nr. 3. Chosen materials and characteristics thereof, ranked by the type of material

Trd (85-90-95) and w (opt -3%, +3%) density calculations											
TrE%=85			TrE%=90			TrE%=95			TrE%=100		
1.07	1.05	1.10	1.13	1.11	1.16	1.20	1.17	1.23	1.26	1.23	1.29
1.50	1.46	1.54	1.59	1.54	1.63	1.68	1.63	1.72	**1.77**	1.72	1.82
1.62	1.58	1.67	1.72	1.67	1.76	1.81	1.76	1.86	1.91	1.86	1.96
1.73	1.68	1.78	1.83	1.78	1.88	1.93	1.88	1.99	2.04	1.98	2.09
w_{opt}	-3%	+3%	w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%
Density ratios											
TrE%=85			TrE%=90			TrE%=95			TrE%=100		
0.61	0.59	0.62	0.64	0.63	0.66	0.68	0.66	0.69	0.71	0.70	0.73
0.85	0.83	0.87	0.90	0.87	0.93	0.95	0.92	0.98	**1.00**	0.97	1.03
0.92	0.89	0.94	0.97	0.95	1.00	1.03	1.00	1.06	1.08	1.05	1.11
0.98	0.95	1.01	1.04	1.01	1.07	1.10	1.06	1.13	1.15	1.12	1.19
w_{opt}	-3%	+3%	w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%
Correction factor (Ed qualifying=Ed measured*correction factor)											
1.65	1.69	1.61	1.56	1.59	1.52	1.47	1.51	1.44	1.40	1.44	1.37
1.18	1.21	1.14	1.11	1.14	1.08	1.05	1.08	1.02	**1.00**	1.03	0.97
1.09	1.12	1.06	1.03	1.06	1.00	0.97	1.00	0.95	0.92	0.95	0.90
1.02	1.05	0.99	0.96	0.99	0.94	0.91	0.94	0.89	0.87	0.89	0.84
w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%

By analysing the mass proportion of a soil of a base and of another density, it can be stated that:

$\frac{G_1}{G_2} = \frac{V_1 \rho_1}{V_2 \rho_2}$, since $V_1=V_2$, $\frac{G_1}{G_2} = \frac{\rho_1}{\rho_2}$, i.e. our calculation does not depend on the effective depth(!). The same logic refers to the change of water content:

$\frac{G_1}{G_2} = \frac{V_1 \rho_1 (1+w_1)}{V_2 \rho_2 (1+w_2)}$, i.e. $\frac{G_1}{G_2} = \frac{\rho_1 (1+w_1)}{\rho_2 (1+w_2)}$, i.e. volume can be isolated from the equation.

Based on the above mentioned, the density and water content correction will be as follows:

$$\varsigma = \frac{\rho_1 (1+w_1)}{\rho_2 (1+w_2)} \qquad (3)$$

3 Correction of the dynamic modulus, qualifying dynamic modulus

Calculation of the dynamic modulus (see formula (1)) occurs on the basis of the measurement of the (s) deflection amplitude. If the density of the measured material changes then so does the deflection amplitude, and accordingly, the dynamic modulus, too. This means that the dynamic modulus is proportional to density, which, at the same time, depends on the density and the water content of soil.

From the suitability test we know the highest dry Proctor-density and the optimal water content of soil. Furthermore, we know the water content tolerance for building-in. Water content has to be measured by all compactness site measurements, and so, these data are available. Where dynamic bearing capacity is measured by the SP-LFWD deflectometer, compactness data can be always available, too. By using the B&C instrument, measured data on the bearing capacity are always recorded for all dynamic compactness measurements because they are measured in one series of measurements, together with compactness. The compactness rate is calculated from 1 to 10 (a maximum of 18) drops, and dynamic modulus from the average of 4-5-6 deflection amplitudes.

By using the correction factors calculated in Table Nr. 3. we demonstrate that the measurement result E_d=40 MPa looks as follows (Table Nr. 4) for materials included in the examination (the series, by order, includes fly-ash, fine sand, silty sand and slag), after corrections due to compactness and water content.

