Method for Measuring Compactness-rate with NEW Dynamic LFWD

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ABSTRACT
A dynamic compactness measuring-theory has developed in Hungary using a special Small-plate Light-Falling-Weight-Deflectometer. It determines the compactness-rate and the dynamic modulus (bearing capacity) in the same time and measures the dynamic modulus with the same stress level like the static bearing capacity test. The accuracy of dynamic compactness measurement results are within ±2%. The B&C dynamic measurement is independent to density; it can be applied at all materials, which react to the compaction with deformation. The application of the dynamic compactness measuring method considerably increases the efficiency and reliability of the QC of the earthworks. The price of the device does not reach the isotopic one. It can be applied as the alternative of the isotopic instrument unnecessarily contaminating the health and environment. The dynamic compactness measuring method is protected with European patent, and got the golden medal of World Inventor Exhibition Geneva in 2003.

Keywords: B&C, SP-LFWD, compactness, compaction-rate, dynamic compactness, dynamic compaction test, reference density, Proctor-test, isotopic measurement, inhomogeneous density, variation of density, measurements, Quality Control, compactness-measuring for fly-ash, tests of blast-furnace course, compacted state, patent

1 INTRODUCTION

In Hungary a new dynamic-method device development started in 2002, which is suitable for executing two main earthwork measurements simultaneously. One hand, the developed small-plate light falling weight deflectometer measures the conventional dynamic modulus, as the *bearing capacity*; and on the other hand it is able to calculate the *degree of compactness* from the compaction curve generated as the result of the drops.

Owing to the little modified light falling weight deflectometer, beside the development of the new method of dynamic compactness measuring executed with a 163 mm plate diameter, the conditions of determining the dynamic modulus also improved. On the new B&C (Bearing Capacity & Compactness-rate) device the applicable Boussinesq's plate-multiplier (rigid, flexible), and the Poisson's ratio also (0,3-0,4-0,5) can be selected. The measured dynamic-modulus and the under-plate stress are very similar to the one experienced at the static bearing capacity test.

The earlier LFWDs (Light Falling Weight Deflectometer) having a 300 mm plate and p=0,1 MPa under-plate stress were far away from the 0,3 MPa load stress level applied at the static capacity, and none of the conversion trials generated correct result.

The new dynamic light weight-drop compactness- and bearing capacity measuring device and the actually developed method of calculation of the dynamic degree of compactness facilitate to measure the compactness by determining the compaction curve measured with *subsidence - featured compaction*; and on the other hand, to measure the dynamic modulus with the similar under-plate stress to the static one. It is outstanding, that a single measurement can determine both the dynamic deformation modulus and the compactness-rate. The revolutionary innovation results in considerable time and cost saving, and ensures a more reliable, more accurate measurement result.

2 ANTECEDENTS

The compactness is the most important quality feature beside the bearing capacity in civil engineering. The earlier applied compactness measurements were based on the density measurement, like the sand-filling, the water-volume measurement or the isotopic density measurements. Firstly, the measured local density was converted into dry density having known the water content; then we compared it to a reference density, given in percentage.

The reference density in Hungary is ρ_{dmax} determined with the modified Proctor test. Today the EN 13286-2 European Union Standard is effective for this. Recently, other reference densities are also known, such as vibrating compression, vibrating hammer or vibrating table test methods. Their comparison and convertibility is not known yet, but different material behaviours are expected. As the EN-ISO standards come into effect, the question arises: the simplified Proctor test or the modified Proctor test should be applied as reference density. In German area the simplified Proctor test with lower density (ρ_{dmax}) is more widespread. Ergo, around the reference densities a lot of questions will arise expectedly, which will increase the actual doubtfulness.

