## Measuring Methods of Compactness-rate & Bearing Capacity in Europe

*(Experiences of BC Part 3)*

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### *Introduction, antecedents*

One of the most important quality parameter of the building of earthworks, of building materials of railway, roadway and waterway embankment structures is the compactness-rate. All European regulations treat the limiting values necessary for avoiding the after compacting, the reduction of the water penetration as important parameters.

The compactness degree is - traditionally - the quotient of the bulk density (reached during the in building) and the reference density, expressed in percentage. The main characteristic of the compactibility test is the maximum measured dry density - as reference density - a possible and widespread applied, in laboratory determined value.

We determine the dry density in the laboratory in Hungary with the EN 13286-2 modified Proctor compaction, with falling weight compacting appliance. German area the simplified Proctor test is characteristic, which is working with smaller compaction work and bigger layer thickness, therefore a higher than 100% compactness degree can be also as a requirement.

**European standard** allows also for laboratory reference density, with other vibrating test:

EN 13286-3 vibro compression with controlled parameters

EN 13286-4 vibrating hammer

EN 13286-5 determination of the reference density with a vibrating table

Their application, trial did not occur yet. An equivalence of these tests with each other is temporarily not known, they do not have conversion. These will accord barely because of the different model effect however expectedly. The fundamental condition with their comparison is that the *compaction work* should be accordant.

Beside the compactness degree newer requirements, recommendations are expanding. Such is for example the saturation, or the prescription of the recommended values of the air content. Already the Austrian FGSV 516, but also the ÚT 2-1.222 ÚME (in Hungary), asks in some cases for the assurance of an air content (≤12%) beside the achievement of the prescribed compactness degree. There is no direct regulation for the tolerable saturation although the mentioned air content can be interpreted is like this for a regulation like such a regulation. D. Adam and Kopf worked out for large surface earthworks a classification opportunity for the control of the compactness and load bearing capacity, defining the state of the compaction with the accelerometer fixed onto the cylinder ($E_{vib}$ and Omega).

Totally new direction can be considered the Hungarian dynamic compactness test –named **BC** - as well, which can be measured with a new SP-LFWD (Small-Plate Light Falling Weight Deflectometer) equipment, with the analysis of the compaction curve taking shape in the course of the drops.

On the invitation of the Portuguese Professor Correira our company ANDREAS Ltd took part in a comparative examination series, so we may report on the new test methods experienced there in this manner.

#### *Compactness measurement in EVORA, Portugal*

On the invitation of the Geotechnical Faculty of the Technical University of Portugal Professor Correia, on a test section - beside many other appliances and methods - the Hungarian B&C dynamic compactness and load bearing capacity device may have been also tested. The Hungarian method which received European and USA patent was developed by the Andreas Ltd. The testing in our country well known examination method was fulfilled beside several new and traditional methods.

The test in building took place beside the city Evora, where a high velocity railway running across the country in East-West direction is getting constructed. The executed traditional and test measurements served for the qualification of the earthwork's compactness and load bearing capacity.

1.

Picture 1. Portugal, finished railway section

Picture 2. Evora, tests in building site

***Compactness measurement with radio-isotopic device***

One of the most widespread measurement procedures (ASTM D6938), in which a detector observes the gamma-radiation let into the soil, than crossing the soil; and the number of the impulsions counted under the measurement time is proportional to the wet density of the soil. Plane probe and pin probe measurements happened as well. For the determination of the compactness degree is needed also the value of the water content and the reference density, to which the field dry density is compared. In Europe characteristically according to the EN 13286-2 is the "modified-", on German areas still the application of the "simplified" Proctor dry density, like a largest dry density in use. The examination time is 15-25 minutes and it is necessary to make three parallel examinations, to average it. Two laboratory technicians is the staff requirement. The measurement accuracy is high +/-5-6%

Picture 3. Isotopic compactness measurement

Picture 4. Sand-filling method

***Sand filling method***

The principle of the measurement (ASTMD4914) is that the soil sample taken out with the chisel, a spoon, is substituted for sand, in order to define its volume. Onto the surface they put the circle disk slot scheme, it is taken out carefully through its slot then, its wet mass and its water content are measured. Later the pit is filled up with dry sand, calculating the correct volume. Definitely time and energy-intensive, indeed it is considered a method "on all fours". The other variant of the method, to put rubber membrane into the cavity, and water with measured volume into it. From the received field density it is - taking the reference density into consideration - the compactness degree calculated.