Table Nr. 4. Standard qualifying dynamic modulus of tested materials in case of a basis of E_d=40 MPa

Edmin qualifying, standard value: Ed measured = 40MPa* correction factor												Substance
65.9	67.5	64.4	62.3	63.8	60.8	59.0	60.4	57.6	56.0	57.4	54.7	Fly-ash
47.1	48.4	45.8	44.4	45.7	43.2	42.1	43.3	41.0	40.0	41.2	38.9	Sa, Basis
43.5	44.7	42.4	41.1	42.2	40.0	38.9	40.0	37.9	37.0	38.0	36.0	Sisa
40.8	42.0	39.7	38.6	39.7	37.5	36.5	37.6	35.5	34.7	35.7	33.7	Gr
w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%	w_{opt}%	-3%	+3%	w%
TrE%=85			TrE%=90			TrE%=95			TrE%=100			TrE%

We calculated the relative ratios from the measured values. We indicate this as a typical range for actually tested cases (which is valid for materials with a variation of both extreme and non-extreme densities) in Table Nr. 5.

Table Nr. 5. Typical relative variation of the extreme values of tested materials

for all the four tested materials	Average	100%
	Min	74%
	Max	148%
	Standard deviation	21%
for ref. base and silty sand	Average	100%
	Min	86%
	Max	116%
	Standard deviation	8%

By summarizing the analysis on dynamic modulus, it can be stated that by examining materials of extreme densities (that are used in the construction practice), the correction factor of the dynamic modulus will modify the modulus value measurably, and the correction factor will have a value between 1.69 and 0.84 (!). Correction cannot even be avoided in case of a smaller density variation and an allowable range of water content, which shows a relative variation of -14% to +16% in a compactness range of 85-100%, and accordingly, in the whole measurement practice. *Based on the above mentioned every measured dynamic modulus needs to be corrected in every case in order to* *enable a correlation thereof with the limit values,* because the variation might be considerable. The correction thereof is usually calculated as follows:

$$\varsigma_E = \frac{\rho_1(1+w_1)}{\rho_2(1+w_2)} \cdot \frac{100}{T_{rE}\%} \qquad (4)$$

If we want to determine dynamic bearing capacity exactly (especially if we want to examine its correlation with the value of E_2 of the static bearing capacity), then conclusions and correlations can not be considered acceptable without some correction. It's only natural that statements made here are to be adapted to all dynamic deflectometers, such as the big-plate LFWD and FWD. By the correction thereof (by introducing the term 'qualifying dynamic modulus') significant progress can be made by the review of correlations. ***Accordingly, it can be stated that the exact value of the dynamic modulus can not be determined without the knowledge of density*** *(compactness rate, water content and Proctor-density).*

4 Correction of the dynamic compactness rate

Based on the previous train of thought, the measured deflection amplitude can also be corrected due to the variation of the values of water content and density.
Since int he calculation of the relative compactness rate we take the deflection amplitude differencess into account, their effects have to be defferent as well. The situation is different in case of a correction due to the variation of water content, because there will be only a small change in the value of T_{rw} around w_{opt}.

We performed analysis of the dynamic compactness rate for materials which had been selected for the present test. These are presented in Table Nr. 6. Here, the multiplier can be transposed before D_m in the formula.

$$T_{rE}\% = 100 - \varphi \cdot D_m \quad \text{és} \quad T_{rd}\% = T_{rE}\% T_{rw} \qquad (5)$$

From the chosen materials we selected data series for examination. Here we examined how the calculated on-site relative compactness rate will change by a chosen continued proportion, i.e. ζ=0.85–0.9–0.95–1.0–1.05–1.1–1.15, beside a correction factor that reckons with the impact of water content and density (Formula (3)).

Table Nr. 6 - Sensitivity of T_{rE}% to the correction of density

ζ	TrE%	56th measurement	62nd measurement
0.85	95.8	92.0	90.3
0.90	95.6	91.6	89.7
0.95	95.3	91.1	89.2
1.00	**95.1**	**90.6**	**88.6**
1.05	94.8	90.2	88.0
1.10	94.6	89.7	87.4
1.15	94.3	89.2	86.9

ζ	Variation	56th measurement	62nd measurement
-0.15	0.70	1.40	1.70
-0.10	0.50	1.00	1.10
-0.05	0.20	0.50	0.60
0.00	**0.00**	**0.00**	**0.00**
0.05	-0.30	-0.40	-0.60
0.10	-0.50	-0.90	-1.20
0.15	-0.80	-1.40	-1.70

