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

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Introduction

The application of light falling weight dynamic compactness and bearing capacity measuring gauges in the qualifying measurements of civil works are more and more popular and wide-spread. The counter-weight, which is essential for the static bearing capacity measurements, here is not necessary; therefore the measurement is simpler and faster. Owing to the axle load of 15 tons permitted in the European Union, at the layers of the newly built surface pavements not having binding material, it is proposed to apply the loading range of 0,3 – 0,4 MPa and the dynamic compactness- and bearing capacity measuring method introduced in the present document in the qualifying measurements. The static bearing capacity test simulates rather the structure – weight loading considering consolidation, while the dynamic test simulates rather that compacting originating from the dynamic stress of the traffic.

Instead of the former measuring method of the dynamic modulus applying 300 mm plate diameter and 0,1 MPa under-plate loading the development of the dynamic small-plate measuring method applying higher loading range became necessary, which measures in the same 0,3 – 0,4 N/mm2 (MPa) loading range like the static bearing capacity-measurement (DIN 18134 or CEN ISO/TS 22476-12). The measurement method suitable for the test without correction +/- 1Trd% accuracy in case of 22-28cm layer thickness, and +/- 2Trd% accuracy in case of 20-31cm built layer thickness.

The small-plate light falling weight deflectometer introduced in this document facilitates the determination of the compactness rate and the dynamic modulus with a single measurement on the newly-built layers preserving the compacting water content. The advantage of the dynamic compactness measurement is that the bearing capacity of the counter surface needed for the compacting is always known and checkable. The method executes the complete compacting with the same work as the laboratory modified Proctor-test, but at site, at all measurements and it determines the original (before measurement) on-site relative compactness of the layer of given moisture content from the calculated ~~depression~~ settlement amplitudes and the compaction-~~depression~~ settlement curve.

In the theory of the compactness rate determined with the dynamic method and the density measurement (isotopic, sand filling, rubber bulb…) is the same, so no new limit value (compactness rate requirement) is necessary to prescribe for the dynamic compactness rate; only the existing requirements need to be met.

The dynamic compactness rate is not affected by the density inhomogeneity or the density anomalies. Accordingly, it is outstandingly suitable for the reliable qualifying of the layers and embankments made of fly ash, blast furnace slag and other secondary materials of inhomogeneous density. The reference density, as the measurement error of the density of the compacted layer does not charge this method, therefore it is more reliable and gives more accurate measurement result.

The dynamic compactness and bearing capacity measurement does not apply any isotope source, but an environment- and health-friend deformation-measuring method.

1 Scope

The present document specifies a method for measuring the dynamic compactness rate and the dynamic bearing capacity modulus with a single measurement on the newly-built layers preserving the compacting water content at ~~road~~ earthworks construction.

2 Normative references

The following referenced documents are indispensable for the application of the present document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13286-1:2003 Unbound and hydraulically bound mixtures Part 1: Test methods for laboratory reference density and water content. Introduction, general requirements and sampling

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

~~MSZ 2509-3 Bearing capacity test on pavement structures. Plate bearing test~~

EN 933-1:1998 Tests for geometrical properties of aggregates - Part 1: Determination of particle size distribution - Sieving method

EN 1097-5:2000 Tests for mechanical and physical properties of aggregates - Part 5: Determination of the water content by drying in a ventilated oven

EN 1097-6: 2001 Tests for mechanical and physical properties of aggregates. Part 6: Determination of particle density and water absorption

CEN ISO/TS 17 892-1 Geotechnical investigation and testing - Laboratory testing of soil - Part 1: Determination of water content

CEN ISO/TS 22476-13 Geotechnical investigation and testing - Field testing - Part 13: Plate loading test

EN 5725-2 Accuracy (trueness and precision) of measurement methods and results - Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 13286-1:2003 and the following apply:

3.1 Dynamic bearing capacity

The feature of either a granulous layer or earth-work with a thickness of a maximum of 30 cm, by which it is able to stand the short-time dynamic loading, under given soil-physical parameters (water content, grain distribution, internal friction).

3.2 Dynamic (bearing capacity) modulus

A parameter characterizing the bearing capacity which is calculated with the Boussinesq-formula from the ~~depression~~ settlement amplitude emerging as an effect of a dynamic loading, besides a given impact number, considering the Poisson's ratio and the diameter of the loading disc. Sign: E_d or E_{dend}, unit: MPa.

3.3 Deflection (~~depression~~ settlement amplitude)

A vertical displacement measured in a given point under defined loading circumstances (loading, loading duration) which characterizes the vertical deformation of the examined material layer during the dynamic measurement. Sign: *s*, 0,01 mm

3.4 Bearing capacity measurement

A procedural method on the bearing capacity measurement, based on theoretical considerations which is executed by the measurement of the deflection (deformation) emerging as an effect of the loading put on the surface of the layer.

3.5 Static bearing capacity measurement

Site examination procedure for determining the static bearing capacity modulus of the earth-work, the sub-soil or the pavement layers, in accordance with ~~MSZ 2509-3~~ CEN ISO/TS 22476-13, by gradual and slow loadings, during which a considerable part of the consolidation occurs.

3.6 Static bearing capacity modulus E_{2V}

Modulus determined through on-site testing according to CEN ISO/TS 22476-13 ~~(MSZ 2509-3)~~, by the Boussinesq-formula, with the ~~fixed~~ rigid disc model multiplier, and calculated from the data of the second pressure-deformation curve. Sign: E_{2V}, unit: MPa.

3.7 Dynamic compactness and bearing capacity measurement

Site examination procedure based on theoretic considerations - executed with light falling weight loading system - for the determination of the dynamic bearing capacity modulus and the dynamic compactness rate through impacts, quick loading, with a SP-LFWD gauge determined from the 2nd sequence, regulated in the present document.

3.8 Small-plate light falling weight deflectometer (SP-LFWD)

The small-plate, light falling weight deflectometer is the manually portable gauge, by which the falling weight of given mass is dropped onto the steel plate connecting to the transmitting spring element from given height repeated in given number. Considering the present regulation the controlling-storing unit of such the deflectometer must be equipped with the suitable measuring software. Owing to the small size of the plate the dynamic loading can be p = 0,35 MPa, therefore the deflectometer is suitable for the determination of the dynamic compactness rate (T_{rd} %) and/or the dynamic bearing capacity modulus (E_d, MPa) also.