According to the series measurement of 30 pieces of the Ramkhamhaeng University of Bangkok the compactness-rate calculated with the sand filling method compared with the B&C dynamic compactness-rate and the average value manifested an onto a tenth identical value.
The examination time of the sand filling method is 25-35 minutes on site; one laboratory technician is sufficient. A parallel examination is not applied.

Pictures 5-6. ASTM Sand-filling test

**Megjegyzés [BB1]:** Más kép

***B&C dynamic compactness-rate measurement***
Very successful Hungarian examination, in which transforming the Light Falling Weight Deflectometer into a small disk measuring device. It generate the compaction curve, in that manner, that we drop the falling weight 10-18 times from a given altitude with a 10kg weight using a damping spring on a D=163mm diameter rigid plate. This compacts the layer with $p_{din}$=0,35 MPa dynamic under-plate pressure (CEN WA 15846 and UT2-2.124). From the series of the fall amplitudes defined the compaction curve and the on-site relative compactness degree, which characterizes the compaction attained - beside the given water content. The dynamic compactness-rate (Trd%) is the multiplication of the on-site relative compactness degree (TrE%) and the moister correction coefficient (Trw). The coefficient taking the effect of the moistness into consideration characterizes the proctor-compactness of the soil depending on the water content. (Trw<=1,00).

Picture 7-8. B&C ANDREAS new dynamic compactness and bearing capacity measuring device

The 2% measurement accuracy of the dynamic compactness measurement enables the correction of the efficiency of the quality control, the fair quality attestation. The measurement is very quick, compared to the other measurement methods, needs one laboratory technician, and forms an average with a parallel measurement. The B&C dynamic compactness measuring method is independent of the density; therefore it is suitable for the measurement of any type of laying materials, even of the very low density flying ash, or of the inhomogeneous density slag, but also suitable for the examination of calcareous stabilisations which unable with the isotopic apparatus. The B&C near the dynamic compactness degree at the same time determines also the dynamic load bearing capacity modulus Ed (MPa) of the soil. A parallel examination is applied.

***BP-LFWD light falling weight device***

As it is known, from the measurement result of the 300mm disk diameter BP-LFWD (Big-Plate Light Falling Weight Device or German LFWD) s/v (deflection/velocity) quotient can be measure the dynamic modulus, and somehow represent the compactibility. The appliance of the LFWD type devices is widespread in Europe for the determination ***only the load bearing capacity***, at which from a given height they drop a 10kg mass body. This creates only $p_{din}$=0,1 MPa press under the 300mm diameter plate (TPBF-StB8.3, RVS08.03.04), using c=2 Boussinesq plate-multiplier. The advantage of the LFWD type appliances is that they don’t need counterweight, loading car. The average settlement amplitude (s) must be determined of the second series, and the dynamic bearing modulus $E_{vd}$ = 22,5/s ($N/mm^2$). The examination time is 10-15 minutes on site; one laboratory technician is sufficient for the measurement. Parallel examination is not applied.

Picture 9. Small plate and Big-plate LFWD light falling weight devices

***PORTANCEMETRE-method***

French instrument for continuous measuring of the load bearing capacity of the earthwork towed with a vehicle. The entire measurement can be commanded from the driver's cabin, where the data collecting and processing system receives placed. The wheel with a vibratory load, the perceptive framework of this are hanged on the frame of the trailer. The measurement velocity is 1m/sec. The great advantage of the examination is that it is continuous, in 30 minutes 1.800 metres are measurable on the site. A laboratory technician and a leader are sufficient for the measurement. As a parallel examination they measure backwards and forwards on a trace beside each other.

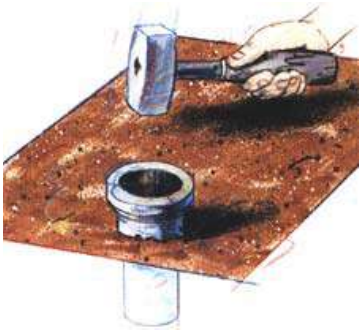
Pictures 10-11. Portancemetre continuous load bearing capacity measuring method

***Compactness measuring method with tube sampling***

This measurement method wasn't applied in the Portugal comparison. The tube sampling method is a well-known old measurement, but its accuracy according to certain estimations is worse than the isotopic measurement. The mass of the substance staying in the cylinder, the value of the water content are needed for the determination of the field density, and then the relation of the dry field density calculated in this manner and the reference density is the compactness degree.