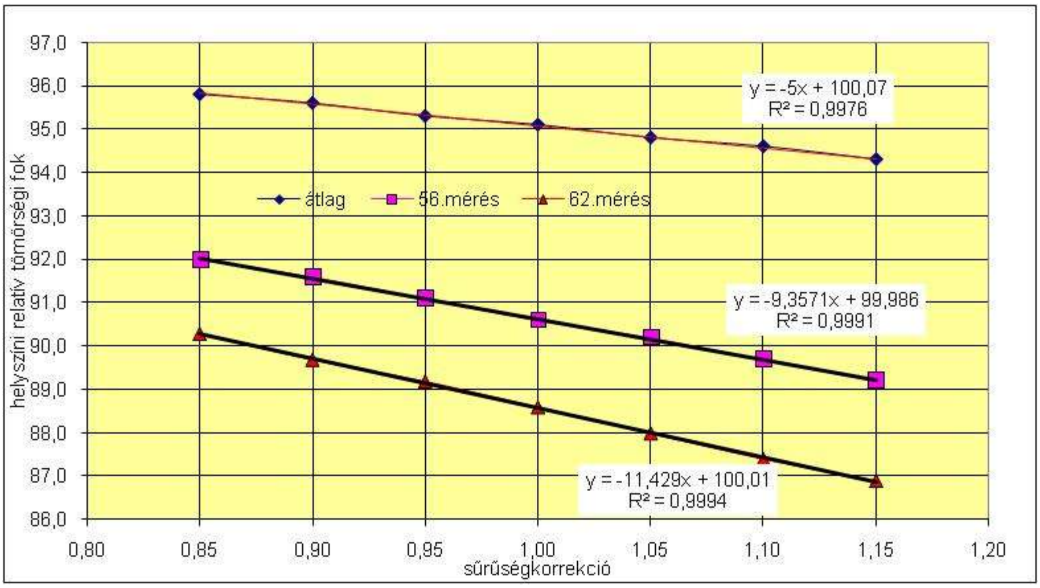
Table Nr. 6. presents the examination of elasticity of 25 measurement data series by 10 to 18 drops, by the use of the B&C deflectometer. Results were processed in such a way that density corrections were also considered by the determination of deflection amplitudes, the on-site relative compactness rate was recalculated, and the variation thereof was determined. For all corrections we calculated the average of the values of the on-site relative compactness rates of 25 measurements, and we took out the 56th and the 62nd measurement, where the on-site relative compactness rate turned to be the lowest, and accordingly, the most sensitive.

To take an example, the T_{rE}% average of 25 measurements changed from 95.1% to 95.8% at a density correction factor of 0.85. Since compactness rates must be rounded to whole numbers, ***it is to be stated that variation of the dynamic compactness rate in case of traditional materials moves around 1% because of the correction of density, which is not significant.***

Figure 1 shows the impact of the correction of density on the average as well as the on-site relative compactness rates of the 56th and 62nd recorded measurements. These are linear, but the slope thereof is different, and the correlation is as follows:

– average of 25 measurements $T_{rE}\%= -5\zeta + 100$
– at the signalled 56th measurement $T_{rE}\%= -9.4\,\zeta + 100$
– at the signalled 62nd measurement $T_{rE}\%= -11.4\,\zeta + 100$

Figure 1. Dependence of the T_{rE}% relative dynamic compactness rate on the correction of density



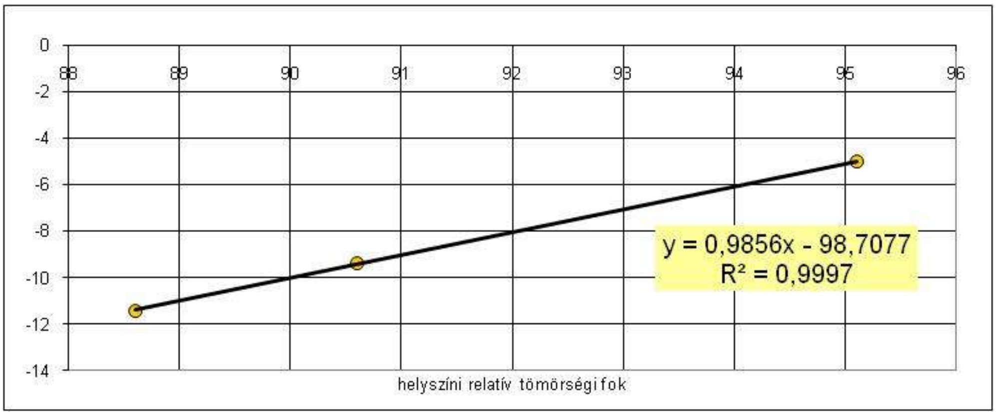
Helyszíni relatív tömörgési fok = On-site relative compactness rate TrE% (%)
Sűrűségkorrekció = density correction