From the point of view of the quality control the accurate compactness-measurement would be important. But the accuracy of the isotopic compactness measuring today is ±5-6 compaction rate %, which does not meet the strict requirements. The random fluctuation of measurements is very high. Expectedly, the isotopic measurement method will not be more accurate in the future either. The measurement is not expedient neither from sanitary, nor environmental aspects. Its application is governed in strict rules, therefore its replacement results in huge administrative and cost savings.

The German FGSV-561 does not propose the isotopic method yet; instead of this applies the sand-filling, volume (the old „scramble" methods); or it tries to replace the compactness-rate by concluding from the special results of the LFWD dynamic capacity-measurement. Similar chance is the CCC-method (Adam & Kopf), which determinates further parameters expected to be in connection with the compaction-rate by the help of acceleration gauge fitted on compaction rollers.

By the above-mentioned things the practical advantage of the dynamic Small-plate LFWD compactness measuring is outstanding. The Hungarian application experiences are high favourable. Its use considerably facilitates the building works; it permits routine decisions. On the basis of the measured parameters it can be unequivocally decided, whether is further compaction needed or not. In Hungary the development of dynamic compactness- and capacity measuring SP-LFWD device and its measurement method is proceeding since 2002; and for regular quality control measurement already 14 laboratories acquired right.

3 THEORY OF DYNAMIC COMPACTNESS MEASURING

Dropping a weight on the soil-layer of given water content at site we make a work of equivalent degree with the laboratory Proctor-engine. The compactness determined is called as local, relative degree of compactness (C_{rE}%) depending on moister. The B&C (Bearing Capacity & Compactness-rate Tester) is such a light drop- weight measuring, whose plate diameter is 163 mm. The 10 kg weight dropped from a height of 70-75 cm, which effects 0,35 MPa dynamic stress under the plate. It is necessary to create the needed compaction work during the drops; and at the same time it serves as a chance to determine the dynamic modulus near to the usual 0,3-0,4 MPa static press range (not with 0,1 MPa load, as the present LFWD).

The relative compactness-rate (achieved beside given water content) determined in this way must be adjusted to the optimal water content, (w_{opt}) to make it equivalent with the degree of compactness (C_{rd} %) calculated from the ratio of the conventional dry densities. The moisture correction coefficient is C_{rw}= (ρ_{di}/ρ_{dmax})/100, which was tabulated in the course of the normal ability test, and the value of water content measured at site can be read out. Ergo, the moisture correction coefficient curve is the normalized Proctor-curve. Since the maximum of the C_{rw} curve of all materials is = 1,0, just their curvature will be different.

The dynamic degree of compactness is $C_{rd}\%=C_{rE}\%*C_{rw}$, i.e. the product of the local relative compactness and the moister correction coefficient. The local relative degree of compactness achieved beside natural water-content depends exclusively on the work of rolling. Therefore, the relative compactness of every Proctor point compacted in the laboratory is 100%. At site the compactness is achieved with 18 fallings to achieve equivalent Proctor-work beside given technical characteristics.

It is important to determine the curve of moister correction coefficient (form of the Proctor-curve), accordingly we offer 7 – 15 Proctor points from the soil test, which is more than the earlier, from which we determined the equation of the Proctor curve and the moisture correction coefficient with regression analysis, with quadratic interpolation method. In the following such can be seen.

It is the essential element of the dynamic compactness measuring method that the compaction is made again and again at the same site with a *work being equivalent with the Proctor's test on the given material at every individual measurement.* Therefore the importance of the inhomogeneous density ant the resulting error disappears. This makes the dynamic compactness measurement outstandingly safety and reliable.

The relative local degree of compactness is determined from the subsidence measured per drop. We examined eight different theoretical methods, till we choose the most appropriate. This is a correlation, which can be deducted from the Proctor's test, whose essence is that samples of the same dry mass moistened with different water content can be compacted to different roll height. This is called as "dray mass" (Md) = constant. At the moment for the different moistened samples we apply the uniform wet volume in the Proctor test, this is V_W=constant. At the optimal water content the Proctor-roll height is the smallest, i.e. the reached compactness is the highest. The height-difference between the rolls can be considered as subsidence (deformation), if it is resulted from the compaction work at site.