3.9 Gauge operability ~~soundness~~ measurement (own control)

A procedure for determining whether the gauge is suitable for any measurements within the error limit in accordance with the present measurement instructions.

3.10 Measurement data

18 deflection values measured at site with the small-plate light falling weight deflectometer, adjusted parameters, gauge ID, measuring method, sign and date, which the deflectometer stores in its data storing until its cancelling.

3.11 Measurement result

Parameter typifying the compactness rate and/or the bearing calculated from the measurement data under identified circumstances, including the reliability range or tolerance and unit.

3.12 Measurement place

Location randomly appointed for measurement and prepared according to the measurement requirements, where three measurements can be executed within the distance of one metre.

3.13 Dynamic compactness measurement

A testing method based on the volume change measurement, characterized by the ~~depression~~ settlement amplitude, by which the site compaction is being carried out with an 18-impact sequence in accordance with the Proctor compacting work ~~effort~~.

3.14 On-site relative compactness rate

Compactness rate determined at site, expressed in the percentage of the highest compactness, which can be reached by the given compacting work beside the effect of the natural water-content typifying the layer. In other words, the on-site relative compactness value determined by BC device on-site, always equal with the quotient of the compactness rate and the moisture correction coefficient. Sign: T_{rE} (%)

3.15 Moisture correction coefficient

A dimensionless number less than or exactly 1,00 which is the quotient of the bulk density (ρ_{di}) read for the natural water content (w_t) at the point of measurement from the density curve determined by the modified Proctor-test and the highest dry density (ρ_{dmax}) defined during the Proctor-test. It is a value characterizing the material type that can be determined in advance with the laboratory suitability ~~soundness~~ test, as a function of the water content change and that can be displayed in a tabular or graphical form. Sign: T_{rw} (%) or T_{rwK} (%)

3.16 Dynamic compactness rate

Product of the site relative compactness (T_{rE}) and the moisture correction coefficient (T_{rw}), which indicates the on-site relative compactness rate of the layer of given moisture content converted to the maximal compactness, which can be reached beside the optimal water content. Theoretically, it can be deducted that it is the same as the compactness rate determined with other measuring methods, like the ($T_{r\rho}$) compactness rate determined from the density ratios. Sign: T_{rd} (%).

3.17 Drop

The single drop of the falling weight of a SP-LFWD ~~light falling deflectometer~~, in a controlled manner. The ~~depression~~ settlement amplitudes (s_{ij}) and the disc-speed (v_{ij}) measured in this moment are marked with the j = 1–3 index beside i = 0-5 sequence. The ~~depression~~ settlement amplitude of the first drop is: s_{01} (mm), the last is s_{53} (mm)

3.18 Sequence

Three subsequent drops of the falling weight ~~of the light falling deflectometer~~ gives ~~the~~ an average of which is also displayed by the gauge. The measured ~~depression~~ settlement amplitudes (s_{ij}) and the disc speed (v_{ij}) are marked with the serial index i = 0 – 5, and j=1-3. During the calculation of the results the average is being determined which is marked by letter „a" next to the serial index. The average of the ~~depression~~ settlement amplitudes of the second sequence is: s_{1a} (mm).

4 Test method

During the test a solid of a known mass is being dropped onto a rigid disc of a given diameter, via a buffer spring, from a given height. The vertical displacement arising from the dynamic loading, i.e. the ~~depression~~ settlement amplitude is measured under the central point of the loading disc. In case of a falling weight of 10 kilogrammes and a dropping height of 72 cm some 7065 N dynamic loading power is transmitted onto the disc which results in a dynamic pressure (p_{dyn}) of 0,3 MPa, by a proper spring constant and a dial diameter of 163 mm. The falling weight and the dropping height must be chosen to the value required for the dynamic loading pressure, for each gauge, through the selection of both the given spring constant and the mass of the falling weight within the confidence interval.

From the second measuring sequence of the ~~depression~~ settlement amplitudes characterizing the deformation one can determine the dynamic bearing capacity modulus: E_d; and from the sixth measuring sequence the final modulus E_{dend}, unit: MPa. The calculation supposes that the loading of the loading disc is transmitted onto a flexible, homogeneous and isotropic half-space. The calculation must be made by the consistent selection of both the Poisson's ratio characterizing the material and the rigid or elastic Boussinesq-disc multiplier.

The dynamic compactness rate (T_{rd}) can be derived from the six measuring sequences of the ~~depression~~ settlement amplitudes characterizing the deformation curve. The calculation supposes that the granulous layer made up of an incompressible solid material is three-phase (air + solid part + water) and unsaturated, and it remains so during the compaction carried out during the testing, too.

The calculation considers that the compactibility (compactness rate) is the best at the optimal water content. In other case it decreases in proportion to the moisture correction coefficient. Among the values of the $T_{rw} \leq 1,00$ moisture correction curve its maximum value ($T_{rw} = 1,0$) is highlighted, where the water content is optimal, and accordingly, the on-site relative compactness is equal to the compactness rate~~s~~. Accordingly, the T_{rd}% compactness rate can be calculated from any of the on-site relative compactness values by the help of the moisture correction coefficient, if the water content is known or could be calculated.

The dynamic compactness measurement method is based on the determination of the compaction curve generated by the help of the site compacting applying the same work as the modified Proctor inspection determined in the 7.4 of EN 13286-2, from which – if the on-site relative compactness and the field ~~real~~ water-content is known – the dynamic compactness rate can be calculated. The character of the compaction curve depends on the efficiency of the preliminary ~~mechanical~~ roll-compaction of the layer, its value falls between the completely uncompacted and completely compacted condition. The on-site relative compactness shows that at a given moisture content can be further compacting executed or not; therefore it is ideal both for the contractors and for the inspectors, and both in quality attestation and in quality control. The present measuring system based on WS33 preliminary work, which based on research of Andreas Ltd and license Axis-Florida LLC.

5 Apparatus and material

5.1 Measuring instrument

It consists of a mechanical manual loading gauge, a loading disc, a measuring block located in the centre thereof and a measuring control and data logger unit *(figure 1).*

5.1.1 *Loading Gauge*

The loading gauge consists of the falling weight and the guide rod. The gauge serves for the generation of 7070 ± 2% N dynamic load (F_{dyn}), therefore the falling weight must be built in the way that it ensures the loading needed for the suitable dynamic loading dropped from the height determined during calibration during given loading time by the help of the transmitting spring element. The centrality of the falling of the weight is ensured by the guide rod. The drop height must be adjusted by positioning the fixing/triggering structure (attaching clamp) placed on the upper stop above the falling weight. The manual lifting of the falling weight must be secured by the circle handle. During transportation it must be fixed.