It results from this that the slope (m) of the correlation between the on-site relative compactness rate and the density correction depends on the relative compactness rate, too (which can be calculated). By analysing the correlation between the slope (m) and the on-site relative compactness rate we arrived at the following result:

$$m = 0.986 \cdot T_{rE}\% - 98.7 \qquad (R^2=1) \qquad (6)$$

According to the above mentioned, in case of traditional materials, density will have only a marginal impact on the relative compactness rate, but in case that high accuracy is requested, it can be calculated easily. In fact, it has significance during the use of fly-ash in the construction industry, because the density thereof is very low.

Figure Nr. 2. Dependence of the slope of correlation on Tr_E%



Helyszíni relatív tömörgési fok = Relative compactness rate on-site (%)

To take an example, let's look at the result of the dynamic compactness and bearing capacity measurement that was performed by the H-TPA laboratory, on the fly-ash embankment of the road section 21+875 km of the M35 highway, marked as 1m.
Measured data were as follows. E_d=18.9 MPa, T_{rE}%=91.7%, w_t=38.3%. The wet density is 1.26 g/cm^3, Proctor ρ_{dmax}=0.91 g/cm^3 and w_{opt}=26%, T_{rw}=0.985. Note: static bearing capacity was E_2=37 MPa, E_{2v}/E_{1v}=1.6 and with a sampling cylinder $T_{r\rho}$=98.3%.

Calculations

- density correction by formula (3) ζ= (0.91 · 1.26)/(1.65 · 1.07)=1.147/1.766=0.649
- calculation of the qualifying dynamic compactness rate:
  m= (T_{rE}% · 0.986)–98.7= -8.3 → T_{rE}% qualifying = - 8.3 · 0.649 + 100=94.6%
  T_{rw}=0.985 → T_{rd}% qualifying = T_{rw} · T_{rE}%= 0.985 · 94.6 = **93.2% > 90%** limit value
- qualifying dynamic modulus
  E_d qualifying = E_d · (1/ζ) · (100/T_{rd}%)
  E_d qualifying = 18.9 · (1/0.649) · (100/93.2)=18.9 ·1.54 ·1.07 = **31.1 MPa ≈ E2v**

It follows from this that, according to the examination of the impulse, the impact on the dynamic compactness rate is irrelevant. This means that, in case of generally used materials, density has no significant impact on the compactness rate. Just to note, we have already made similar experiences during the analysis of the Proctor-test, where we examined the value of Φ, both at the level of theory and of practical use. In case that fly-ash is used, the measured on-site relative compactness rate has to be corrected, too, but the impact thereof is not so significant, either, that it could not be neglected for safety.

5 Summary

Typically, there is no specification on dynamic moduluses measured by the German-type LFWD deflectometer, and it is not specified, either, how parallel results, averages should be determined. There is only one test for the determination of the result, and so, data are especially sensitive. The specifications CWA 15846 (and ÚT 2-2.124) state that in case of measurements by B&C, the standard dynamic modulus must be determined by two measurements within one metre, this must be averaged then, and so, it seems to be less sensitive.

All dynamic measurements use the act of impulse in order to create a loading on the surface of the earthwork. The links and weights thereof are known. The purpose of this essay is to make statements as regards possible consequences of the density variation of soil, by looking at and analysing these links, and by revealing the potential correlations thereof. We deemed it necessary to do an analysis on the impact and on the correlation of materials with different densities, or rather - in case of different substances - of different soil conditions, but especially, of the dynamic modulus measured under extreme circumstances. Is it necessary or is it possible to make corrections there? It is of high importance to mention slag, cinder stone, fly-ash, stablization by fly ash and calcareous soil stabilization which, due to their density or material, can be measured only hardly or not at all by the isotopic deflectometer as secondary source materials or as stabilizing technologies. Because of that, it is difficult, or even impossible to qualify them by the traditional methods of compactness measurement.

