Effectiveness of Earthworks Qualification Tests in Hungary

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(Experiences of BC Part 1)

Introduction

While technological development is unarguably affecting both our laboratory testing devices and our laboratory techniques, we must examine the long-term changes resulting from progress in the performance of our laboratory tests. Indeed, monitoring the progress of laboratory measurement techniques is the best way for laboratories to replace their customary practices with procedures making their work more accurate, faster and cheaper.

Site qualification laboratory measurements and tests in Europe and in Hungary can be divided into three main operational phases:

- Sample preparation phase – preparation of the measuring location,
- Test phase – making of the actual measurements,
- Processing phase – preparation of the test report.

Changing technology has noticeably affected all of the above-mentioned phases: devices exist in each one that help to increase effectiveness.

If we analyse more specifically the steps included in the test phase of a qualification test, then we can see that most of the tests actually include the same steps, in fact repeatedly so. By considering the time taken and the human resources employed in these steps, we can calculate the cost-benefit ratio of the measurement.

When a laboratory is being developed or a device purchased, the cost-effectiveness of the measurement process must be known in order to make a good decision. In several cases, despite a higher purchase price, returns on the device investment are made quickly, since, while the labour costs are high owing to difficulties in distributing the work equally in time, the other costs of the test are highly advantageous. The investment in the machines and procedures to increase efficiency is thus quickly recovered.

Considering this, we analysed the measuring gauges and devices representing a comparatively high rate of measurements made in earthwork qualification, such as the gauges and measuring methods used to determine compactness and load-bearing capacity.

Compactness test: dynamic or isotopic?

Typically, there are considerable cost differences in the test market, consequently, the income can be estimated well, depending mainly on the number of orders.
In principle, we agreed to compare two standard compactness measuring methods, which can be applied in technically the same way and which differ mainly in the qualification measurement of a given earthwork or base layer.

The measurement principle of the dynamic compactness measuring device CWA 15846 (UT2-2.124 UME) differs from that of the devices generally used for this purpose; the device

calculates the compactness from the compacting curve generated by deformation through dropping.
The test done by the isotopic device (in Hungary MSZ 15320 and ÚT 2-3.103) determines the compactness indirectly by measuring the density of the material. Besides the nuclear device operating with an isotopic source, the wet density can be determined, using the sampling cylinder, cavity filling or rubber membrane method, from the volume measured with water and the weight of the material sample. The latter measuring methods are very slow and difficult as well as labour-intensive since the isotopic method is hazardous for the environment and is very inaccurate.

Operating principle of the B&C dynamic deflectometer CWA 15846

During the test, a body of known weight is dropped onto a rigid plate of a certain diameter from a given height through the transmission of a buffer spring. The vertical movement measured is that generated by the dynamic loading under the centre point of the loading plate, i.e. the depression amplitude. In the case of a 10-kg dropping weight and a 72-cm dropping height, a 7070 N dynamic loading force is transmitted onto the plate, which, with a suitable spring constant and 163-mm plate diameter, is equal to p_{din} = 0.35 MPa dynamic pressure. The dropping weight and height must be selected for each device between the limit values of the given spring constant and dropped weight, according to the prescribed value of the dynamic loading pressure.

The dynamic load-bearing capacity modulus E_d (MPa or N/mm^2) can be determined from a second series of depression amplitudes typical for the deformation. The calculation assumes that the loading of the plate is flexible, homogenous and that it is transmitted onto the isotropic half. The calculation must be carried out by selecting the Poisson coefficient typical for the material and the Boussinesq rigid or flexible plate multiplier typical for the applied plate thickness.

From six measurement series of the depression amplitudes typical for the deformation, the dynamic compactness T_{rE}% and T_{rd}% can be determined. The calculation assumes that the granular layer consisting of non-compactable solid materials is three-phase (air + solid part + water), and is unsaturated and remains so during the compacting carried out in the test. The calculation considers that compactibility is best with optimal water content; otherwise it decreases to a degree which can be calculated using the moisture correction coefficient (Trw $\leq$ 1.00).