The technical requirements are detailed in Annex **B.1.**

~~Falling weight mass: m =10,0 kg ± 0,5 kg~~

~~Drop height: h = according to calibration, but usually 72 ± 5 cm~~

~~Loading time: t = 18 ms ± 2 ms~~

~~Loading force: F_{dyn}= 7070 N ± 2%~~

The number of measurement serves for its identification; it must be increased with one per measurement fluently.

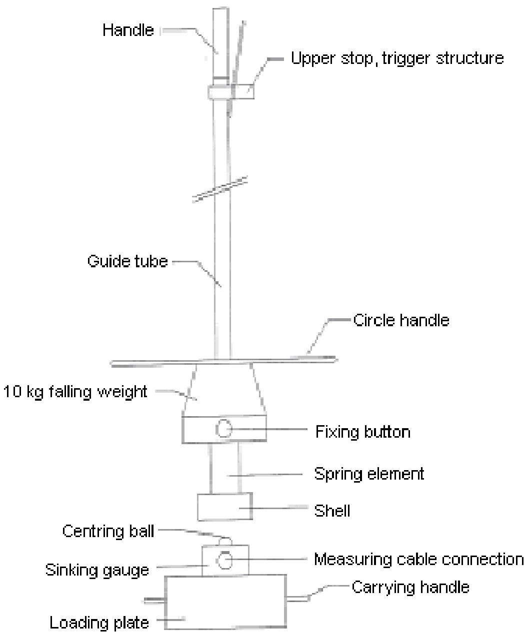

Figure 1 – Basic structure of small-plate, light falling weight deflectometer

5.1.2 *Loading disc*

The measuring and centralizing unit shall be placed into the central point of the loading disc. The transmission of the dynamic loading must be made via an in-built centring ball. The loading disc must be equipped with a handle suitable for manual shipment; and in the centralizing block a measuring hollow must be formed. The diameter of the loading disc must be (163 ± 2) mm, its thickness must exceed the minimum 20 mm.

5.1.3 Determination of the ~~depression~~ settlement amplitude

The plate's ~~depression~~ settlement amplitude must be measured by the suitable method with an accuracy of 0,01 mm during the loading time. For its determination the acceleration gauge placed into the measuring groove of the loading disc is the suitable method. The vertical deformation must be on the basis of the time measured with an accuracy of 0,005 sec and the acceleration between 0 – 50 g. The signs must be transmitted to the control – data logger unit (or PC), which counts and stores the measurement as travel data.

5.1.4 Control – data logger unit (or PC)

The control – data logger unit must be developed in the way that it continuously and automatically registers the measurement data, has the buttons needed for the measurement, and the function switch, display and data logger unit, and the PC connection for the printer and the data transfer. During measurement the display of the gauge must indicate the measurement commands, the measured data ~~of sequence~~, the error symbols, the charging level of the power-supply voltage and other information regarding the operation. The unit must have an internal clock and ~~the battery to provide the~~ own power-supply needed for the operation, which can be charged from 220V/110V alternating current and from the 12 V direct current of the cars.
To reach this goal may be used PC, notebook, tablet, Smartphone with appropriate software (sign PC in the following).

The operation of the measuring–control unit (or PC) must be included in an operating manual or in operating instructions by the manufacturer~~ or the distributor~~, which includes at least the followings:

- method and steps of start-up of the unit;
- handling of the control unit (or PC), functions, connections;
- operating modes:
  - controlling mode
  - measuring mode
  - calibrating mode
  - printing mode (alternative)
  - data transfer mode (in case PC unnecessary)
- operation and course of modes;
- storage and maintenance of the gauge;
- calibration of the instrument and accuracy of the measurement;

The control unit (PC) must serve for the storing of the measured data and the calculation of the results also. The possibility must be ensured to print the stored measurement results at site and the data transfer to the PC (if the control-data store unit is a special instrument). It is advantageous, if the data can be displayed graphically.

5.1.5 Printer

It is an offered unit serving the on-site printing of the data by which the data can be printed from the control – data-logger (PC) unit on site. The printer shall be able to print the following data:

- identification data;
  - number of gauge, number of measurement and date
- dynamic bearing capacity measurement data and results:
  - under-plate press ~~loading level~~ (p = 0,35 MPa)
  - plate multiplier ($c = \pi/2$ rigid plate according to the Boussinesq model)
  - path-time graph at s_{11}, s_{12} and s_{13} measurements (together)

- Poisson coefficient according to CEN ISO/TS 22476-13 ~~MSZ 2509-3 standard~~ selected from μ = 0,3-0,4-0,5 or other, minimum three different Poisson coefficient values
- measured values of deformation s_{11}, s_{12}, s_{13} (mm)
- loading disc speed v_{11}, v_{12}, v_{13} (mm/s)
- averages: s_{1a} and v_{1a} rounded to two decimal figures (0,01 mm)
- s_{1a}/v_{1a} quotient rounded to two decimal figures without dimension
- result: E_d dynamic modulus MPa,

• in case of dynamic compactness measurement plus:
- ~~depression~~ settlement of first drop: s_{01}
- ~~depression~~ settlement averages of drop sequences s_{0a}, s_{1a}, s_{2a}, s_{3a}, s_{4a}, s_{5a}
- result: on-site relative compactness rate (T_{rE}%)
- entered value of the moisture correction coefficient (T_{rw})
- result: dynamic compactness rate(T_{rd}%)

On the printed form enough space must be provided for the manual site comments, such as name of the project, location of measurement (km-section, side, meter, GPS position), name of examined layer, properties, code of staff ~~measuring personnel~~, weather, and other comments. It is advantageous if the compaction curve and the bearing capacity curve can be displayed graphically.

5.2 Accessories

The following accessories ~~must be provided~~ suggested at least in order to ensure the measuring mode, to enable higher-mass measurements, or rather to transfer data:

- ~~reserve battery~~
- mains charger and connector
- voltage supply connector, 12 V
- interface cable for data transmission (if needed)
- printing cable (if needed)
- Thermo-printer and paper.

5.3 Sampling instruments

The site sampling instruments needed for the preparation and forming of the measurement location and for the determination of the material type and thickness of the examined layer are the followings:

- manual shovel
- plastic bag (for soil sampling)
- air-tight, closing container ~~vessel~~ (for the moister ~~water~~ content determination)
- floating rule to ensure the even surface

5.4 Materials

The materials needed for the test are as follows:

- regulating carpet of sand, approx.~~10~~ 5 kg
- reserve paper roll for the printer.

