Analysis of Nuclear and the SMART-BC Dynamic Compactness Rate's Deviation on Trial-sections

(Background of BC-theory Part 6)

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1 Introduction

Experts around the world have been concerned about the avoidance of settlement on public utilities, railways, public road embankments and waterway construction works for a long time, by looking for more efficient methods for the process, the determination and the quality of compaction. One can see this effort best in the limit values, that have become more and more stringent, which can be seen also in the increase of the number of regulations as regards both the compactness rate and the bearing capacity. It is compactness and bearing capacity that are the most important parameters to be observed at earthworks and soil foundations during construction. During the certification of the construction quality of our civil engineering objects it is the accuracy. The precision of applied measurements is crucial for the behavior during their life-time. One reason for the settlement might be improper compactness measurement accuracy.

The determination of the measurement accuracy of various compactness test methods should occur as a part of trial-section, which has been specified in Section 4.4.3 of the Hungarian Road Specification ÚT 2-1.222:2007 (EN 1997-1 Eurocode 7) 'General geotechnical rules of building roads and highways', under 'adjustment and calibration of planned measurement methods'.

In our analysis we present measurement results made during the test compactions of the completed section of M7 motorway section and of M6 motorway section, as well as the analysis of standard deviation of compactness measurements between the traditional isotopic and the BC new dynamic compactness measuring methods. The analysis is also justified by the fact that it has become necessary to use second source materials, like the blust furnace slag and the fly ash more and more often, and these materials cannot be qualified well by traditional methods of measurement.

The new dynamic compactness measuring method makes it possible for us to measure the compactness rate as calculated from a compaction deformation, and this eliminates density inhomogeneous. The expansion of this method has raised a demand for the analysis of measurement accuracy, on the one hand, and for the determination of possible fields of application, on the other hand. The appearance of any new method has its advantages and disadvantages, and to see these, a realistic technical evaluation is crucial.

It is possible to compare the range and the accuracy of results measured by different measuring gauges if we do an analysis of standard deviation of measured results of given materials, which we won from trial-sections with the given measuring gauges, by mathematical-statistical methods.

2 Theory of Dynamic Compactness -rate

In the Civil Engineering, we use two important quality parameters of earthwork's qualification, the Bearing Capacity (E2v) and the Compactness (DPr% or Compatness-rate).

The traditional way is to determine the compactness rate by isotopic (Nuclear) or sand-filling (Sand Cone) test, and comparing the field densities to reference (proctor) densities. But in 2003 a new theory was born in Europe, which based on a deflection-curve, measured 10-18 blow of light falling weight. In this way the portable (and modified) LFWD may use to measure not only the dynamic modulus, but the dynamic Compactness rate also.

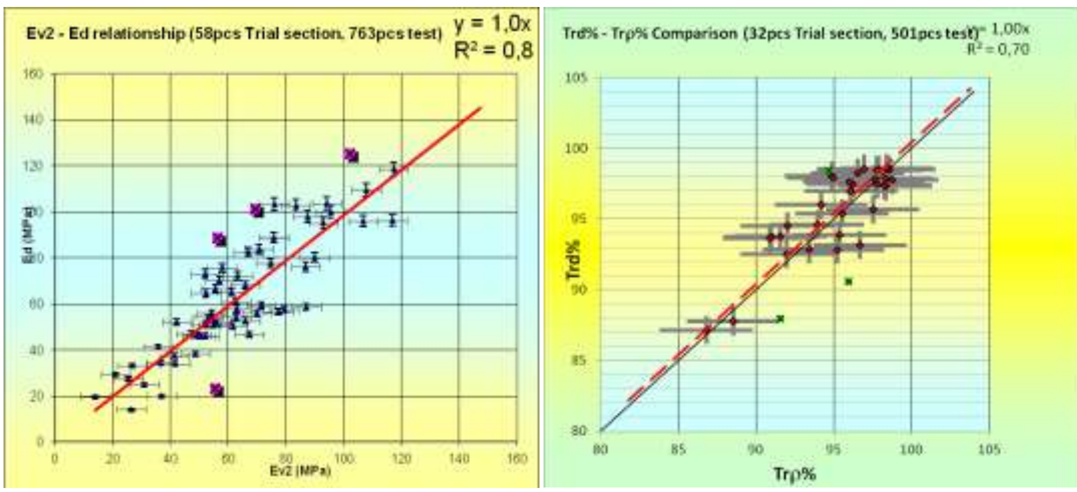
This new adaptation of LFWD tester measured two parameters at the same time, the modified Compactness-rate% from the deformation curve gain from 10-18 drops and the Dynamic Modulus - using the well known Light Falling Weight (LFW) loading system with a small modification. The D=163mm diameter small-plate deflectometer allows to reaching 0.35MPa stress under the plate, which providing suitable compaction work for an "on-site Proctor test" called BC (Bearing Capacity and Compaction-rate Tester). This press similar to the static load plate test and gives similar measuring range.