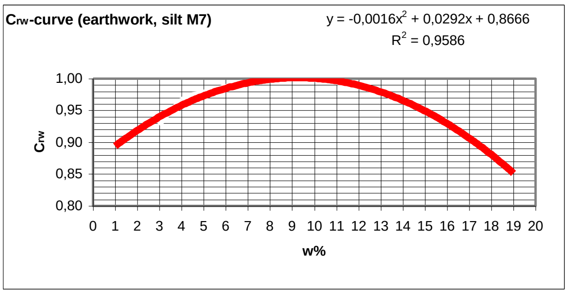

fig.1. Curve of moisture correction coefficient

Since the subsidence (height difference) and the degree of compactness of the Proctor-rolls closely correlates, the (initial) degree of compactness can be calculated from the deformation achieved with the same work. The difference between the rolls of the local measurement and the laboratory Proctor test only is that at site the roll height changes not owing to the water content, but owing to the compaction work. But it is indifferent, while the density is the ration of the dry density and volume, i.e. only the height difference resulting during the compaction work depending on the compactness. Such approach of the Proctor-test can be calculated from any conventional test result.

The relationship of the height differences (deformation) and the compactness-rate, which can be considered as linear, can be determined individually from every Proctor-test. From hundreds of tests the Hungarian prescription observes it with a slope of Φ=-0,365+/-0,025 and it can considered typical.

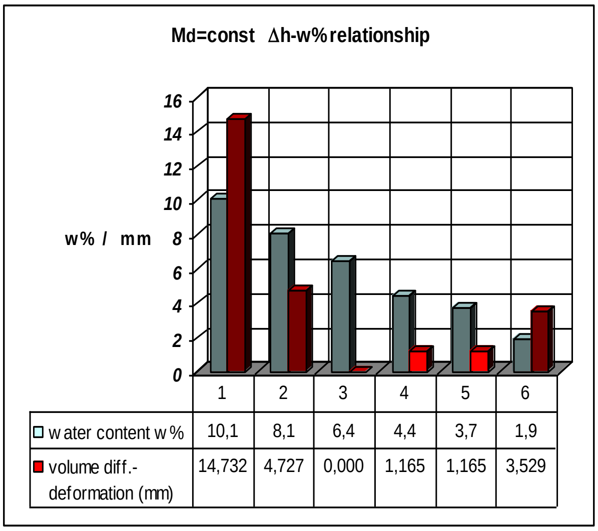

fig.2 Heigh difference of Proctor-rolls (M_d=constant)

4 ADVANTAGES

Dynamic compactness is independent from the density and homogeneity. We examined the correlation of the degree of compactness and subsidence on 3-3 samples at five different materials of considerably different density, processing 150 Proctor-points (fig.3). Despite the considerable material and density differences the linear coefficient of deformation – degree of compactness relationship is Φ=-0,364 beside R^2=0,997 regression coefficient. The relationship for the calculation of relative compactness is C_{rE}%=100-Φ*D_m, where the D_m deformity index is a weighted mean.

If we process the subsidence data according to the M_d=constant Proctor-model and we approximate it with a quadratic relation, the relation has a minimum at C_{rE}%= 70,8 % beside R=1,00 regression coefficient, which *theoretically is the lowest degree of compactness* at any level of water content, which we can determine on the basis of this theory. According to our theory lowest compactness cannot be established. According to Prof Dr Kézdi the lowest relative compactness value – despite of several trials – could not be determined in a laboratory.

The Hungarian specification of dynamic compactness test UT2-2.124 introduced the concept of *simplified dynamic compactness measuring*. Earlier, 18 drops was necessary for the measurement of dynamic compactness. The new method in „simplified" mode conditions the number of drops by the form of the compaction curve considering the slope of the end tangent line of the subsidence curve. The program starts to monitor the existence of the condition after the first nine drops; and if it is satisfied, it generates the missing data line from slope created from the two last points. While the degree of compactness calculated with substitution is a little bit worse that the one calculated with the complete series, the neglecting is in favour of the safety.