5.5 Modes of the measuring instrument

The modes and description of the measuring instrument must be included in an operating manual issued by the manufacturer (distributor). The operation of the following modes must be ensured at least (both of control-unit and PC). The number of measurement serves for its identification; it must be increased by one per measurement.

5.5.1 Measuring mode

5.5.1.1 Bearing capacity measuring mode

It serves the routine execution of the bearing capacity measurements on site. During the measurement the value of the dynamic modulus rate must be determined by averaging, after a three-drop pre-loading, from a three-drop dynamic loading. At least the following measured values must be displayed on the control – data-logger unit:

- single values: s_{11}, s_{12}, s_{13} deformations with an accuracy of 0,01 mm
- average value of the ~~depression~~ settlement amplitudes: s_{1a} with an accuracy of 0,01 mm
- dynamic modulus: E_d, MPa with an accuracy of 0,1 mm

It is advantageous if during the three dynamic loadings required for the inspection the measuring instrument displays the loading disc's path-time ~~depression~~ settlement curve also.

5.5.1.2 Compactness- and bearing capacity measuring mode

The compactness measurement can be simplified (BCP) or complete-sequence (BC) measurement. At the complete sequence the ~~depression~~ settlement amplitudes must be determined at all 18 drops. While the first six drops is necessary for the bearing capacity measurement also, continuing the drops determined in 5.5.1.1 further 4 x 3 = 12 drops is necessary for the complete-sequence determination of the dynamic compactness rate. In case of simplified compactness measuring mode the programme watches the slope of the compaction curve after the ~~9~~ 10th drops. If it is less that $\alpha\Delta = 0{,}05$ between two points, then assuming linearity, it calculates the remaining points. This measurement gives the bit smaller compactness rate, i.e. it can be eliminated in favour of safety. The simplified or complete-sequence measurement must be indicated during the data recording.

The average ~~depression~~ settlement amplitude must be determined from the measured values by arithmetical averaging per sequence; and accordingly from this the dynamic modulus and the dynamic final modulus, the on-site relative compactness rate and the dynamic compactness rate as determined in 5.5.1.1 and at least the followings:

- individual ~~depression~~ settlement value: s_{01}, deformation of 1st drop with 0,01 mm accuracy
- average of ~~depression~~ settlement amplitudes: s_{0a}, s_{1a}, s_{2a}, s_{3a}, s_{4a}, s_{5a} with 0,01mm accuracy
- on-site relative compactness rate: T_{rE}% with 0,1 mm accuracy
- moisture correction coefficient: T_{rw} with 0,01accuracy (selected input value)
- dynamic final modulus: E_{dend} MPa with 0,1 accuracy
- dynamic compactness rate: T_{rd}% with 0,1 accuracy

It is advantageous, if during inspection at the s_{11}, s_{12}, s_{13} three dynamic loadings the path-time diagram of the loading disc and the ~~depression~~ settlement curve of the compactness measurement can be displayed graphically also by the control-storing unit.

5.5.2 Calibration mode

Mode used for own control and calibration also. In this mode the ~~depression~~ settlement amplitude of only one drop is measured and displayed. In calibration mode the display must indicate the maximal ~~depression~~ settlement speed of the loading disc (v, mm/s) and the data to be checked determined by the manufacturer, for example: calibration factor and all values, which must be read out for the calibration.

5.5.3 Printing mode

In printing mode the direct on-site printing of the measurement data ~~must~~ may be ensured. In this mode the gauge shall operate in the same way as in the measuring mode.

5.5.4 *Data transfer mode*

The transfer of the measured data must be enabled from the control-storage to a PC. By selecting the data transfer mode the measurement data shall be transferred to a PC for further storing and processing via the data cable or other data-transfer device connected (or wireless) to the gauge.

~~NOTE In printing mode the direct on-site printing of the measurement data must be ensured. In this mode the gauge shall operate in the same way as in the measuring mode.~~

6 Measure Procedure~~s~~

6.1 General

It must be tried to know the material of the measurement place preliminarily and to execute control test regarding the compactibility (EN 13286-2), grain-size distribution (EN 933-2), water-content (EN 1097-5), water absorption, saturation lines and in-building water-content limits (EN 1097-6).

The manual technique of the measurement must be learned by the staff ~~personnel~~, especially the safety catching of the circle handle of the falling weight rebound ~~flying back~~ and its suitable fixing. It must be considered that at low dynamic modulus and loose, non-compacted layers the falling weight hardly jumps ~~flies~~ back at the first drop.

In frozen layer it is forbidden to execute the dynamic measurement. If the saturation $S > 0{,}95$ (which can be determined from site water-content measurement) and if the air content < 5 %, then the reliability of all type of dynamic measurements is limited owing to the incompressibility of water, therefore it must be handled conditionally, and this fact must be indicated among the comments. This is similar all of falling weights test.

6.2 Preparation of the measurement site

The place of inspection must be prepared for the measurement. The prepared surface must be even, and must have an even texture typifying the material layer and its moister content. The loading disc must seat on the surface without tilting. The diameter of the prepared surface must be approx. 50 cm larger than the diameter of the loading disc and almost horizontal. The uneven surface must be corrected with the floating rule or cutting.

If the surface of the earthwork or the material layer is loose, dried, cracked or uneven, then this layer must be removed in the necessary volume and the place of measurement must be formed in an area of the required size.

If the good seating cannot be ensured in another way, the unevenness of the surface must be filled up with air-dry fine 0/1 sand. During the preparation it must be tried to ensure that the thickness of the regulating sand does not exceed the value, which is absolutely necessary for the up-filling of the gaps. It shall fill up only the gaps and unevenness of the surface and ensure the whole-surface seating. The method of preparation of the surface – if its material considerably differs from the material of the examined structure – must be indicated in the test report among the comments.

In frozen layer or in all situations, when the free deformation originating from the drops is limited, the measurement is forbidden.