This new Small-Plate LFWD is very different to the other earlier ones (Zorn, HMP, Loadman, Dynatest, Prima) which allows under plate press p=0.1MPa and use D=300mm plate diameter. This method has spread all over the world very quickly. The method does not require any counterweight – like static one, 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 (e.g. more just and economical) qualification mode, on the other hand. Furthermore, it has increased the efficiency and the reliability of the quality control of pavements, earthworks and other granular substance layers.

For example the TPBF-StB8.3 using fixed c=2 Boussinesq plate-multiplier (flexible) and 0.5 Poisson-ratio - from this comes the Cμ=22,5 and formula E_{vd}=22,5/s (N/mm^2). The average settlement amplitude (s) must be determined of the second series (from the 4-5-6 drops). Parallel examination is not applied. The main questions are: why not can be applying the real Piosson ratio as an input, if we know the soil type? Why we use the flexible Boussinesq plate-model multiplier (and not Pi/2 like in the static plate test). Why we use the low p=0.1Mpa press under the plate? This old LFWD method suitable to determine only the bearing capacity – may be say – tests from the last century, and need to revise.

BC method allows You to choose between the input parameters (Poisson-coefficient, Boussinesq plate-factor) and the press under the disc is 0.35 Mpa (near the static test). In case of the suggested BC-tester practically one test can give an information on both the compactness-rate both the bearing capacity. The theoretical background of the calculations was described fully at first in the article of *19th International Conference on Soil Mechanics and Geotechnical Engineering, presented in Seoul 2017.*

Based on database measured on M43, M7, M6 Hungarian motorways trial sections 10-15 years ago, ALLTEST Ltd analyzed the relationships again. They involved 58 trial sections, on different soil, all of them 763 measured data point. The investigation shows that the Plate-test static modulus $E_{2v} \cong E_d$ or $E_{2v}=1.0*E_d$ (R^2=0,8), so the approximately the same value like the BC's E_d value. The regression degree is rather good, which means that CWA15846:2015 may be a useful standard and BC device in civil engineering practice.



1. Figure Static Plate E2v-Ed dynamic Modulus and Nuclear Compaction-rate –Trd% dynamic Compactness regression (CWA 15864)

Number of trial section and investigation was built in Hungary between 2006-2016, before worked out this regressions and conversions.

The SMART-BC with a smartphone application (EU and state-funded project), which is under developing now in ALLTEST Ltd, will also provide more information near the measurement results from the regression calculations.

The estimated settlement of the embankment body (compactness rate changes from 90% to 100%): $\Delta S=\Delta T_{rd}\% /0.475$ (mm/25cm layer) Example: if the TrE% now 90.0% and after ten years will be 98.0% then $\Delta S=\Delta T_{rd}\% /0.475$ 16,8mm/25cm, means for 6m high embankment self-compaction will 6*4*1.68cm=40,3cm as a backfilling- without subsoil consolidation.

Dynamic Bedding Coefficient from BC test**:** used in industrial flooring $c_d = 0.0761 / S_{0a}$ (N/mm3) where S_{0a} = (drop No. 1 + 2 + 3) / 3 (mm) Regression R^2=0,92. Example: S_{0a}=1,33mm then c_d=0,0761/1,33mm = 0,06N/mm^3

E_{vib} (BOMAG) from BC dynamic test: $E_{vib}=0,5E_d+57$ (R^2=0,93) E_{vib} CCC-method (University of Ljubljana Prof Petkovsek). Example: if E_d=86,8MPa then E_{vib}=100,4Mpa

