# Test and Method is Proposed for Measuring The Dynamic Compaction-rate and Dynamic Modulus in Earthworks

## Test et méthode sont proposés pour mesurer le taux de compression dynamique et le module dynamique dans les travaux de terrassement

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ABSTRACT: Dynamic compactness-rate in-situ test is a new concept in Civil Engineering, developed to measuring the two most important quality parameters of earthworks 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 (LFWD) loading system from the first 6 drops. The D163mm small-plate deflectometer allows to reaching 0.35MPa stress under the plate, which providing suitable compaction work for on-site Proctor test. This press similar to the static load plate test and gives similar measuring range. This is very different to the other earlier p=0.1MPa (D300) LFWD dynamic press. Thus, practically one test can give information on both the compactness-rate both the bearing capacity. The theoretical background of the calculations is described. Analyzing the test results of eight years experience it is concluded that this environmental friendly green test conducted by a light weight portable equipment is more reliable, faster and economical than the other methods. Modification to the “CWA15846 Measuring method for Dynamic Compactness & Bearing Capacity with SP-LFWD” is proposed. This standard worked out by WS33 group in Hungary, adapted in Korea, China, Japan, New Zealand, Russia, Brazil, European Member States and lot of other countries.

RÉSUMÉ : Le test in-situ du taux de compacité dynamique est un nouveau concept en génie civil, développé pour mesurer les deux paramètres de qualité les plus importants des travaux de terrassements en même temps: le taux de compacité modifié% du gain de courbe de déformation de 10-18 gouttes et le module dynamique - utilisant le système bien connu de chargement de poids de chute de lumière (LFWD) à partir des 6 premières gouttes. Le déflecteur de petite plaque D163mm permet d'atteindre une contrainte de 0,35 MPa sous la plaque, ce qui fournit un travail de compactage approprié pour le test Proctor sur site. Cette presse est similaire au test de la plaque de charge statique et donne une plage de mesure similaire. Ceci est très différent de l'autre presse dynamique antérieur p = 0,1MPa (D300) LFWD. Ainsi, pratiquement un test peut donner des informations à la fois sur le taux de compacité et à la fois sur la capacité portante. Le contexte théorique des calculs est décrit. En analysant les résultats des essais de huit ans d'expérience, on conclut que ce test vert respectueux de l'environnement mené par un équipement portable léger est plus fiable, plus rapide et plus économique que les autres méthodes. Une modification pour la "CWA15846 Méthode de mesure de la capacité de compacité et de roulement dynamique avec SP-LFWD" est proposée. Cette norme a été élaborée par le groupe WS33 en Hongrie, adaptée en Corée, Chine, Japon, Nouvelle-Zélande, Russie, Brésil, les États membres européens et dans beaucoup d'autres pays

KEYWORDS: New Small-Plate LFWD, Measuring theory, Compactness-rate% from deflection, One test for two soil parameters.

## 1 INTRODUCTION, THEORY OF DYNAMIC COMPACTNESS-RATE

### 1 .1 *Measuring in laboratory - Proctor test*

Proctor test described in EN 13286-2 modified or simplified use $V_{wet}$=constant model in all laboratory. We cut the compacted sample after remove the top ring. One can determine the water content and mass, calculate the soil density, and dry density.

| | | |
|---|---|---|
| $\varrho_{i-1}$ | $\varrho_i$ | $\varrho_{di+1}$ |
| $\varrho_{di-1}$ | $\varrho_{dmax}$ | $\varrho_{di}$ |
| $w_{i-1}$ | $w_{opt}$ | $w_{i+1}$ |

Where $\varrho_{di-1} < \varrho_{dmax} > \varrho_{di+1}$

$w_{i-1} < w_{opt} < w_{i+1}$

The compacting work is the same (regulated in the standard). The cylinder volume takes part air, water and soil grain. (a = air volume, w = water volume, s = soil part volume, and $A=D^2.\pi/4$=const. The $M_{di}$ is different, $V_{wet}$=constant so the soil-cylinder density is:

$$\rho_{di}=M_{di}/V_i \quad \text{(g/cm3)} \tag{1}$$

The Proctor Compaction-rate is:

$$C_{Pr}= \rho_{di}/ \rho_{dmax} \quad \text{(g/cm3)} \tag{2}$$

Where the density is the highest, the water content is the optimum. Proctor compactness-rate is given in % in our country.