6.3 Preparation of gauge for measurement

6.3.1 Preparation of gauge for site test ~~measurements~~

The check of the suitability of the gauge and its preparation for measurement must be executed before the daily measurement task keeping the following requirements:

- ~~continuous~~ checking of the mechanical operation of the gauge (trigger structure, guide tube, triggering of the transportation protection, cleaning and silicone lubrication)
- checking the free falling of the falling weight
- inspection of the possible damages of the electronic connectors/ data transfer
- inspection of the possible damages of connecting cables/ data transfer unit
- checking the charging level of the battery (control unit or PC and printer)

The own control of the gauge and the control test determined in 6.3.2 must be executed already in the plant before starting to the measuring site. If mechanical damage, jam, ~~cable breakage~~, data-transfer problems, contamination or corrosion is explored, then the errors must be eliminated. If the battery's charging level is lower than 50%, then it must be charged up or replaced. ~~Before larger tasks the batteries shall be charged up completely.~~

6.3.2 Control test

Before departure ~~After arriving to the site~~ the gauge must be switch into measuring mode. ~~at the typical measurement location.~~ One control test must be executed. If the display indicates the measurement error, the set-up of the gauge and its cables/connections must be checked, and then the measurement must be restarted. If the error message is still displayed, run the tests of the acceleration gauge or the measuring unit. The inspection cannot be started with faulty gauge.

If the gauge operates well, the difference of the individual dynamic modulus values also must be checked in the control test ~~at the first measurement~~. If this difference does not exceed the prescribed value and the graphical figure of the three drops is close to each other, then the operation of the gauge can be considered as acceptable and the measurements on-site can be started and the first measurement is acceptable.

6.3.3 Date setting

At the control test ~~site~~ printings the date and time of inspection are also printed out, therefore its correctness must be checked before measurement. It is expedient to check it during the preparation determined in 6.3.1. If the date and time data are not correct, they must be set according to the operation instructions of the gauge.

6.4 Dynamic bearing capacity measurement

6.4.1 Steps of the dynamic bearing capacity measurement

After the preparation of the measurement place deflectometer device must be positioned on the surface:

- positioning the loading disc on the prepared surface with the steadily, but not dropping it down, and adjusting it by turning it left and right in 45^o, ensuring the seating without tilting
- connecting the transmitter of the loading disc with the control-storing unit by the help of the measuring cable / or data transfer unit
- positioning falling weight onto the centring ball of the loading disc
- triggering the securing lock ~~pin~~ of the transportation protection of the falling weight
- pulling up and fixing the loading weight

- switching on the measuring-control unit (or start the measuring softwer on PC), ~~switch into~~ and select measuring mode

6.4.2 Operations of the dynamic bearing capacity measurement

a) Pre-loading must be done on the measurement by three drops (b–d).

b) The falling weight (if not lifted) must be pulled up to collision and fixed by a locking handle. Look to it that the seating of the centring ball is not raised from the disc and the disc is not displaced. When connecting the falling weight to the trigger mechanism both hands must be used so that we pop up our thumbs to the clamp of the blocking element from above. The falling weight must be directly lifted to the buffer until they mesh. By pulling up the falling weight slowly, the blocking/trigger structure will catch the weight. A too quick, sudden lifting may result in faulty measurement.

c) Along with the vertical positioning of the conductor the falling weight must be trigged. After the recoiling thereof the falling weight shall be put back into the locking gauge by catching the circular handle and pulling it up.

d) As a second sequence, the third pre-loading is followed by three measuring drops (f–j).

e) It is not necessary to store the data of the pre-loadings offered.~~ If the control gauge has not yet been switched on, then this must be done.~~

f) The conductor rod shall be carefully pressed on the loading disc in a vertical position while the falling weight must be trigged. By raising it after the recoiling the falling weight shall be put back. It may be advantageous if the control device gives a sound signal indicating that it is ready for the next drop, too. After the drop one must confirm whether the control unit accepted the measurement or it must be repeated.
The display must show the measured ~~depression~~ settlement amplitude sign: s_{11}

g) After a further drop the falling weight must be caught and fixed. The display must show the latest measured ~~depression~~ settlement amplitude: s_{12}

h) After the last drop the falling weight must be caught and put into a lower position. Now the display must show all three ~~depression~~ settlement amplitudes and the average thereof: s_{11}, s_{12}, s_{13} and s_{1a}.
If the single ~~depression~~ settlement amplitude values deviate considerably from the average, the measurement must be repeated. If we accept them the dynamic bearing capacity measurement is finished.

i) In this moment, the display shall show the dynamic modulus value along with the number of the measurement, beyond the average value of the ~~depression~~ settlement amplitudes. The ~~sequence~~ number of the measurement serves the marking of the measuring; it shall automatically increase by one unit per measurement. The identification of the measuring place have to note down in a testing diary.

j) If needed, the measurement data shall be printable or review. After finishing the measurement the measuring-controlling unit must be switched off; and the falling weight must be fixed for the secured for transport. By this time the auxiliary and identification data must be recorded; it is reasonable to write it next to the printed results.

k) The gauge shall be carried to the next measurement site with two hands, by the help of the handles positioned in the gravity centre. Be careful that you do not kick the centring rod to anything and avoid its damaging during the shipment.

l) If the display indicates an error message after a drop it must be repeated. In case of a considerable difference in the deflection amplitude the measurement cannot be continued. The error can as well be caused by the dislocation of the centring of either the loading disc or the falling weight. If the error message continuously appears after the repeated drops it might be caused by either the measured material or the failure of the transmitter, the connect~~or~~ion ~~or~~ the cable /data transfer unit. In order to explore the reason of the device failure it is reasonable to make the ~~soundness~~ suitability test.

6.4.3 *Site measurement under special circumstances*

It is a special circumstance when the measurement is being made in a working ditch, on the surface of partial backfillings or on a sloping surface. In these cases special attention must be paid to the safety regulations during the measurement (collapsing, traffic). Measurements can be made only at such points where the conditions for safe work are ensured. During the examination on a sloping area the slipping and displacement of the loading disc must be observed. The measurement can be executed only after the creation of an almost horizontal measurement ~~site~~ surface.

6.5 Dynamic compactness and bearing capacity measurement

6.5.1 *The dynamic compactness and bearing capacity measurement in general cases*

The preparation of the deflectometer is the same as introduced in 6.3.1 – 6.3.2 – 6.4.1. The dynamic compactness measurement is executed simultaneously with the bearing capacity measurement, and the ~~depression~~ settlement amplitude of the drops made as pre-loading must be measured also. After the second sequence needed for the dynamic bearing capacity measurement further four sequences are necessary with 3-3 drops. In this way for the complete dynamic compactness measurement aggregately 18 drops must be executed. The simplified compactness measurement can be executed according to 7.3.1.2, which controls the number of the necessary drops from the ~~9~~ 10^{th} drop depending on the slope of the ~~depression~~ settlement amplitude curve up to the 18^{th} drop.