German LFWD E_{vd} from BC dynamic test: $E_{vd} = 0{,}42E_d$ (R^2=0,90), or $E_{vd} = 0{,}69E_{dend}$ (R^2=0,91) the smaller. Example: E_{vd}=0,42·E_{dEnd}=0,42·131,6=55,3MPa; E_{vd}=0,69·E_d=0,69·86,8=59,9MPa; the smaller: E_{vd}=55,3MPa

CBR% calculation from BC dynamic test results: From the well-known formula E_{2v}=10*(CBR%$^{2/3}$) may calculate from the BC test result: CBR%=(Ed/10)$^{3/2}$ Example: if BC beraing capacity is Ed=30Mpa, then CBR=5%

3 Determination of compactness measurement's standard deviation

There are no studies, calculations on the standard deviation and reliability of the LFWD measurement, so we have studied the BC (Small-Plate LFW), and compared to the nuclear method. The traditional way of compactness test in Europe is the wet density measurement, where the calculated the dry density value and compared to the laboratory reference dray density, expressed as a percentage (or only a decimal number). Since wet density and water content are both measured on site, there are a total of three measuring accuracies that cumulate in the isotopic compactness rate: the measuring accuracy of Proctor-test, the on site water content and the wet density.

3.1. Standard deviation, range and accuracy of the nuclear test

Isotopic density measurement is one of the most widespread method. In such measurements gamma-rays, that are directed into and passing through soil, are sensored by a detector, and the number of impulses counted during the measurement duration are proportionate to the wet density of soil. For the determination of the compactness rate, it is necessary to measure the water content of soil. If You have a reference density to which the dry density of the site can be compared, You know the actual compactness rate on filed. In Europe it is usual to apply the „modified" Proctor density specified in the standard EN 13 286-2, using as a maximum dry density – we do also.

Measurements were carried out in needle probe mode. By shaping a probe hole next to the prepared surface of the trial-section construction, at a point that is unimportant to compaction area, the method used for the determination was as follows: by locating the instrument, the probe was pull down 20 cm deep. By turning and stop it into a *random direction*, 21 measurements had to be performed, We calculated the wet volume densities (ρ_n) and the related water contents (w%) had to be recorded.

From the result series we calculate the statistics (average value, standard deviation, maximum, minimum) of the fundamental set, with a special own theory. Since the measurement results are *statistically independent from each other (in this case)*, we can presume that at one single measurement we could have measured any three elements of the data series - like a standard measurement. Accordingly, from the result series we can form a triple moving average line, and so, we will come to a density value measured from three-three partial results. We call this a "group result". From each of the group results, the statistics (average, standard deviation) of the given fundamental set (wet density, dry density) can be calculated.

We calculated the measurement accuracy with a reliability of 90%, (α=0,1 or p=0,9) by the Student's distribution used for small-sample statistical analysis (for both density and water content), with the following formula. The expected value (M), the measurement range and the accuracy are as follows:

$$\Delta = \pm \frac{tS}{\sqrt{n}}, \quad \text{the expected value: } M = X \pm \Delta \qquad \text{where:}$$

Δ – the range from the expected value, as the accuracy range of measurement
S – standard deviation of the measurement fundamental set
n – sample number 3, because an isotopic measurement is averaged from partial results measured from three different directions, in accordance with regulation in Hungary (ÚT 2-3.103)
t – 2.92 at a Student's coefficient $\nu = (n\text{-}1) = 2$ degree of freedom and $\alpha = 0.1$ significance level
X - average value of measured test results (middle of expected range)

By this formula we calculated accuracies of the every triple result group of water content and wet density (Δw and $\Delta\rho_n$). Besides, we calculated the values of ρ_{wmin}, ρ_{wmax} and w_{min}%, w_{max}% for each partial result.