In Europe characteristically according to the EN 13286-2 is the "modified-", on German areas still the application of the "simplified" Proctor, largest dry density in use. The examination time is 10-15 minutes and it is necessary to make three parallel examinations, to average it. One laboratory technician is sufficient for the measurement.

We are aware of a comparative measurement on a flying ash filling on the motorway M35.  The values of the B&C measurement were some percentages lower, than the tube sampling results.



Picture 12. Tube sampling method

Picture 13. Durham MDI

***Durham MDI (Moister Density Indicator) density and water content measuring device***

American instrument working on principle of dielectric constant. It measures not only the water content, but also the density with this method, after a calibration. Its mistake is minor, than the one of the isotopic instruments, but it may not void the reference density. The value of the measured water content is needed for the determination of the field density, then the proportion of the dry field density calculated in this manner and the reference density - typed into the apparatus by the operator - gives the compactness degree. The application of the according to the EN 13286-2 "modified-", respectively the "simplified" Proctor, maximum dry density is possible as well, just as like by the other measurements applying measurements. The examination time is 10-15 minutes. An American measurement regulation was made according to our knowledge, we do not know about a European variant. Apparently one laboratory technician is sufficient for the measurement. This measurement method wasn't applied in the Portugal comparison.

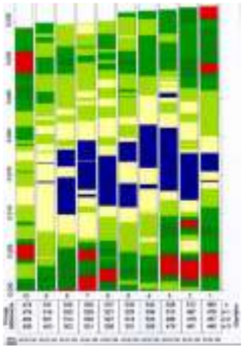
***Continuous Compaction Control (CCC) – Large surface compactness measurement***

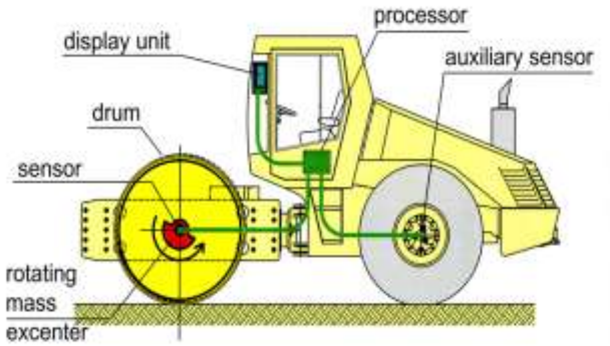
CCC was invented by Dr. Heinz Thurner in 1978 and was further developed by TU Wien under the auspice of Prof. H. Brandl, by his assistants Dr Adam and Dr. F. Kopf.

This method can be used to qualify the large surface earthworks in terms of compactness and load bearing capacity. With the accelerometer fixed on the cylinder from the changes of the measured amplitudes the $E_{vib}$ modulus and the Omega index-number can be determined. (The inventor/developer of the Terrameter and the Omega-value was Dipl.-Ing. Uwe Blancke, Bomag, Germany).

The measurement gives a three dimension table result, which identifies with colour codes the for the compactness typical measurement results. It is related to the compactness degree in an experiential way. Some excellent correlation were found between dynamic load plate tests ($E_d$) and the CCC values by TU Wien and these were used to elaborate a standard. These correlations were also examined with the BP-LFWD light falling weight device, facilitating its application.

This standard for calibration etc. in the Austrian Codes of Road Engineering has been used for more than 15 years for road- and highway-engineering, railway engineering, for airfields, for all earthworks (dams, dykes, etc.) and even for landfilling/waste deposits.
We remark that the studies of the Geotechnical Faculty of the Technical University Slovenia manifested an outstandingly good correlation ($R^2$=0,92) between the B&C dynamic bearing capacity (Ed) and the value of the CCC $E_{vib}$.






Pictures 14-15. CCC large surface compactness test

***Compactness coefficient determined from static load bearing capacity modulus***
The load bearing capacity was examined in Evora according to the static plate examination traditional (used also in Hungary) 300mm (ASTM D1194) and the D=600mm French standard (NF P 94-117-1). The ratio of the two modulus (Ev2 load bearing capacity modulus coming from the second uploading and Ev1 arising from the first loading) is the compactness-coefficient known as a related parameter with the compactness (see UT2-3.206). The uploading sections and the valuation of the measuring methods differ in some points from the one accustomed in Hungary.
The examination time is 25-35 minutes on the site, one laboratory technician is sufficient for the measurement. For the loading a counterweight is necessary. Parallel examination is not applied.