The new theory calculates from the $M_{dry}$ this is the real situation on the field. This mean, that the different water content causes different cylinder height.

The smallest cylinder gives the Proctor water optimum. The cylinder volume takes part air, water and soil grain. (a=air volume, w=water volume, s=soil part, and $A=D^2.\pi/4$=constant.

If the $M_{di}$ is constant, the $V_{wet}$ is different so the compacting of the soil-cylinder causes lower soil-cylinder height. The volume different between the different Proctor point can be calculated from the Proctor soil-cylinder heights, (supposing that A=constant). The compacting work is the same (regulated in the standard).

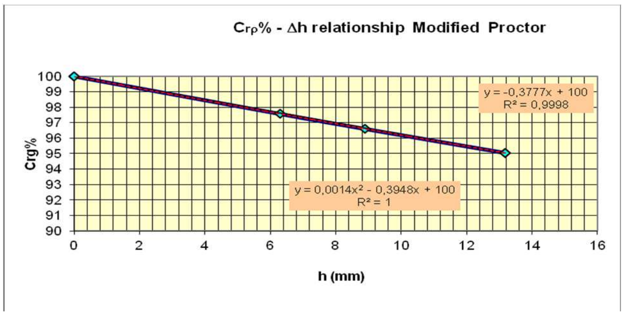
$V_{opt}$ is at the smallest cylinder height, we sign it V*. $\Delta h_i=h_i-h^*$ where h* is the smallest, the Proctor optimum, and $h^*=h_i-\Delta h$. The Proctor Compactness-rate is:

$$C_{Pr}=V^*/V_i=A.h^*/A.h_i=(h_i-\Delta h)/h_i=h_i/h_i-\Delta h/h_i= 1-\varepsilon \quad (3)$$

This shows that the compaction rate can be calculated from the height different, which can be seen as a deflection (settlement), in case of specialized surroundings.

*Deduction:* In the $M_{dry}$ model (on the field) the compactness rate is:
$C_{Pr}=V^*/V_i=(M^*/\rho_{dmax}) / (M_i/\rho_{di})$ but $M_d$=const, so $M_i=M^*$
$C_{Pr}=V^*/V_i=(M^*/\rho_{dmax}) / (M^*/\rho_{di})$
$C_{Pr}= \rho_{di} / \rho_{dmax}$ which is the traditional compaction rate, and this means that this model and calculation leads the same result. This justify that the compaction rate calculated from the height different is equal with the compaction rate calculated from the density-ratio.
Example: siSa, silty-sand Proctor test results:

| | | | | | |
|---|---|---|---|---|---|
| w % | 8,9 | 10,9 | 11,1 | 12,5 | 13,9 |
| ρd (g/cm3) | 1,99 | 2,06 | 2,06 | 2,01 | 1,96 |




1 Figure Relationship between Proctor Compaction rate, and settlement mm as the height different of soil cylinders in model Mass-dray

Proctor mould was "A", rammer "B" EN 18286-2. Assuming that the cylinder $M_d$=constant, and the compaction work=constant, can be calculating the volume components, and the heights of cylinders. The chosen basic volume is arbitrary $V_{opt}$=2065 cm$^3$ (calculated from the Boussinesq depth effect ≈ 253mm and the area of Proctor mould bottom). If we determine the regression between the height different Δh and the Proctor compaction rate in the laboratory Proctor test, we've got really good $R^2$ value. The slope of the linear regression we call Φ, and we found it is constant. The linear regression formula is

$$C_{rd}=100-\Phi^*\Delta l \ (R^2=0{,}999) \quad (4)$$

the non-linear (polynomial) formula is:

$$C_{rd}=(100-0{,}014\Delta l^2-0{,}39\Delta l) \quad (R^2=1{,}0) \quad (5)$$

This shows that the minimum of the actual compactness is about 71%.