$\rho_{wmin} = \rho_{average} - \Delta\rho_w$,
$\rho_{nmax} = \rho_{average} + \Delta\rho_w$,
$w_{min}\% = w_{average}\% - \Delta w\%$,
$w_{max}\% = w_{average}\% + \Delta w\%$

By varying the two densities and two water contents we come to four dry densities by using the usual (and generally applied) formula:

$$\rho_{di} = \frac{\rho_{wi}}{(1+w_i)}, \text{ or } \rho_{di} = \rho_{wi} \cdot \frac{1}{(1+w_i)} \rightarrow where\ w_i = \frac{w_i\%}{100}$$

3.1.1 Test accuracy of the nuclear measurement without the Proctor-test's fault

Values of the four random dry densities were one by one correlated as a percentage to the maximum dry density of the tested material, which served as a reference density (the maximum density determined by Proctor-test), and by this, we came to the varieties of the compactness rate. We chose from these varieties the maximum and the lowest values, and by using the formula we calculated the range. $\Delta = (T_{r\rho max}\% - T_{r\rho min}\%)$

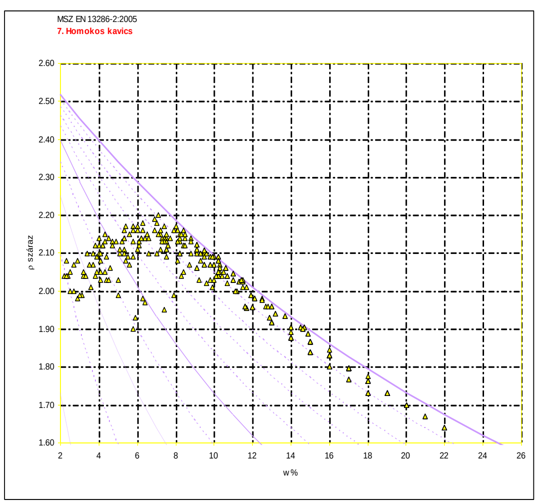


Figure 1. Repeatability of Proctor-density test (ring test with 14 lab)

We defined half of this range as an accuracy, i.e. accuracy to be reached by the given measurement, among given circumstances, and with a given type of material. It does not take the reliability, the accuracy of the reference dray density into consideration.

3.1.2 Accuracy of the nuclear density-test with the impact of the Proctor's reliability

By observing the measurement accuracy, the fault of the reference density, ρ_{dmax}, that has been determined by the Proctor-test, the accuracy of the isotopic measurement becomes worse. One can calculate the measurement accuracy of the reference density by performing and analysing several Proctor-tests, but this would be a time-consuming task. Some years ago, we analysed the results of a Proctor round tests. You can see the repeatability in sample sandy-gravel (Figure 1).

It is a well-known fact that the accuracy of Proctor-density might even reach the value of +/- 0,1g/cm^3, which has yet raised controversy between the contractor and the control laboratory. In this analysis we accepted that the allowed tolerance of the maximum density of Proctor-test should be much less, i.e. ± 0,025 g/cm$^{3.}$ It is usual in practice to accept this limit value, not to take a new Proctor from the soil sample for our isotopic measurement. Since wet density, water content, as well as reference density accuracies, ± deviations have to be observed one by one, in different standard deviations, we come to 228 (19x4x3) pc compactness rates.

From these compactness rates we calculated the range $\Delta = (T_{r\rho max}\% - T_{r\rho min}\%)$, or to be precise, half of this as a measurement accuracy to be reached by the given method of measurement. It is important to note that for the measurement of standard deviation, the average of $T_{r\rho}$% is indifferent, it is enough if the range is between $T_{r\rho}$%=90-100%.

3.2 SMART-BC Dynamic compactness measurement

The measurement principle of the BC dynamic compactness deflectometer is something totally new: it doesn't determine the compactness rate from the reference density, but from the compaction to be reached by the dropped load, from the deformation curve. The dynamic compactness rate, T_{rd}%, is the product of the 'on-site relative compactness rate', T_{rE}%, and the moisture correction coefficient $T_{rw.}$ According to the theory T_{rd}=1-ε (where =Δh/h) if we take a M_{dry}=constant model (see the theory).

The B&C deflectometer measures the compaction curve at the given (field) water content, i.e. it determines the field relative compactness rate T_{rE}% with 10-18 drops. It is as if we performed on-site Proctor-compaction at a given water content. If there is no compaction (no deformation) as a result of the drop series then the on-site relative compactness rate will be T_{rE}% = l00%. The on-site relative compactness rate characterizes the efficiency of the compaction rolling, and thus, it is a very important parameter of BC measurement.