6.5.2 *Operations of the measurement*

The measurement data of the first two sequences (six drops) are necessary for the dynamic bearing capacity measurement and the dynamic compactness measurement also. The execution of the measurement is the same as introduced in 6.4.2 until the second sequence. After then in further four sequences further three-three drops must be executed (without moving ~~displacing~~ the loading disc). Accordingly, the work on the layer compacted by aggregately 18 drops is nearly the same as the value of the compacting work applied in the modified Proctor measurement.

The measuring and error messages during ~~between~~ the measurements are the same as introduced in 6.4.2. In case of a faulty drop, after dropping the weight, it cannot be repeated; new positioning is needed at a new measurement place.

At measurement, during the continuous drops the control-measuring unit (PC) must indicate the ~~depression~~ settlement amplitude per sequence. Finally, all of the available ~~depression~~ settlement amplitudes: s_{ij} where $i = 0 – 5$ is the measurement sequence and $j = 1 – 3$ is the number of drops. By this the individual ~~depression~~ settlement amplitudes of the 18 impacts become known.

6.5.3 *Controlling the measure's compaction work*

It is necessary to control if the compaction work is enough or not, in case of soft soils, increased accuracy, >28cm layer thickness, disputable results, non-coursed compactions or analysis of natural settled soils, or in case of low compactness degree (high D_m deformation modulus).
It can be checked as follow:
- after the first compactness measurement (18 drops) we do one more test without moving the disc. If this second measurement is $T_{rE2}\%<98\%$, we must correct our first measuring results; if it is bigger or equal, we can accept the further measurements without correction.
- the compaction work correction is CWC= $(T_{rE2}\%)/100$
This correction must be use in the next measurements till the circumstances similar, like the material, thickness, in a build section.

The corrected value we consider hereafter with the CWC correction of the Trw moister-coefficient; announce in the point 7.3.
The compaction work must be control in case of qualifying test series, measuring the trial test section – after the first measuring without moving the plate – one occasion.

7 Calculation and expression of results

7.1 Deflection, ~~depression~~ settlement amplitude

The ~~depression~~ settlement amplitude is the range of the movement curve measured during the time of plate measurement (18ms); the degree of its ~~depression~~ settlement. Sign: s_{ij}, unit: mm, where $i = 0 – 5$ means six sequences and $j = 1 – 3$ means three drops per sequence. The individual values must be recorded per drop or stored in the control unit. Mathematical average must be calculated from the individual values per sequence. Sign of the averages: s_{ia}, the average of all three drops. The ~~depression~~ settlement amplitudes and their averages must be determined with an accuracy of at least 0,1 mm

7.2 Dynamic bearing capacity modulus

7.2.1. Dynamic bearing capacity modulus

The dynamic modulus E_d, unit MPa (N/mm^2, or MN/m^2), whose value must be calculated from the following Boussinesq formula, from the s_{1a} average value of the s_{11}, s_{12} and s_{13} ~~depression~~ settlement amplitudes:

$$E_{d,C,\mu} = \frac{c.(1-\mu^2)p_{din}.r}{s_{1a}} = \frac{C\mu}{s_{1a}}$$

where: c: Boussinesq plate multiplier (considering c=π/2 rigid plate)
s_{1a}: average vertical ~~travel~~ settlement of the centre of the plate, 0,01 mm
μ: Poisson-coefficient (according to CEN ISO/TS 22476-13 ~~MSZ 2509-3~~ standard)
r: radius of the loading disc, mm
p_{dyn}: F_{dyn} /A value of the under-plate dynamic loading, 0,35 MPa

where: A: loading disc surface, mm^2

$$F_{dyn} = \sqrt{2.m.g.h.K}$$

where: m: mass of falling body,
g: acceleration of gravity m/s^2 (on our latitude it is 9,81)
h: drop height, m
K: spring constant, N/m

Specific dynamic bearing capacity modulus is the final modulus ~~also~~, which at the end of the dynamic compactness measurement typifies the bearing capacity of the completely compacted layer and its value can be calculated from the E_d calculation formula, but from s_{5a} average value of the s_{51}, s_{52}, s_{53}, ~~depression~~ settlement amplitudes.

NOTE 1: The value of the dynamic bearing capacity modulus must be stated rounded to one ~~two~~ decimal figures. In favour of the complete understanding of the dynamic modulus, beside the result the followings must be stated or indicated also: selected c multiplier applied in the formula and the applied Poisson coefficient. At one ~~measurement~~ place, ~~within one measurement two measurements~~ two tests must be executed for the standard measurement (see 7.2.2)

NOTE 2: CONVERSIONS
Comparing to the static modulus (D300 plate) was found $E_{2v} \cong E_d$ (E_{2v}=0,94 E_d with regression R^2=0,93) approximate the same value like the SP-LFWD's Ed value (Subert).

Dynamic bedding coefficient may be calculated by an approximate formula c_d=0,0761*s0a (R^2=0,92) from the average of first three dropping SP-LFWD test (Subert).
CBR% may be calculated by an approximate formula CBR%=(E_d /10)^{1,5} from the SP-LFWD's Ed value (Boromisza).
CBR% value: CBR_5=5,43/s_{0a} ;$CBR_{2,5}$=4,07/s_{1a} ;and the end CBR% is weighted average of this two. The weighted of CBR_5 is 1-(s_{0a}/(s_{1a}+s_{0a}))= 0,231; the weighted of CBR2,5 is 1-(s_{1a}/(s_{1a}+s_{0a}))=0,739. The sum of the weight-values equal 1.(Subert).
Evib may be calculated Evib=0,5 E_d+57 R^2=0,93. (Univerza v Ljubljani) Evib parameter well-known from the CCC method.
E_{vd} dynamic modulus measured with 300mm diameter plate converting formula E_{vd} = 0,69E_d (R^2=0,90), or E_{vd} = 0,42E_{dend} (R^2=0,91).
This conversions are approximate informative values only, but shows, that the regression degree rather good.
Density correction of bearing capacity: In case of high density materials correction needed. E_d=K·E_d, where K=1,766/((r_{dmax}·(1/1+w_{opt})) example: r_{dmax}=2,28; w_{opt}=12,2; K=1,766/2,032=0,87 If E_d=86,6 MPa then E_{dkorr}=0,87·86,8=**75,5MPa** (Subert)