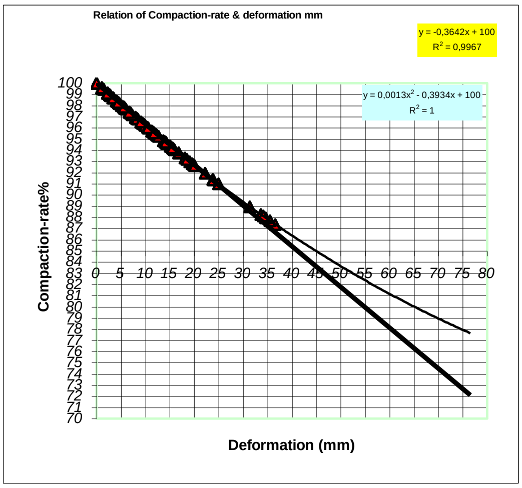

fig.3 Relation of Proctor points of five difference density

Apply of the relative compactness for checking the isotopic measurements

A radiometric compactness measuring calculates the dry density from the measured wet density and the measured water content; and compares it to the ρ_{dmax} reference density determined with Proctor-test. We determine the $C_{r\rho}$% isotopic compactness-rate in this way with the reference density and from the measured local density. While $C_{r\rho}$%=C_{rd}% and the degree of compactness is the product of local relative compactness and the moister correction coefficient, the *isotopic relative compactness-rate*, which typical to the efficiency of rolling, can be calculated from the result of the isotopic density measurement with the formula "C_{rEiz}% = $C_{r\rho}$% / C_{rw}". If we have got a relative compactness higher that 100% calculated with dividing from the results of isotopic compactness-rate, it would have been only a defect measurement. Accordingly, this method is perfectly suitable for checking the poor reliability of the isotopic measurement method.

Information content of the dynamic compactness measurement

The great advantage of the new dynamic compactness test method is, that on the basis of the measured parameters immediately can be decided, whether the compactness is appropriate or not; and if not, what should be done. *The relative compactness (beside given moisture content) shows exclusively the efficiency of rolling*, therefore in case of C_{rE}%<97 it is expedient to apply further compaction with some runs. In additionally, for this it is unnecessary to know the Proctor characteristics of the material (nor the moister correction coefficient). So if the compacted soil-layer approximately has the optimal water content, or we just want to execute an under-produce quality test, this is enough information for the efficiency of compactness. *From the relative compactness-rate the efficiency of rolling can be determined in site without further information, and it can be said, whether the layer can be compacted further or not.*

The moister correction coefficient depends on exclusively the moisture content of the material, therefore it can be seen already during the ability testing, whether beside given natural moisture content maximum a compactness of what percentage can be achieved with perfect rolling. If, let us say, the value of C_{rw}=0,922 at the measured w_t% local water content, then owing to the relation $C_{r\rho}$%=C_{rd}%=C_{rE}%*C_{rw} in case of the rolling-caused maximum possible C_{rE}%=100% relative degree of compactness can be only 92,2% compactness-rate; so $C_{r\rho}$%=95% cannot be achieved in any case. *From the moister correction coefficient it can be prognosticated, whether the mined or supplied material of known water content will be suitable for achieving the given degree of compactness, or it is needed to moistened or dried. Accordingly, the moister correction coefficient must be given as the part of the ability laboratory test.*