The moisture correction coefficient T_{rw}, is a material characteristic that is determined in the soil-laboratory by modified Proctor test; it shows the dependence and the behaviour of soil by wet content. It is nothing else but the normalized form of the Proctor-curve (dray densities divided by the maximum dray density). $T_{rw} \equiv 1.0$ at the optimal water content, and < 1.0

therefore to the right (wet) and to the left (dry) branch. The lower the radius of the curve is, the more sensitive the soil will be by the moisture. If the water content of soil equals to w_{opt}, then the measured on-site relative compactness rate, T_{rE}%, coincides with the dynamic compactness rate, T_{rd}%. Nevertheless, the water content usually different, and that's why it has to be corrected by the moisture correction coefficient. It is proven that the dynamic compactness rate is equal to the isotopic compactness rate derived from the density ratio.

The biggest advantage of the SMART-BC dynamic compactness measurement is that it divides and measures separately the two main characteristics which are in practice very important: the adequacy of the rolling work and the adequacy of the water content of the used material. T_{rE}% characterizes only and solely the quality of the rolling compaction (at the given on-site water content) while T_{rw} shows only the behaviour of the material by the moisture. It follows from this that with the SMART-BC deflectometer one can only measure T_{rE}% on site, while the T_{rw}-curve needs to be determined from the Proctor-tests during the qualification test.

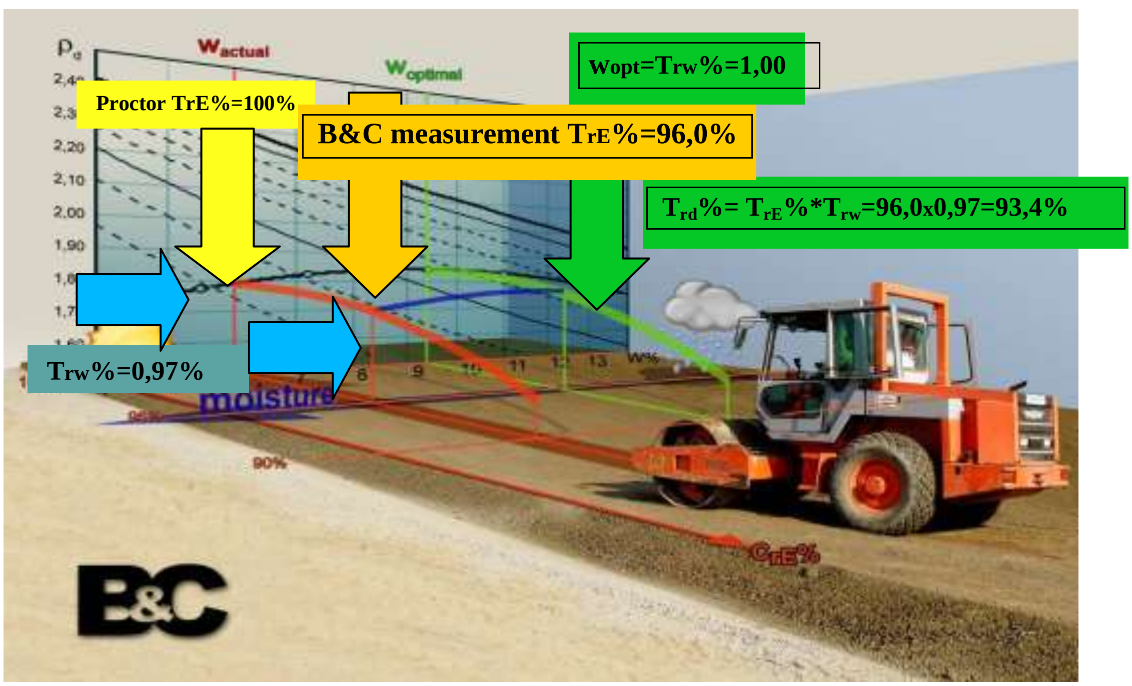


Figure 2. Introduction of the dynamic compactness measurement's theory

3.2.1 Standard deviation, range and accuracy of the dynamic compactness measurement without the Proctor-test's fault

In the series of SMART-BC tests, during the test compactions, we used 1m^2 for measurements in order to determine the accuracy of BC Small-Plate LFW dynamic compaction, in such a way, that we did three measurements next to each other, in three rows. This means that there were a total of nine measurement results. According to the relevant regulation CWA 15846 (Hungarian

MSZ15846 and ÚT 2-2.124), the standard result needs to be formed from the result of two partial measurements within one metre. Therefore, we calculated the partial results from a randomized measurement data series by a double moving average, and we did the same way by calculating both the on-site relative compactness rate T_{rE}%, and the standard deviation thereof.