Principle of the isotopic compactness test (MSZ 15320)

In this case, we analysed the most often applied sampling cylinder measurement, for which it is best to make the soil's compactness test with the largest depth adjustment (25−30 cm). If the soil is so hard or consists of such coarse grains that the striking pin cannot be pounded in without the risk of damage, or if the soil layer to be measured is too thin, then a measuring depth of 20; 15 or 10 cm can be also applied. Of course, during the evaluation a suitable calibration curve must be applied. The measuring points must be made smooth. All dry, loose material must be removed from an area of 60×80 cm^2. At least two measurements must be carried out at every measuring point, turning the device 180º. The probe must be checked after each switch-on against the calibration block included, in accordance with the instructions for use. The results obtained on the calibration block must be recorded on a measuring report to be prepared on-site. During the measurements, any such measuring time must be determined, so that the impulse rate measured on the soil exceeds the 10,000/min value, or at least approximates it.

Water content must be known for the density measurements. When determined by isotopic measurement, it often has to be repeated in the case of new soils or soils of varying materials. In all cases, a control must be made by the laboratory dry-back test of the water-content samples taken from the measuring location (drying box). If there is a considerable difference affecting the result of the test, the laboratory results must be considered authentic. If the absolute value of the laboratory and site test result exceeds 5% of the laboratory result, then the test must be repeated.

Finally, to determine the compactness, a reference density is also necessary, to which the previously-determined site dry density is compared. In Europe, this is now carried out with the "Modified Proctor test" in accordance with EN 13286-2. Note that its result must be repeated very often in the case of new soils or soils of varying materials, since its dispersion can reach 5 per cent of the density. This means that another risk of error is inherent in the reference density.

Comparison of measuring methods

Cost price and operating costs

To compare the two measurement methods properly, we selected two of the most frequently used measuring gauges which meet the above-mentioned requirements. We chose the dynamic light falling weight method (with B&C deflectometer) and the Campbell MC-3 device generally applied in isotopic compactness tests.

In determining the purchase price, the prices considered were those indicated in the tender for both the MC-3 device and the B&C. The other costs' coefficient was calculated with the real operating costs of the H-TPA laboratory, in euros.

The 4,640 Euro difference between the total annual costs of using the two devices is already considerable. The reason why it has not been noticed until now is that this old isotopic technology has been used for so long that its costs have been completely built into the cost of the laboratory tests.

It should be noted that the lifetime of a device is 10 years. Our laboratory carries out several tests in a year, approximately 1,000 tests per device, i.e. 10,000 tests in the device's whole lifetime. The costs incurred during this period (including maintenance costs, for which we calculated a maximum of 400.-Euro per annum), divided by the total number of measurements gives the cost price per measurement.

	B&C	**MC-3**
Calibration costs	€ 270	€ 360
Operational costs: • Radio-protective supplement • Extra human resource requirement (operator) • Transport of radiant material • Training in use of radiant materials	 0 0 0 0	 € 1,600 € 2,400 € 400 € 150
Average total annual cost	**€270**	**€ 4,910**

This calculation method is not quite complete since it eliminates many things which are the same for both methods (such as the cost of travel to the site, etc.); similarly, the unit prices included here cannot be compared with the prices given in the laboratories' price lists, but this is not necessary either. The difference for the two methods is therefore given only in cost per test:

B&C CWA ~6,700/10,000 = € 0.67 per test
Isotopic Test ~53,100/10,000 = € 5.31 per test

The difference is **eightfold** and is entirely due to the isotopic source and labour costs. Neither the purchase price, nor the operational costs make such a huge difference.

If we examine the labour costs, these will increase considerably in time, owing to the European price convergence in Hungary, as will the purchase price of the devices and the operational costs.

Also to be considered are those costs incurred by having to store the isotopic device in safe, suitably licensed premises, as well as those related to the health of the workers in contact with the device. The costs of such a system and the licensing procedure are considerable.