### 1 .2 *Measuring on field –in situ Proctor test*

The differences of the heights (the chosen base is the optimum water content cylinder height) can be consider as settlement. Each difference (settlement) has a pair of compactness Proctor-degree. Proctor work=constant, Proctor compactness of each sample is 100%, because of the same Proctor work, only the effect of water content causes the differences.
Moister correction coefficient comes from the Proctor dry densities curve $T_{rw}=\rho_{di}/\rho_{dmax}$ and on all Proctor points is valid, that

$$CPr_i=T_{rwi} \ . \ 100\ (\%), \text{ where } T_{rw}=\rho_{di}/\rho_{dmax} \quad (6)$$

and $T_{rw}$<=1 value, so we must determine the Proctor behaviors for the dynamic compactness rate also.
If we call this measured point on site as a relative on site compactness, we can say, that the on-site measured compactness rate ( %) is

$$C_{rd}\%=C_{rE}\%*T_{rw} \quad (7)$$

The Small-Plate Light Falling Weight (SP-LFW) loading system based on dropping a cc 10kg weight from 72cm, and loading the soil surface p=0,35MPa under-plate stress, using D=163mm diameter. With an accelerometer and quartz-clock can determine the settlement:
$s=a/t^2$ where
- "a" the acceleration m/sec2,
- "t" time (sec)

CEN 15846 requirement need 10-18 drops, and this settlement shows decreasing with the drop number. The difference of this settlement can assumed as a permanent settlement. In this way, one can calculate the summed permanent settlement from the beginning to the actual drop number.

$$D_m = \left[ \sum_{i=1}^{i=17} d_i * \sum_{1}^{i} SUM\ \Delta s \right] * \frac{1}{17} \quad (8)$$

Because of the settlements decreasing, the weighted average of this lines give a value of resultant settlement, and average - divided the sum of this line by 17. This called as a deformation modulus (Dm).

When plotting this value depending on drops, the second part of the settlement curve becomes a near linear line, so after 6-8 drops can be *estimated* the other part of the compaction-line. This is the shortened compaction test, needs minimum 10 drops, instead of 18. This $D_m$ ($C_{rE}$%) result will be a little bit worse than the 18 drops would be.

### 1.2.1 *Effect of layer thickness*

Determined this relationship between the height different, can be extrapolated on the layer thickness of built earthwork (structure). Settlement can calculate from Boussinesq-formula, on different $E_i$ modulus. The situation in the laboratory is different from the field. The effective depth and the hypothetic (under-plate) cylinder height is different. The ratio is $F_{eff}/H_{Pr}$=1,25
Proctor Φ value depending on layer thickness. We found that no need correction between 22-28cm layer thickness if we accept Φ=0,380 near TrE%=±1% accurate range. No need correction between 20-31cm layer thickness if we accept Φ=0,380 near TrE%=±2% accurate range. In other cases the Φ correction is:

$$\Phi=9.1185\ h^{-0.9871} \text{ where h is the thickness in cm} \quad (9)$$

CrE% is the measured test value using the BC SP-LFWD device, which represents the roller work effectiveness, independently from the optimum water content, near the given field-water:

$$C_{rE}\%=100-1{,}25.\Phi^*.D_m \text{ and } C_{rd}\%=C_{rE}\%*T_{rw} \quad (10)$$

### 1.2.2 *Controlling the sufficient compaction work of test*

CWA 15846 determine the layer thickness limits, to ensure the accuracy of the dynamic compactness test. Lot of cases may be the layer ticker, or must to know if the compactness work was enough or not. In this situation the rule is the next:

Perform a new compactness test, without moving the plate. If the result $C_{rE}$% is smaller than 98%, then correction needed on Trw value:
CWC=Control Work Coefficient = CrE%/100 and
Trwcorr=Trw . CWC
In this way the dynamic compactness rate measuring can be considered as an independent test from the layer thickness.

$$D_m = \left[ \sum_{i=1}^{i=17} d_i \cdot \sum_{1}^{i} SUM\ \Delta s \right] \cdot \frac{1}{17} \quad (11)$$

1 .2.3 *Corrections for Simplified Proctor Compaction-rate*

The dynamic compaction rate works with modified Proctor (in the $T_{rw}$). The simplified (standard) compactness-rate one can calculate

$\beta = (\rho_{dmax\ simplified})/(\rho_{dmax\ modified})$ and (12)

$T_{rd\ Simplified}\% = (1/\beta)\ .T_{rd}\%$ (13)