Pictures 16-17. Static load bearing capacity test with D=600mm plate

**Young modulus**
For load bearing capacity feature's determination suitable applied the GeoGauge electromechanical method (D 6758 – 02). The instrument recommended for the measurement of granular materials without cohesion, and for the analysis of slightly muddy and clayey substances, that are not exposed to

the change of the moisture content. The disadvantage of the method is that vibratory load of the environment disturb the measurement result very easily. According to our knowledge the compactness cannot be characterised, but from the load bearing capacity it is possible to deduce the suitability based on the test compaction. The examination time is 10-15 minutes on the site, one laboratory technician is sufficient for the measurement. A parallel examination is not applied.

Pictures 18-19. Geogaue instrument

***Questions of reference density***

The regulation for the modified Proctor test in Hungary was the MSZ 14043/7, after joining the EU the standard became MSZ EN 13286-2 recommended (respectively its point 7.4 s modified Proctor test), without any significant change. Since 2005 is in Hungary the standard EN 13286-2 valid reflecting the European regulations.

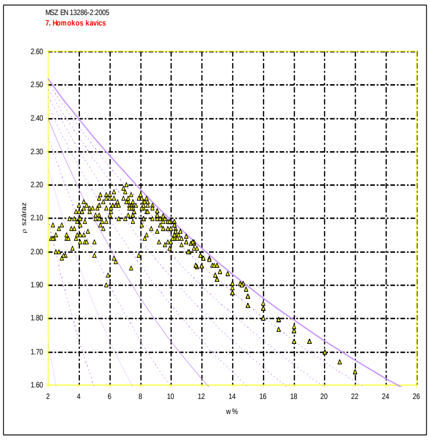
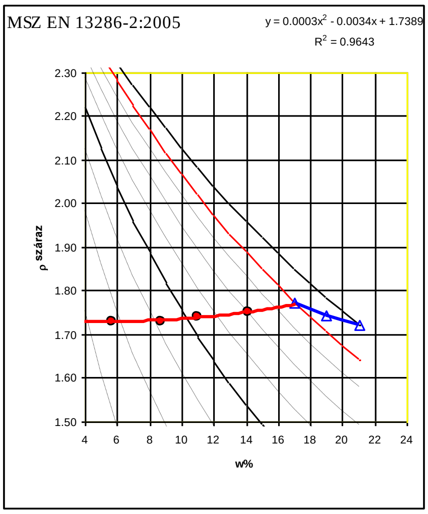


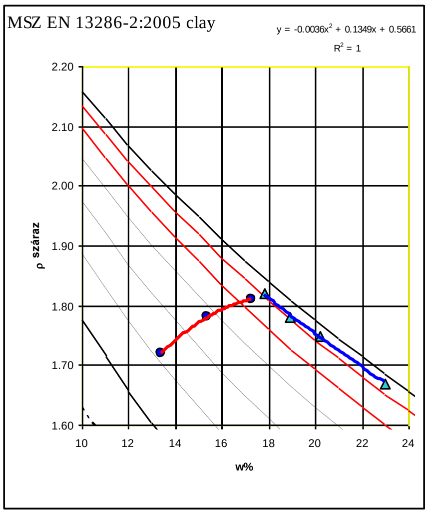

Figure 1. Proctor laboratory-round test: sandy Gravel (saGr)

It is not well-known that the error of the compactness degree calculated with the reference density in some measurements can reach even +/-4 to 5 %. The compactibility test is so long and circumstantial that a measurement series with large sample number is getting prepared most rarely for the definition of the examination standard . We made an analysis from a numerous round examination (Proctor round-test of year 2005), which presents the problem well.

For the characterisation of the tendency we indicated on the figure some calculated values in the range of the high water contents for the characterisation that we can justify by the shape of the characteristic Proctor curve, that it osculates to the saturation lines clings in the wet branch (see Figures 1-2-3)

We do not detail, allude to our previous publications only, in which we suggested the separation of the saturation line belonging to $w_{opt}$ (for example saturation S=0,88) and the section right, resp. leftwards from the intersection point of the dry branch Proctor curve. The reason of this is that the behaviour of the material changes in the wet branch significantly and because of this it is mathematically not to treat with identical conditions. The common point between the curves with two types does not give an authority for us to treat them as an identical mathematical model, one curve.