Measuring time
The measuring time can easily be evaluated since more than 4,000 tests were carried out with both devices during 2005 and 2006. From this experience, the following average times were obtained:

MC-3 ~10 minutes per test
B&C ~2 minutes per test

The above times include the preparation of the measuring point and the test itself with an experienced laboratory assistant, assuming continuous work. Already here there are very big differences, but further valuable minutes lapse during the data processing and report preparation. The test data indicated on the handwritten measuring sheets are recorded on the PC one-by-one in the case of the isotopic test; while the data can be transmitted from the B&C device direct to the PC, where they are downloaded; which simplifies the procedure considerably. In data processing, the B&C is faster by a ratio of approximately 5:1, hence, during the processing of one isotopic test, five B&C tests can be processed. This time difference can be used to make the measuring raster more frequent at the same cost or, during the saved labour time, other measurements can be carried out, or simply more tests can be executed per day.

Importantly, in case of the B&C device, it is not essential to know the laboratory Proctor-density for the interpretation of the measured values; it is enough to determine its change depending on the water content, i.e. the curve. The relative compactness degree typifies the maximum compactness that can be reached at a given water content, which can also be measured with the B&C device on an unknown material. Consequently, this method does not delay the construction work while the laboratory Proctor density is found in order to determine the compactness degree reachable by rolling on the finished earthwork.

Furthermore, it must be emphasized that we examined and compared two compactness tests. With the B&C device we carried out a small plate dynamic load-bearing capacity test simultaneously with the dynamic compactness test; and with a 300-mm plate diameter (large plate) a further (p = 0.1 MPa) light falling weight dynamic test can also be executed. Hence, , three tests can thus be carried out with this single device over a short time, thus improving cost-efficiency even further.

Analyses of efficiency

After analysing the above-mentioned cost price and operating costs as well as the measuring time, we can be sure about the returns.

Even if we have all the necessary infrastructure, licenses, qualifications and documents needed for using an isotopic device – which appears as potential costs – the application of the B&C dynamic compactness measuring method is advantageous. And if the work is to be done on a new site, where the above-mentioned infrastructure, construction of the site laboratory and purchase of the devices are not yet available, several tests can be carried out quickly and at very low cost with the B&C dynamic compactness measuring device. Accordingly, this device can work to shorter deadlines while providing high-quality service on the market for compactness or load-bearing capacity measurements.

Measurement accuracy

Test methods requiring less labour are more economical in the long run on every account than methods providing the same final results but requiring more human resources.

But we must also consider whether have they the same accuracy and are equally reliable.

When selecting test methods, we must consider the *measurement uncertainty and accuracy*. Measurement uncertainty can be caused not only by disturbances caused by environmental changes, but also – and we must acknowledge that this is the situation at most of our tests – by the workers carrying out the tests.

Test results obtained using an automated, programmed system operating without human intervention always approximate the real values closer than results of measurements by manual methods with the multiple risks of human error. The smaller dispersion, the higher reliability of the measurements.

In our example, the accuracy of the two devices examined is not equal; the reason being the different theoretical foundation of the measurement methods. The isotopic compactness degree is determined from the measurement of three parameters (wet density, water content and reference density), while the measurement accuracy of the B&C dynamic compactness degree depends only on the accuracy of the deformation test. Of course, the dispersion is higher for tests whose results are calculated from the measurement of three parameters, than those based on the measurement of one.

The following comparative table shows the measured test dispersions of the two devices:

	H-TPA				Andreas		Control labor			
	Isotopic		B&C		B&C		Isotopic		B&C	
Method	Trρ%	TrEiz%	Trd %	TrE%	Trd %	TrE%	Trρ%	TrEiz%	Trd%	TrE%
Average	91,8	94,1	94,3	96,6	94,9	96,8	86,9	88,3	94,4	96,5
deviation	7,4	7,8	3,3	1,9	2,3	1,8	7,3	6,4	2,4	3,1
No. of samples	23	23	23	23	17	17	5	5	5	5

Comparing the dispersions from 50 measurement results on one material at a time, the following results were obtained:

Dispersion for the isotopic compactness measuring device: 7.2 per cent,
Dispersion for the dynamic light falling weight deflectometer: 2.5 per cent.