5 ALTERNATIVES OF THE REFERENCE DENSITY

After the issue of the MSZ-EN European Standards the earlier applied ρ_{dmax} reference density can be given not only according to EN 13286-2 (by the simplified-, or modified Proctor-test) but other new model-effect methods can be applied, such as vibrating compression EN13286-3, vibrating hammer EN13286-4, or the vibrating table EN13286-5 as a reference density. Their comparison could not be executed up to now, but it is surely unavoidable. The isotopic density measurement method of high accuracy causes a great dilemma, and it can be expected that owing to the several reference densities the chaos becomes final in the measurement, which is very sensitive to the reference density. The question is important and absolutely practical, while owing to the increased sharpening quality requirements the strict quality in compactness-rate (and bearing capacity) can be achieved more and more uneconomically. It is typical for the current Hungarian motorway construction works (tender requirements) that e.g. for the top 1,0 meter layer of the top earthwork $C_{rd}\%\geq 97\%$ is prescribed, beside a reference density determined with modified Proctor-test. Several contractors and laboratories face enormous difficulties in meeting the strict prescriptions using isotopic compactness tests.

6 COMPARISON OF COMPACTNESS TESTS

In this motorway project the different measuring methods could be compared. The laboratory of the contractor STRABAG was the H-TPA Ltd. The laboratory of Andreas Ltd as an engineer took part in the parallel measurements, and an appointed independent quality control laboratory ÁKMI executed the control tests. Preliminary geotechnical expertise was issued by the Technical University of Budapest, Geotechnical Chair (Prof Dr Farkas). Analysing laboratory tests were executed by the Building Material Laboratory of the Technical University of Budapest. The sampling cylinder and sand filling measurements were made by the ML Laboratory, and the CEMKUT Research Institute helped the work with microscopic surveying. The University of Győr Geotechnical laboratory helped in the execution of parallel soil identification tests. The considerable data base created in the course of the team work was summarized by the METROBER independent Engineer. The water content was determined by isotopic measurement and laboratory drying method. The applying in site water-content meter was T-90 Trident (USA) measurement.

The average of the measured dynamic compactness-rate was $T_{rd}\%=94{,}1\%\pm 2{,}7\%$, and the average of isotopic measurements was $T_{r\rho}\%=94{,}4\%\pm 2{,}5\%$. The average of relative compactness-rate calculated from the isotopic measurements 96,8%; in five cases was up to 100%, which refers to the upper section of isotopic measurement errors occurring randomly. The average of relative compactness-rate of the dynamic measurements was 96,4 %. It is typical that while the result of isotopic measurement shows high random variation, the dynamic compactness-measurement always turned out to be convincing owing to its realistic compaction curve.

7 TEST ON WASTE-MATERIAL LAYERS

The recycling of spent materials and secondary raw materials is spreading in civil engineering also. It is an understood thing that the determination of degree of compactness on ash-embankment is difficult owing to its very low density. The dynamic compactness measuring method abided all tests up to now; so at such locations also, where the compactness could not be determined with the isotopic measurement method. Such was the compactness measuring on ash-layer and in some cases on lime in site-stabilizations also. We can mention as an example the measurement of the H-TPA laboratory during the building of the motorway Nº35 on fly-ash embankment, where the compactness-rate was determined with sampling cylinder and dynamic compactness measurements. The isotopic measurement was ignored, while owing to its value up to 135% so the laboratory could not issue the report either. On the contrary, the degree of compactness determined with sampling cylinder was 98,3%, the dynamic compactness-rate (B&C) was 91,7%.

The blast-furnace cinder placements are also uncontrollable regarding the compactness, while their density unhomogeneity is very high. The sampling cylinder test is unsuitable in this case because of the large crashed material particles. The sand filling or water volume method is difficult (scramble) and it depends on the reference density very much. In case of such materials the execution of Proctor-test needed for the reference density is also very difficult.