2 DYNAMIC MODULUS

2 .1 *Traditional way how to test the Dynamic Modulus*

The application of dynamic load measurement methods has spread all over the world very quickly. The method does not require any counterweight, and the measurement is much quicker in comparison to the earlier static method. It has enabled a measurement of the same modeling 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. (Dynatest, KUAB, German LFWD, HMP, Loadman)

As it is known, from the measurement result of the D=300mm disk diameter Big-Plate Light Falling Weight Device the s/v (deflection/velocity) quotient somehow can represent the compactibility also. The appliance of the LFWD type devices (Zorn, HMP) is widespread in Europe for the determination *the load bearing capacity*, at which from a given height drop a 10kg mass body. This creates only $p_{din}$=0,1 MPa press under the plate (TPBF-StB8.3, RVS 08.03.04), near using c=2 Boussinesq plate-multiplier (flexible) and 0.5 (clay) Poisson-ratio (from this $C\mu$=22,5) and $E_{vd}$=22,5/s (N/mm$^2$). The average settlement amplitude (s) must be determined of the second series (from 4-5-6 drops). Parallel examination is not applied.

In the extension of the CCC method Professor Bradl-Kopf-Adam suggested to use this method as a very informative, pre-calculated calibrated test.

This tests are measuring only the dynamic modulus, for the measuring of compactness must use another devices, like tube-sampling, Sand-Cone method, Nuclear Density Device. The used formula is the same:

$$E_d = \frac{(1-\mu^2)\cdot c \cdot p_{din} \cdot r}{s_a} \quad (14)$$

2 .2 *Correction of the Dynamic Modulus-suggestion*

Dynamic modulus should be corrected (German-type and ASTM BP-LFWD and LFW also should be) depending on soil density due to Low of Impulse. Correction must be done for $E_d$ only, it has smaller effect on $C_{rE}$%. Correction must only be done in case fly-ash, slag or other high-density materials

$E_{d\ KORR} = E_d$ *K where K= 1.766/ $(\rho_{dmax}$*1/(1+$w_{opt}$)) (15)

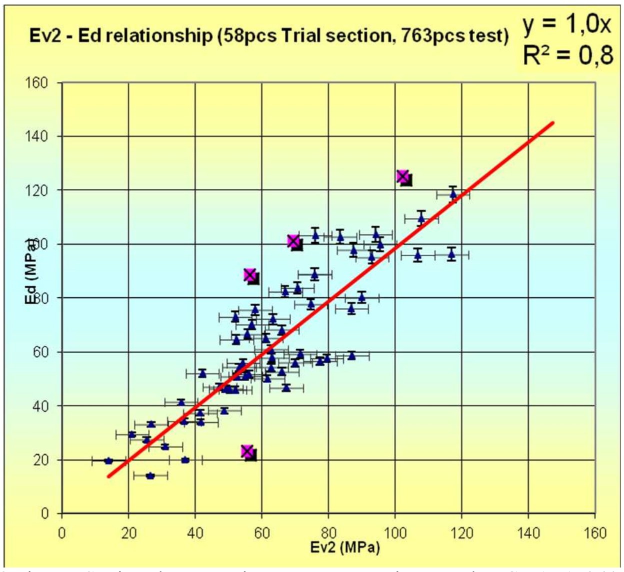
3 RELATIONSHIPS WITH THE TRADITIONAL TESTS

3 .1 *Correlation Between Static Bearing Capacity Test*

Based on Hungarian motorways M43, M7, M6 trial sections database, we analyzed the relationships. We involved 58 trial sections, on different soil, all of them 763 measured data point.

The investigation shows that the 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 SP-LFWD's $E_d$ value. The regression degree is rather good, which means that CWA15846:2015 may be a useful device in civil engineering practice.

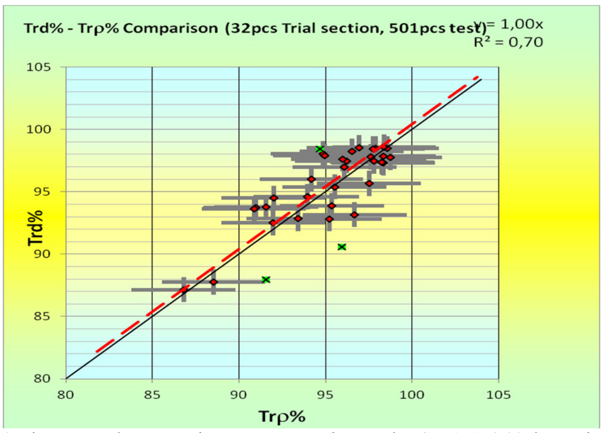
Static Load Plate tests have carried out by MSZ2509-3 (D=300mm) and the dynamic with BC-1 Dynamic Compactness- and Bearing Capacity device. The considered tolerance of static plate test is ±5MPa, the real calculated tolerance of CWA 15846 Ed value was ±2,6MPa. (Fig. 2).