We calculated the standard deviation, the range, and the accuracy of the measurement with a reliability of 90%, by the Student's distribution used for small-sample statistical analysis with the following formula. The expected value, the measurement range and the accuracy are as follows:

$$\Delta = \pm \frac{tS}{\sqrt{n}} \quad \text{the expected value: } M = X \pm \Delta$$

where:

S – standard deviation of the measurement set
n – 2, because a B&C measurement is averaged from two partial results
t – 3.078 at a Student's coefficient $\nu = (n-1) = 1$ degree of freedom and $\alpha = 0{,}1$ significance level
X - average value of measured test results

Since here we didn't observe the impact of Proctor-curve $T_{rd}\% = T_{rE}\% \cdot T_{rw}$, $T_{rw}=1$, $T_{rd}\% = T_{rE}\%$.

3.2.2 *Accuracy of the dynamic compactness measurement with the Proctor's reliability*

The result of the dynamic compactness measurement is affected rather by the curvature of the Proctor-curve through the value of T_{rw} than by the absolute value of ρ_{dmax}. During our examinations we assumed that the water content of the built in test material is in the range of w_{opt} ± 3%, by keeping to the usual conditions of requirement and tender, and we considered the fluctuation thereof as an accidental factor. Our choice was further confirmed by the fact that during the Proctor-test a deviation of the water content of $\Delta w \approx 3\%$ needs to be coupled with a variation of ± 0,025 g/cm^3, and this means, that it coincides with our assumption at the analysis of the standard deviation of the isotopic measurement.

We calculated the T_{rw} value from the suitability (Proctor) test that had been done in the laboratory, as depending on the water content stages. Then we calculated the moisture correction coefficient by using a stage of Δw=1% for the water content range w_{opt} ± 3%. We assumed that these would have a randomized forming process during the B&C measurement. We calculated the 27 dynamic compactness rates by the variation of the 9 standard relative compactness rates and the 3 moisture correction coefficients. Similarly as earlier, we calculate the range

$$\Delta = (T_{rdmax}\% - T_{rdmin}\%)$$

thereafter, and half thereof made out the accuracy to be reached with the given measurement type, on the given material, at the given thickness. We calculated the accuracy of the measurement with a reliability of 90%, by the Student's distribution used for small-sample statistical analysis, by observing the deviation of T_{rw} ± 3% as regards the given range of water content. Since $T_{rd}\% = T_{rE}\% \cdot T_{rw}$, we came to different values by a water content of ± 3%.

The mathematical-statistical analysis prepared in this way made out nine pages calculations for each trial-section.

4 Comparison of standard deviation range and test accuracy

Results on the measurement accuracy processing, that we've got from the range calculated on the basis of the standard deviations, on the M7 motorway, where accredited laboratories did a total of ***19 trial-sections*** by the method described above, are presented in Table Nr. 1.

The two different types of compactness measurement were analysed the same way during the analysis of the year 2008 trial-sections, which aimed at the determination of the standard deviation of the isotopic measurement, as well as of the standard deviation, the range and the accuracy of the dynamic compactness rate measured by the BC SP-LFWD.
We went on by using different materials for test compactions on the motorway M6 (section 76+200 – 109+700 km). So far a total of seven test compactions have been carried out, the results thereof are summarized in Table Nr. 2.

Table Nr. 1. Results of compactness measurements at 19pcs trial-section of M7 highway