The dynamic method shows that the accuracy almost three times better than that of the old method based on the radio-isotopic density test. But accuracy is not everything. During the test, the client is very keen to know the measurement result, whether the construction meets the compactness and load-bearing capacity requirements and whether he can transport the compacting roll, for example. If the compactness is not acceptable, he is also interested in knowing what he must do to be ready as soon as possible, etc.
The on-site relative compactness T_{rE}% measured by the B&C deflectometer shows the efficiency of the rolling, while the moisture correction coefficient T_{rw} shows the effect of the moister, the compactibility of the material. Accordingly, in all cases where the measured result is not acceptable, it can be decided on the spot what to do and what the problem is: if the compacting work was insufficient, we continue the rolling, or if the problem is with the water content, we dampen or dry it. The same cannot be done in the case of isotopic measurement because the reason for the unacceptable compactness cannot be determined unequivocally on site, only its existence.

In recent years the recycling of industrial by-products is taking place increasingly in road construction. More and more cinder and scale are used as backfill and in the construction of embankments. These materials behave in a different way then usual; therefore their qualification tests are more risky.
On cinder or scale, density measurement with the isotopic device is appalling; and the density test with a sampling cylinder is not a simple task either. The density of cinder is very non-homogeneous, while that of scale is around 1.0 g/cm^3. In such cases, it is not so much a question of measurement accuracy, but simply of the test's feasibility. Tests on scale are by

no means rare either, since a lot of situations occur in which the density test cannot be done owing to contamination or other anomaly. In any case, it is very practical to have a method that determines compactness in another way – and incidentally the load-bearing capacity at the same time too.
The CWA 15846 B&C dynamic deflectometer worked well on both materials, determining the compactness degree not on the basis of the density test, but on the basis of the deformation.

Comparison of different measurement methods
As can be seen from the above, the compactness measuring method selected affects the final result to a large degree. Several methods exist for determining compactness. In the following table we compare four different measuring methods, three principles and four methods based on these three principles. The characteristics considered negative are indicated with a "-" sign and the positive ones with a "+" sign.

			
- It applies a radiant isotope - Minimum of two measurement staff needed - It transmits the error of the reference density on to the measurement result - Its transportation is difficult - Its measuring uncertainty is high - It requires special knowledge + It is well known and accepted	- Low productivity as it is slow - It transmits the error of the reference density on to the measurement result - The vibration load of the environment can easily disturb the measurement results - It does not measure water content + Only one operator needed + Easily portable + Not radiant	- Very low productivity - Obtaining on-site results is difficult - It transmits the error of the reference density on to the measurement result - The examining staff have a big impact on the measurement results - In case of granular soils, its use is difficult or impossible + Not radiant	- It does not measure water content + High productivity + Not radiant + No error of reference density + Separated solution to resolve the compacting and water content problems + No special knowledge needed + Only one operator needed + Easily portable

Summary

Development of the technology is progressing in the right direction if the laboratories can carry out qualification measuring tasks and tests in a more effective, cheaper and faster way than before.
The site qualification laboratory measurements and tests used in Western Europe and Hungary have recently undergone considerable changes, this is partly due to the new B&C dynamic deflectometer, for which:
- *Operational costs are an eighth of those of the isotopic device;*
- *Measurement time is halved;*
- *Efficiency is considerably higher even with one order;*
- *Measuring accuracy is almost three times better;*
- *Application can be extended to cinder and scale, which were considered as extreme materials up to now.*

In the CWA 15846 regulated B&C dynamic compactness and load-bearing capacity deflectometer compared very favourably with the other compactness measuring methods and, in our experience, showed outstandingly good features; we therefore expressly recommend it for the qualification tests of earthworks in other laboratories also.

According to our experience of several years and covering several devices both in Hungary and in Western Europe, the dynamic compactness test can be applied more effectively and with more accurate and reliable measurements of compactness.

Literature

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