2.Figure Static Plate Bearing Test comparing to the CWA 15864 dynamic Modulus

3 .2 *Correlation Between Isotopic and Dynamic Compactness*

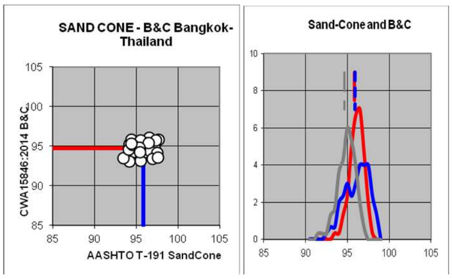
Based on Hungarian motorways M43, M7, M6 trial sections database, we analyzed the relationships also. We involved 32 trial sections, with all of 501 measured data point (figure 7.)
The investigation shows that $T_{rd}$% dynamic Compactness-rate equal to the other, density-ratio systems. ($R^2$=0.7).




3.Figure Nuclear Density Test comparing to the CWA 15864 dynamic C ompactness-rate

3.3 *Correlation between Sand-cone Test and the Dynamic Compactness*

Tested in RAMKHAMHAENG University, Bangkok Thailand Department of Civil Engineering (Comparison of B&C LFWD and sand filling method –Ramkhamhaeng University, Thailand Ms.Panarat-Mr Korrakoch Taweesin: Calibration Certificate B&C, Gabor Enterprise CO Ltd. 2007)




4. Figure AASHTO T 191 Sand Cone test comparing to the CWA 15864 dynamic compaction rate (Bangkok-Thailand) N=30pcs

## 4 CONVERSIONS

Number of trial section and investigation was built, before worked out this regressions and conversions:

*The estimated settlement* of the embankment (compactness rate changes to 100%): $10 \cdot D_m$ (if $D_m$=2,01 then 20,1mm/25cm, and 8cm/1m backfilling)

*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$^3$

*$E_{vib}$ from BC dynamic test:* $E_{vib}=0{,}5E_d+57$ ($R^2$=0,93) $E_{vib}$ CCC-method (University of Ljubljana). 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

$E_{vd}=0{,}42 \cdot E_{dEnd}=0{,}42 \cdot 131{,}6=55{,}3$MPa;

$E_{vd}=0{,}69 \cdot E_d=0{,}69 \cdot 86{,}8=59{,}9$MPa; the smaller: $E_{vd}$=55,3MPa

*CBR% calculation from BC2 dynamic test results:*

$CBR_5=5{,}43/s_{0a}$ ;$CBR_{2,5}=4{,}07/s_{1a}$ ;and the end CBR% is weighted average of this two. Chosen of CBR% is different from the habitual, because the loading curve is different in case of static method and the dynamic one. The weight of $CBR_5$ and $CBR_{2,5}$ to be determined for CBR% can be calculate from the rate of measured amplitudes $s_{0a}$ and $s_{1a}$. The weighted of $CBR_5$ is $1-(s_{0a}/(s_{1a}+s_{0a}))$; the weighted of $CBR2_{,5}$ is $1-(s_{1a}/(s_{1a}+s_{0a}))$. The sum of the weight-values=1. The election and the method of calculation reflects the property of dynamic compaction curve, reflects the nature way and the manner of assessment weighting for individual. Example: $s_{0a}$=1,33mm and $s_{1a}$=0,47mm, $CBR_5$=5,43/1,33= 4,1% ; $CBR_{2,5}$=4,07/0,47=8,7%; CBR25 weight is (1-(s0á/(s1á+s0á))= 0,231; CBR2,5 weight is (1-(s1á/(s1á+s0á))=0,739;

CBR%=4,1·0,231+8,7·0,739=CBR%=7,5%

## 4 CONCLUSION

The application of the CWA15846 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 self-control ISO 9001 both in accredited qualifying.