Type of soil	**ACCURACY-RANGE [compactness rate, ± Δ%]**			
	without effect of ρ_{dmax}		with accuracy of ρ_{dmax}	
	Type of compactness test			
	Nuclear	***dynamic***	*Nuclear*	***dynamic***
188 + 600, formation level, silty-sand	4.5	***0.9***	6.0	***1.5***
188 + 600, mixed in plant sand	5.0	***1.5***	6.5	***2.8***
197 + 500, local filling material	3.5	***1.9***	5.0	***2.0***
180 + 110, receiving surface	3.5	***0.3***	4.5	***1.7***
180 + 110, aggregate Polgárdi	8.5	***0.3***	9.5	***2.4***
180 + 120, earthwork surface	10.5	***0.9***	11.5	***1.5***
194 + 940, local filling material	3.5	***1.8***	4.5	***2.1***
179 + 100, receiving layer	5.0	***1.2***	6.0	***2.3***
173 + 270, fine silty-sand	3.0	***0.9***	4.0	***2.3***
173 + 270, receiving layer	3.5	***0.8***	4.5	***2.2***
183 + 860 - 940, crushed stone	9.5	***1.3***	10.5	***2.4***
178 + 900, bridge back filling, mixed material	4.5	***1.7***	5.5	***2.4***
195 + 700 - 800, receiving layer, silty sand with gravel	5.5	***0.9***	7.0	***1.8***
195 + 700 - 800, mixed crushed stone 70% + local material 30%	6.5	***1.7***	7.5	***2.1***
189 + 340 - 360, Letenye - Bónya, sandy gravel	5.5	***0.8***	6.5	***1.5***
192 + 600 - 650, receiving layer	6.0	***1.8***	7.0	***2.4***
192 + 880, 8 kg/m2 by the mixing of cement	4.5	***1.6***	6.0	***1.6***
192 + 880, 12 kg/m2 by the mixing of cement	4.0	***1.7***	5.0	***1.4***
192 + 880, 16 kg/m2 by the mixing of cement	5.0	***1.3***	6.0	***1.3***
Average ±delta	**5.3**	***1.2***	**6.5**	***2.0***
Standard deviation of ±delta	2.1	*0.5*	2.1	*0.4*

It is practically impossible to measure compactness rates by the nuclear method with an accuracy that's specified in the present, strict regulations (i.e.97%). The isotopic measurement with the calculated accuracy 95% ± 6 $T_{r\rho}$%, means that there is the same chance that the nuclear instrument will show as a result of $T_{r\rho}$%=89% than 101% (or even with 90% probability in this range anything else result - normal distribution), at an actual compactness rate of $T_{r\rho}$%=95%.

The average accuracy range of the nuclear measurements at the M7 highway (half of the range determined by standard deviation) was ±6.5$T_{r\rho}$%. In case of the dynamic compactness measurement it was much lower: ±2.0T_{rd}%. The average accuracy range of nuclear measurements at the M6 highway was ±8.8$T_{r\rho}$% from a sample which contained also blust furnace slag aggregate of an inhomogeneous density while in case of the dynamic compactness measurement it was much more favourable, only ±2.5T_{rd}%.

It can be stated on the basis of the processing of available data that the B&C dynamic compactness rate seems to be more accurate and to have a smaller range than the isotopic method of measurement.

Table Nr. 2. Results of compactness measurements at the trial-sections of M6 motorway

Type of soil	**+/- ACCURACY-RANGE [compactness rate %]**			
	without the effect of ρ_{dmax}		with accuracy of ρ_{dmax}	
	Type of compactness test			
	Nuclear	***dynamic***	Nuclear	***dynamic***
84+600 km, receiving surface, silt	3.7	***1.8***	5.0	***2.3***
84+600 km, 25 cm layer, gravel	3.3	***1.1***	4.5	***3.0***
92+400 km, 50 cm, silty sand	9.4	***0.9***	10.5	***2.3***
102+140 km, 25 cm layer, fine silty sand	6.2	***0.8***	7.4	***1.8***
78+100 km, 25 cm layer, gravel	5.3	***0.8***	6.4	***1.7***
106+900 km, 25 cm, fine silty sand	6.8	***1.9***	8.0	***2.8***
182+100 km, 25 cm layer-blust f.slag	19.0	***1.6***	20.1	***3.6***
Average ±delta	**7.7**	***1.3***	**8.8**	***2.5***
Standard deviation of ±delta	5.4	*0.5*	5.4	*0.7*

So the CWA15848 regulated SMART-BC dynamic compactness rate test is much better than the isotopic one.

5 Summary

The application of the CWA15846 regulated SMART-BC dynamic compactness measuring method considerably increases the efficiency and reliability of the quality control of the earthworks and other particulate materials. It facilitates the recognition of measurement results being closer to the real conditions and the application of a more accurate and reliable qualification method both of constructor's self-control ISO 9001 both in accredited qualifying.