7.2.2 Standard dynamic modulus

In case of qualifying tests causing legal effect and in case of control tests mathematical average must be calculated from at least two measurements executed simultaneously within one metre. If they differ from average with more than its 20%, then a newer, third measurement is necessary in the averaging. The value standard dynamic modulus must be stated rounded to integral number. In favour of the complete understanding, beside the result the followings must be stated/indicated also: plate diameter and the applied ρ_{dyn} dynamic loading.
For example: $E_{dM/\ D/p}$ = 24 MPa
NOTE: If during the dynamic compactness measurement the saturation value calculated from the measured water-content is S > 0,95, then the layer is saturated with water. While the water cannot be compressed with dynamic impact, it results in smaller ~~depression~~ settlement amplitude, i.e. the measurement cannot be standard (it ~~applies~~ valid for all dynamic measurements).In this case, the measured value of the dynamic modulus measurement must be considered as informative, while the conditions of the measurement are met limitedly. In this case, the inspected layer cannot be compacted with compacting roller either, the layer must be dried or ventilated.

7.2.3 Equivalent dynamic modulus

The equivalent dynamic modulus must be calculated from the coefficient typifying the material of the earthwork/layer calculated from the results of the tests executed with different measuring instruments, if at the deflectometer the c = 2 plate-multiplier or the μ = 0,4 coefficient were fixed or the $c = \pi/2$ and the real Poisson-coefficient could not be adjusted. It is often at the gauges having burnt-in program. These results can be converted to compare the results correctly.

The equivalent dynamic modulus can be converted only from the measurement results of gauges of the same plate diameter and the same dynamic loading for a layer of real Poisson-modulus or for the rigid plate-multiplier; therefore this fact must be indicated.

Conversion:

$$E_{dE,D,p} = E_d . k_\mu . k_c$$

where:

k_μ conversion multiplier for the Poisson coefficient, if it could not be adjusted during the measurement

k_c conversion multiplier of plate model multiplier, if it could not be adjusted during the measurement

If the c = 2 and μ = 0,4 coefficient is fixed, then:

μ = 0,3 granular material → k_μ= 0,923 and
μ = 0,5 bound material → k_μ= 1,120
k_c = -0,785 → $c = \pi/2$ instead of c = 2.

If the measurement was executed with fixed c = 2 flexible ~~rigid~~ plate multiplier and real μ Poisson-coefficient, then $E_{dM,D,p} = E_d$, i.e. no conversion is necessary.

The value of the equivalent dynamic modulus must be stated rounded to one decimal figure. In favour of the complete understanding, beside the result, the followings must be stated/indicated also: plate diameter (e.g. 163) and the applied dynamic loading: e.g.: $E_{dE\,/163\,/0,35}$ = 16,3 MPa

7.3 The dynamic compactness rate

The T_{rd}% dynamic compactness rate is the product of the on-site relative compactness and the moisture correction coefficient:

$$T_{rd}\% = T_{rE} \cdot T_{rw} \equiv T_{r\rho}\%$$

where T_{rE} on-site relative compactness ~~is the compactness rate~~ (see 7.3.1.2.) reached by the compaction beside ~~given~~ field water content, and

T_{rw} is the moisture correction coefficient needed for the conversion for the optimal water content.

The resulted compactness rate is the same as the value of the compactness rate ($T_{r\rho}$%) determined by the ~~isotopic~~ density-rate measurement. The dynamic compactness rate has far better accuracy – in comparison with other compactness measuring methods ~~(isotopic or water (sand)-filled poured bulk density and compared to the reference density) – has far better accuracy~~.

~~Before the~~ Calculation of the T_{rE} on-site relative compactness ~~calculation~~

The ~~depression~~ settlement amplitudes measured during 18 drops must be corrected according to the $s_{ij} \geq s_{i,j+1}$ condition, by which the compaction curve accidental variations are decreased in favour of the higher safety. The T_{rE} on-site relative compactness value representing the compactness rate reached at the natural water content must be determined from this corrected curve ~~from~~ with the following formula:

$$T_{rE}\% = 100 - 1.25 \cdot \Phi_0 \cdot D_m$$

where: Φ_0 the linear coefficient of the $\Delta V_{mm} - T_{r\rho}$% straight calculated from the Proctor-test Mdry=constant model, in general it can be taken 0,380 ± 0,020 (which an revealing parameter ~~typical value localized by several measurements~~).

D_m deformation index, it is weighted with the number of drops; it is calculated from the sum of the elements of the data line formed from the difference of the subsequent ~~depression~~ settlement amplitudes up to the drop.

$$D_m, mm = \frac{\left[\sum_{i=1}^{i=17} d_i \cdot \sum_1^i SUM\Delta s_i\right]}{17}$$ where $SUM\Delta si = \Delta s_1 + \Delta s_2 + \ldots + \Delta s_i$,

where one permanent considered deformation $\Delta s_i = s_{i+1} - s_i$, and d_i the drop number (i=1-18).

The sum of subsequent descent summa amplitudes, summarized the differences, length the given drop number (the amount of strain differences for the number of drop), and determine the weighted average of the 17 summed differences data line.

$\Delta si = s_{i+1} - s_i$ one permanent deformation

d_i the drop number (i=1-18).

Because of ±1 T_{rE}% accuracy between 22-28cm layer thikness, ±2 T_{rE}% accuracy on 20-32cm layer thikness no needs correction. Other case the thickness correction is:

$$\Phi_K = 0.38 \cdot \frac{25}{h}, or \rightarrow \Phi_K = 9.1185 \cdot h^{-0.9871}$$ where h the layer thickness in cm

NOTE 1: The M_{dry}=constant model means the theoretical model being equal to the natural site conditions, where the dry mass of the samples are the same and only the water-content is different. Therefore, the (dried or real) height of the measurement cylinders after compacting with the same work is the smallest at w_{opt} and the ΔVmm volume, as a height difference of the cylinders is increasing moving outward on the dry- and wet branch. The difference of the cylinders of the same dry mass can be considered as the difference of the cylinder heights also owing to the equal diameter of the cylinders, such as the values compared to the adjacent cylinder, which can be considered as the ~~depression~~ settlement compared to this previous one.
While conventionally, the cylinders' dry density is known from the Proctor ~~control~~ test, the relation of the $T_{r\rho}$% compactness rate calculated from the dry density can be determined with the difference of the volumes. Considering this relation as linear, $T_{r\rho}\% = 100 - \Phi.\Delta l_{mm}$ (where Δl=ΔV/F=deformation), from where the *Φ* value can be determined beside $R^2 \geq 0{,}9$ correlation coefficient.