Two very different measurements (compaction test and bearing capacity test) can be executed with one device according with CWA15846 using B&C 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.

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## 6 REFERENCES

CWA15846:2008 Measuring method for Dynamic Compactness & Bearing Capacity with SP-LFWD (Small - plate Light Falling Weight Deflectometer)

EN 13286-2 "Unbound and hydraulically bound mixtures 2.Test methods for the determination of the laboratory reference density and water content. Proctor compaction"

CEN ISO/TS 22476-13 Geotechnical investigation and testing – Field testing, Part 13 Plate Loading Test

MSZ 2509-3:1989 Útpályaszerkezetek teherbíró képességének vizsgálata. Tárcsás vizsgálat.

MSZ 15320 Földművek tömörségének meghatározása radioizotópos módszerrel

MSZ15846:2015 Dinamikus tömörség és teherbírás mérés SP-LFWD kistárcsás könnyűejtősúlyos berendezéssel. Hungarian Standard

ÚT 2-2.124 Dinamikus tömörség és teherbírás mérés kistárcsás könnyűejtősúlyos berendezéssel.

D.Adam, F.Kopf (2004) Operational devices for compaction optimization and quality control (Continuous Compaction Control & Light Falling Weight Device). *Proceedings of the International Seminar on Geotechnics in Pavement and Railway Design and Construction*, Rotterdam.

Brandl, H. and Adam, D. (2004) Basics and Application of the Dynamic Load Plate Test in Form of the Light Falling Weight Device. *A.W. Skempton Memorial Conference. Proc. of Imperial College*, London.

Anna Petkovsek (2008) Report on usage of Andreas dynamic load bearing capacit ity of Ljubljana Katedra za mehaniko tal z laboratorijem. Univerza v Ljubljani Faculteta za gradbenistvo in geodezijo. *Report* p.:10

Ms. Panarat (2007): Comparison of B&C LFWD and sand filling method Ramkhamhaeng University, Thailand. *Calibration Report*

Dr Boromisza Tibor (2005) Megjegyzések Subert István: A dinamikus tömörség- és teherbírás mérés újabb paraméterei és modulusok átszámíthatósági kérdései c.cikkéhez. *Közúti és mélyépítési Szemle* 55.évf 2.szám. p.:35-36.

Subert (2006) Method for measuring Compactness-rate with New Dynamic LFWD. *XIIIth Danube-European Conference on Geotechnical Engineering Ljubljana*, Slovenia 2006, V.2. p:125-130.

Subert (2006) CWA15846-WS33 Measuring method for Dynamic Compactness & Bearing Capacity with SP-LFWD (Small - plate Light Falling Weight Deflectometer) Draft. p.26

Subert (2016) CWA15846:2008 Modification Draft and Main Background Studies. Conference on Engineer Geologies and Rock Mechanics Budapest 2015 p.379-394.

Subert (2014) Isotope-free Compaction-rate & Bearing Capacity Measure on Lime Stabilization – Self control. Article and Presentation. *Carmeuse Conference*. 09 sept 2014 Vecsés, Hungary p.:10

Subert (2014) Izotópmentes tömörség- és teherbírás mérése – Önellenőrzés. *2014EPB Konferencia Gyergyószentmiklós, Románia*, p:14, á 6.

Subert-T.Q.Phong (2009) Az izotópos és a dinamikus tömörség szórásának vizsgálata. *Transport Science Bulletin / Közlekedéstudományi szemle* apr p:23-27.

Subert (2009) A tömörségi fok átszámítása az egyszerűsített és módosított Proctor vizsgálatok között". *Transport Science Bulletin / Közlekedéstudományi szemle* jun-2009 p:23-28.

Subert-T.Q.Phong (2007) Proctor-vizsgálat új értelmezési lehetőségei. *Revue of Roads and Civil Engineering / Közúti és mélyépítési szemle*, ISSN 1419-0702 , 57. évf. 12. sz. p.7-12.

Fáy M., Király Á., Subert I. (2006) Közúti forgalom igénybevételének modellezése új, dinamikus tömörség- és teherbírásméréssel. *Urban Transport / Városi közlekedés*, 46. évf. 5. sz. 274-278. o