8 RELATIONSHIP BETWEEN STATIC AND SMALL-PLATE DYNAMIC MODULUS

In the recent time several publication attended to the comparison of the E_{vd} dynamic modulus used LFWD measurement (p=0,1 MPa) and the E_{v2} deformation modulus of static bearing capacity. On the actual sections we did not measure with 300 mm plate LFWD, only with B&C (SP-LFWD). The comparison of this latter one with the static modulus was interesting, because the p=0,35 MPa underplate stress is similar to the static capacity test. We summarized the E_{v2} static modulus and the E_{vds} dynamic capacity values. It was well-marked, that the new small-plate dynamic modulus shows better similarity with the static E_{v2} modulus value than the earlier E_{vd} method. It must be stated here that *all of dynamic tests the local water content should be measured*, because above s=0,9 saturation the water cannot avoid. I.e., when there is not enough removable air in the soil-system, then the impact does not make the water run out and accordingly the instrument detects smaller deformation, i.e. higher and subsequently *false dynamic modulus*. Therefore it is necessary to meet the strict measurement specification and the measurement of the local water content.

Another innovation in the test, that we introduced the concepts of dynamic terminal modulus ($E_{vds\text{-}end}$), which considers the average of the last 18 drops being necessary for the determination of dynamic compactness, like the *dynamic modulus being typical to the compacted state*. In comparison with this the E_{vds} dynamic modulus determined from conventionally 4-5-6 drops we can reason for the actual conditions, far from compactness of the E_{v2} static modulus.

9 REPRESENTATIVES OF THE PROCTOR-TEST

The dry density – water content Proctor-points determined during the Proctor-test usually are simply joined. Mostly the determination of 4-5 points is general. We introduce a silty-sand material examined by us, whose grain-size distribution can be said uniform and identical. Nevertheless, it has a very high dispersion. We gave four laboratories charge over determining the ρ_{dmax} maximum dry density. On the following figure we indicate the determined Proctor-points, the reproducibility of ρ_{dmax}. It can be concluded that the dispersion of Proctor-points is a completely natural testing effect. It is not the fault of the laboratory operator or the laboratory, but it is typical for the testing method and especially some of the materials, therefore it is expedient to make further tests in any way.

10 CONCLUSIONS

The new dynamic compactness-rate and dynamic bearing capacity measuring by SP-LFWD device and the theory of the dynamic compactness-rate worked out currently facilitate the measuring of compactness with *subsidence-featured compaction* by determining the compaction curve in site. It measures the dynamic modulus with the same stress level, like the static bearing capacity test; therefore its results corresponds well under s=0,9 saturation. The accuracy of dynamic compactness measurement results are within ± 2%, which is outstanding in comparison with the earlier compactness measuring methods. The new dynamic B&C measurement is not sensitive to the variation of density; accordingly, it can be applied at all materials, which react to the compaction with deformation.

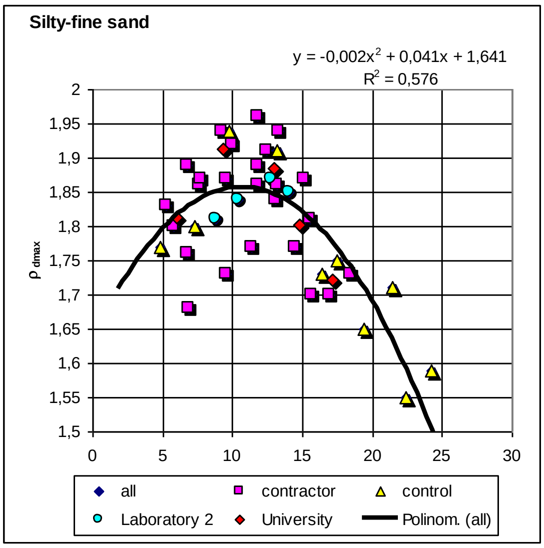

fig.4 Proctor-points one sample – four laboratory

The application of the 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.

Two measurements can be executed with the B&C dynamic SP-LFWD measuring device, while the price of the device does not reach the purchase and maintenance costs of the one isotopic device. It can be applied as the alternative of the isotopic instrument unnecessarily contaminating the health and environment.

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