The essay proved that, ***by the determination of the dynamic modulus, it is not possible to provide a standard qualifying result without the exact knowledge of density, water content and compactness rate.*** If we want to determine dynamic bearing capacity exactly, or even examine the correlation thereof with the E_2 value of static bearing capacity, then conclusions and correlations will not be reliable without these corrections. The higher the variation from the selected basis is, the rougher corrections will be. In case of calculations of dynamic moduluses, corrections must be observed in all cases. Alone as a result of this, measured values might deviate by 10 to 20% from the standard qualifying value, not to mention the requirements on bearing capacity limit values, which are uniform and not categorized by materials.

It's only natural that statements made here can be adapted to *all dynamic deflectometers*, such as the big-plate LFWD and the FWD. At the same time, through the correction thereof, significant progress can be made by the review of correlations.

Efforts that aim at a qualification without the measurement of the dynamic bearing capacity and without the determination of compactness cannot be supported by this theory: it is essential to know the compactness rate in order to be able to convert the measured dynamic modulus into a standard qualifying modulus. The essay confirmed that in reality it is enough to set one limit value for the dynamic bearing capacity in specifications and tenders, there is no need to specifiy them by each type of material, in case, that measured values are corrected onto standard qualifying values.

It is to state that the exact value of the dynamic bearing capacity can not be determined without the exact knowledge of compactness rate, water content and density.

By the use of the B&C deflectometer it is very easy to make corrections due to the variation of compactness and water content, because all needed data are recorded and calculated as an input: soil, Proctor, optimal and measured water content, and compactness of the given material. ***No doubt that, on the basis of the present tests, it is advantegous and highly recommended to apply and to make use of the B&C deflectometer in an ever wider range, and in particular, on frequent sites with high requirements for quality.***

Correction of the measured dynamic modulus must be performed in case of so-called big-plate BP-LFWD instruments, which have a plate diameter of D=300 mm, too, because without a correction, single results will not be suitabe for producing standard qualifying results with an adequate accuracy. The issue of correction cannot be avoided even by the standardization of standard results obtained from several measurements (as it is in case of B&C). One cannot avoid correction even by this, either.

It proved to be true that the application of the B&C deflectometer will bring adventages even if only the bearing capacity, and not compactness has to be determined. The essay brings up the necessity of measuring compactness together with the dynamic modulus in all cases. With the use of the B&C deflectometer, this means in practice 6 drops instead of 10, and so, everything can be settled easily, without defining any pre-conditions.

The second part of the essay proved that there is no need for correction with respect to the **on-site relative dynamic compactness rate**, T_{rE}% (except for fly-ash), since the varitation of density has only a minimal impact on the result. The impact is irrelevant because calculations only include the variation of deflection amplitudes, i.e. the remaining deformation.

The knowledge of both the bearing capacity and the compactness is essential for civil engineering geotechnics, despite their impact on each other. Even if the limit value for bearing capacity is fulfilled, it can come to post-compaction, deflection, or, as the present essay proved, it may happen that while the measured result seems to meet the limit value for bearing capacity, in reality, it is incorrect. Based on the present essay, the necessary corrections can be made, and the standard ***qualifying result*** can be calculated in a reliable way. This will have to reach the prescribed limit value for bearing capacity then.

Quality control and quality certification today can not go without adequately exact measuremets. Work that may be qualified as wrong due to the processing of measurement errors has to be avoided (because of unnecessary repair costs), and the same refers to a quality that has been ranked as good but is in reality inadequate. Earthworks, that do not meet the requirements, lead to defects, which will always and visibly pay off. Additional correction of an improper foundation is difficult, to say the least, it's a nightmare. Unfortunately, one can see deformation and deflection on completed highways very often, even if they have all met the qualifying standards.

Continuous improvement of the B&C deflectometer and theory enable a correct quality certification, thusly avoiding controversy on the compactness rate based on a reference density. Furthermore, it makes causes of possible deviations clear. The present technical analysis confirmed the highly favourable features of the B&C deflectometer, and so, we recommend its wide application warmly.

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