Two very different measurements (compaction- and bearing capacity) can be executed with one device according with CWA15846 using BC dynamic SP-LFWD, while the price of the device does not reach the purchase and maintenance costs of one isotopic device. It can be applied as the alternative of the isotopic instrument unnecessarily contaminating the health and environment.

Experts around the world have been concerned about the avoidance of settlement around our rail, public road and hydraulic constructive works for a long time, by looking for more efficient methods for the process, the determination and the quality of compaction. One can see this effort best in the limit values, that have become more and more stringent, which can be seen also in the increase of the number of regulations as regards both the compactness rate and the bearing capacity.

It is the compactness and the bearing capacity that are the most important parameters to be observed at earthworks during construction. During the certification of the construction quality of our civil engineering objects it is the accuracy, the precision of applied measurements which is crucial for the qualification thereof. A well qualified, but actually impropoer compactness may lead to the uneven settlement of the earthwork. And an earthwork qualified as improper, and thusly recompacted and corrected will cause financial damage by unnecessary work.

The determination of the accuracy of various compactness test methods should occur as part of trial-sections, which has yet been specified in Hungarian regulation Road Specification ÚT 2-1.222:2007'General geotechnical rules of building roads and highways', under 'adjustment and calibration of planned measurement methods'.

In the framework of our examinations we did measurement on 26 trial-sections with the aim of determining the standard deviation of the isotopic and the dynamic compactness measurement, and of determining the range and the accuracy of the compactness rate therefore.

We presented the data of test compactions on the highway section of M7 and the motorway section of M6, and furthermore, the difference of standard deviation, range and measurement accuracy of compactness measurements between the traditional isotopic and the B&C dynamic compactness measurement methods.

Important statements to make, as based on above mentioned facts
- the extension of the dynamic compactness measurement is justified in all layers, because it provides a much more exact measurement result with a smaller standard deviation than methods used earlier;
- it is necessary to examine the accuracy and the standard deviation of measurements on trial-sections in order to make the qualification justified and to choose a measurement method that can reach the adequate accuracy;
- the accuracy and the actual reliability of the dynamic compactness measurement might be further increased by measuring the water content more exactly. At present it is not usual to measure this value on site during the process of construction.

It is important to emphasize that, from the two main elements of the dynamic compactness measurement, the relative compactness (measured on site T_{rE}%) shows the efficiency of the rolling work, while the value of T_{rw} means the adequacy of the water content of the material. This means, that it would be yet possible to correct the compactness on site. It follows from this that in the phase of both construction and control (i.e. in our specifications) much more emphasis should be given to the measurement of the water content as well as to the application of the dynamic compactness measurement.

We recognised what a deviation of 'only a few percent' in the compactness rate might cause. At an embankment height of six metres, the post-compaction from 90% to 98% (ten Ys) leads to an embankment settlement of 40cm on the surface, without the impact of the subsoil. It follows from this that the *settlement of the embankment is not only a problem of the subsoil*.

Based on the above mentioned, it is suggested to review the prevailing limit values of compactness as well as the applied method of measurement, because

- consolidation time gets shorter and shorter because of the deadlines set by politics;
- real embankment compaction may result in significant settlement;
- the chosen method of compactness test has an important impact on problems, and resolutions;
- one should choose that method for the test of compactness-rate which is better and more accurate;
- for qualification it is not good to use approximate, inaccurate isotopic method

We all live together with construction problems, with work stress, both in winter and summer, in rain or summer chill. It's worth thinking about, how easy it would be to help oneself. Alltest Ltd. considers it important to improve and to make use of the theory of the SMART-BC dynamic compactness and bearing capacity method continuously.

This cannot go without analysis and comparison, by the means of which it can be confirmed on the basis of facts why we recommend the widespread application of BC-type SP-LFWD, and what advantages it may have in the everyday life of an investor, a constructor or an engineer.

According to analyses, the application of the SMART-BC device may cease or release actual problems as regards the settlement of embankments, fillings, which is in the interest of all partners, i.e. the investor, the constructor, the maintainer, and last but not least, the people who pay the taxes, as travellers, and as those who use the built infrastructure for traffic.

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