sand clay

Figures 2-3. Proctor curves processed by the new method

After the "***two sections one curve***" theory valuing the Proctor curve (2006 Phong - Subert) examined it is determinable that the processing show different optimal water contents. We showed that the curve of the dry branch is mostly convex, but sometimes a linear, or even a slightly concave curve. The wet behavioural curve section osculates typically always between the saturation lines and finally approaches to saturation S=1 (2-3 Figure). Because by high saturation the field compaction is also impossible, therefore it does not make sense to draw the curve into the mathematical model. The Proctor curve can be calculated with a regression analysis from the measured points and at the same time it provides also the moister correction curve necessary for the dynamic compactness measurement ($Trw=\rho_{di}/\rho_{dmax}$).

As an example we present a typical case when the optimal water content differs. In the new processing the breakpoint is evident. (See on Figures 4-5.).

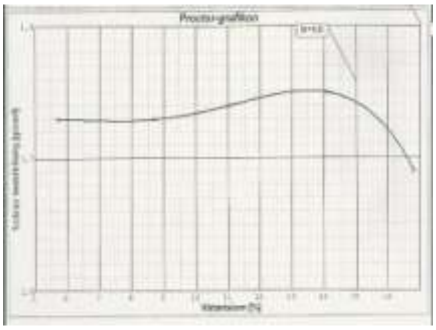


Figure 4. Conventionally processed Proctor curve

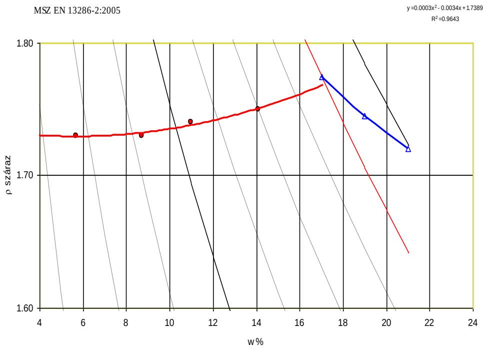



Figure 5. With the new method processed , complex Proctor curve

### *Correlation of saturation and air content with the compactness-rate*

In the framework of a research with the processing of 566 pieces of Proctor results, we determined for eight different materials the correlation of the air content belonging to the optimal water content and the saturation. It is characteristic to have far lower air content than 12 tf% at the water content proving to be the optimal one. This is how to find at the available highest dry density that is equal the 100% compactness-rate.

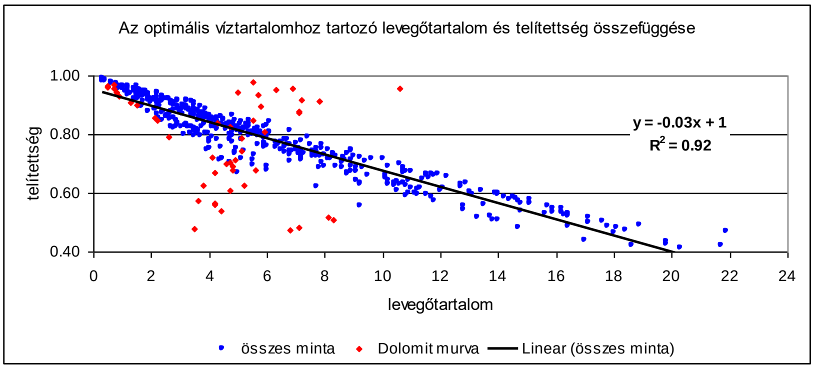



Figure 6. Relationship between the optimum air content belonging to $w_{opt}$ and the saturation

Setting up a correlation from the regression analysis the optimal saturation belonging to the 100% compactness appeared for one between S=88–94. This is of deciding importance from the aspect of the dynamic compactness measurement, because dynamic methods are applicable in three-phase systems only (neither large plate LFWD, nor Dynatest nor KUAB), because the water can not be compressed by the dynamic hits. According to Figure 7 the proposed lower value of the saturation, may mark in S = 0,88, as a conclusion from this statistical examination. According to this the saturation belonging to the optimal water content is approximately the air content with threefold weight deducted from one.

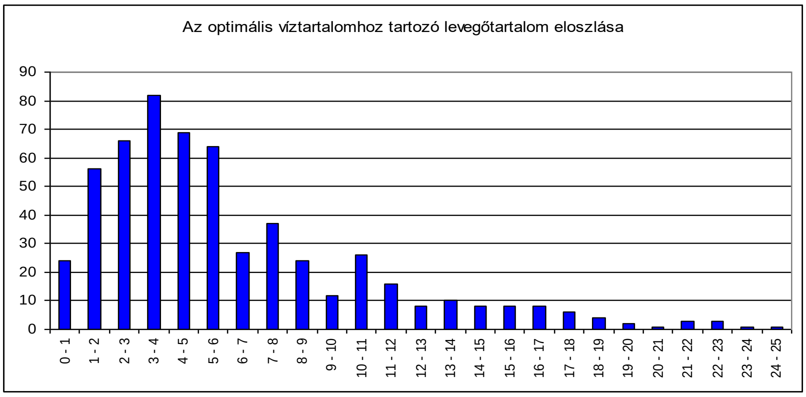



Figure 7. Distribution of the air content belonging to the optimal water content

***Literature:***


- Brandl H., Kopf F., Adam D.: Continuous Compaction Control (CCC) with differently excited dynamic rollers. Federal Ministry of Traffic, Innovation and Technology, Road Research Volume 553, Vienna 2005
- Correia A. Gomes, Brandl H. (2001) Geotechnics for Roads, Rail Tracks and Earth Structures. A.A. Balkema Publishers, Lisse, NL ISBN 90 2651 844 7
- FGSV 516:2003 Merkblatt für die Verdichtung des Untergrundes mit Unterbaues im Straßenbau.
- "Measuring Method for Dynamic Compactness & Load bearing capacity with SP-LFWD" CWA 15846
- MSZ EN 13286 – 2 "Unbound and hydraulically bound mixtures 2.Test methods for the determination of the laboratory reference density and water content. Proctor compaction"
- MSZ EN 13286 – 3 "Unbound and hydraulically bound mixtures 3.Test methods for laboratory reference density and water content. Vibro-compression with controlled parameters"
- EN 13286 – 4 "Unbound and hydraulically bound mixtures 4.Test methods for laboratory reference density and water content. Vibrating hammer"
- Report on usage of Andreas dynamic load bearing capacity and compactness deflectometer / University of Ljubljana Katedra za mehaniko tal z laboratorijem.
- D. Adam & F. Kopf "Operational devices for compaction optimization and quality control"
- Ms. Panarat "Comparison of B&C LFWD and sand filling method" Ramkhamhaeng University, Thailand
- ÚT2-2.124 "Measuring of dynamic compactness and dynamic load bearing capacity with small plate light falling weight deflectometer"
- Dr J.Pusztai– Dr E.Imre– Dr J.Lőrincz– I.Subert – T.Q.Phong: "Development of large surface dynamic compactibility measurements with location identification and the continuous on site measuring of the sinking of the compacting cylinders" Report of COLAS K+F year 2007.
- Subert I. - Phong T.Q.: "New intendments of Proctor tests" Mélyépítéstudományi Szemle 2007
- Király Á. - Morvay Z.: The questions of efficiency of the quality tests of earth works in Hungary
- Subert: Method for measuring Compactness-rate with New Dynamic LFWD. XIII. Danube-European Conference on Geotechnical Engineering Ljubljana, Slovenia, 2006
- Subert I.: „Dynamic compactibility measurements on Hungarian highways and reconstruction in cities" Geotechnical Conference 2006 in Ráckeve, Hungary (17-18. October 2006.)
- Fáy M. - Király Á. - Subert I.: "Modelling of the use of city traffic with new measurement of dynamic compactness and dynamic bearing capacity" Városi Közlekedés, 2006
- Fáy M. - Király Á.: - Subert I.: "Recovering and solution of an earth work-compactness anomaly" Mélyépítéstudományi Szemle. 2006
- Subert I.: „Actual questions of dynamic compactibility measurement. New experiences of dynamic compactibility measurement." Geotechnical Conference 2005 Ráckeve, Hungary.
- Subert I.: „New, environmental friendly, economical measuring gauges in traffic constructions" Geotechnical Conference 2004 Ráckeve, Hungary.

- Subert I.: „New parameters of dynamic compactness and load bearing capacity measurements and the questions of conversion of the modulus.”
  Közúti és Mélyépítési szemle 55. évf. 2005. 1. sz.
- Subert I.: „B&C dynamic compactness measurement”
  Mélyépítés Oktober-December 2004 (p.:38-39).
- Subert I.: „B&C – a useful partner” Magyar Építő Fórum 2004/25 (p.:36).