NOTE 2: The simplistic (standard) compactness rate one can calculate with the next formula, which needs both the simplified ($\rho d_{max\ simplified}$) and the modified maximum Proctor density ($\rho d_{max\ modified}$). The conversion factor:

$$\beta = (\rho d_{max\ simplified}) / (\rho d_{max\ modified}) \text{ always } <1{,}0$$

The simplified compaction rate is:

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

To calculating the $T_{rE\ simplefied}$ on-site relative compactness simplified rate must be determine the $T_{rwsimlefied}$ on the same water content from the simplified Proctor curve. After this the simplistic compactness rate is:

$$T_{rE\ simplified}\ \% = T_{rd\ simplified}\% \ / \ T_{rw\ simplified}$$

Calculation of the moisture correction coefficient:

The moisture correction coefficient must be calculated simultaneously with the measurement or from the water-content value measured in the laboratory:

$$T_{rw} = \frac{\rho_{di}}{\rho_{d\max}}$$

Accordingly, the moisture correction coefficient is the density ratio calculated from the laboratory Proctor control test, i.e. a normalized Proctor-curve. The ρ_{dmax} value must be read off from the at least 4-point modified Proctor control test of the material sample according to 7.4 of EN 13286-2 and the ρ_{di} value must be read off from the curve of the Proctor measurement, if the w_t% water-content of the measurement place is known. In case of larger projects or a material type applied on large surface (e.g. protection layer) the T_{rw} multiplier can be prepared in tabular form previously depending on the water-content and it can be used at site. (see Annex B.3)

~~NOTE 1:~~

In case of more accurate demand (like the qualifying tests or trial section-tests), the corrected moisture correction coefficient must be applied:

$$T_{rwk} = CWC \cdot T_{rw} = \left(\frac{T_{rE2}\%}{100} \cdot T_{rw} \right)$$

where CWC is the compaction work correction 6.5.3. and the dynamic compactness rate is:

$$T_{rd} = T_{rE}.T_{rwk}$$

~~NOTE 1: In case of more accurate demand, the corrected moisture correction coefficient can be applied:~~

~~$T_{rd} = T_{rE}.T_{rwk}$ where $T_{rwk} = \frac{(T_{rw} - \Delta)}{(1-\Delta)}$, and $\Delta = \frac{(s_{01} - s_{53})}{\sum s_{ij}}$~~

NOTE1 ~~2~~: The Proctor-curve ~~is~~ may be determined according to precedent, or from the 6th degree polynomial curve (suggestion Fleming-Gilbert), ~~or with a second-degree curve~~ from the Proctor points by regression analysis. The measured Proctor points can be completed with two fictive points. By this method the moisture correction curve calculated from the modified Proctor inspection can be calculated for the whole water-contents and it can be stated preliminary. Please find an example in Appendix B3.

7.3.1 Standard compactness rate

7.3.1.1

In case of qualifying tests (which causing legal effect) and in case of control tests the mathematical average of two dynamic compactness rates measured within one metre must be calculated and the value of the standard dynamic compactness rate must be stated rounded to integral number. Example: T_{rdM} = 95 %

If the difference of the dynamic compactness rate (ΔT_{rd}%) drawn in into the calculation and the average is larger than 3,0 T_{rd}%, then a third measurement (executed also within one metre) is necessary for the averaging,

NOTE: If the D_m deformation index value calculated during the dynamic compactness measurement is >3 and at the same time, the measured dynamic modulus E_d < 10 MPa, then the result of the dynamic compactness measurement "Not valuable". This can be considered as informative result only, while the conditions of the site compactibility are met limitedly. In this case, the loadable counter surface needed for the compactness is missing, and the layer cannot be compacted suitably during the measurement, In this case, the inspected layer cannot be compacted suitably with compacting roller either; the bearing capacity must be increased and the compaction must be repeated!
If the saturation value calculated from the water-content measured during the dynamic compactness measurement is S > 0,95, then the layer is full saturated with water. While the water cannot be compressed with dynamic impact, it results in smaller ~~depression~~ settlement amplitude, i,e, the measurement cannot be standard (just for all dynamic measurements),In this case, the measured value of the dynamic modulus measurement must be considered as informative, while the conditions of the measurement are met limitedly, In this case, the inspected layer cannot be compacted with compacting roller either, the layer must be dried or ventilated!

7.3.1.2 Simplified compactness measurement

Depending on the mechanical roll-compacting of the layer, but typically in most cases, the measured layer compresses before the 18 drops, i,e, the number of drops could be decreased, The reason is that the number of the necessary drops is determined for soft soils ~~loose~~, non-compacted layers. If we check the slope of the end of the compaction curve during the measurement – in the software – and it is smaller than 5 %, then the other remaining deflection amplitudes can be calculated from this slope. This gives the simplefied on-site relative compactness rate, which is worse then the ~~really~~ full sequence measured compaction curve, with maximum some decimal figures, i.e. This method can be applied ~~safely,~~ for the benefit of safety and less measuring time.

NOTE During trial section compacting or comparative, parallel measurements the complete measurement sequence must be applied with 18th drops, according to 7.3.1.1. point. ~~see 7.3.1.1.~~

8 Test report

The test report must include the number of the present regulation, the ID data of the inspecting laboratory ID, measurement right, and the followings:

- type and serial number of the light falling weight deflectometer
- measurement place and ID data, date, number of the measurement
- name of inspected structure, earthwork, soil-layer
- references of the connecting documents (Proctor-test, water-content tests)
- partial measurement results (dynamic modulus, compactness rate)
- standard results (standard dynamic modulus, standard compactness rate)
- accuracy and reliability of the inspection, reference to the ambiguity of the measurement
- possible weather and other conditions, circumstances affecting the result
- name and signature of the personnel making the inspection
- name and signature of the person in charge for the technical content of the test report, date

NOTE It is expedient to indicate any other data in connection with the run of the laboratory considered necessary (project number, code of personnel, page number, company logo, address, contact info, telephone, fax, e-mail) as further informative data. The test report must include that the measurement results are valid only for the inspected samples; the partial measurement data are included in the measurement sheets, which are available for the Client any time. The test report can be copied only in complete volume with the written approval of the inspecting laboratory. The test report cannot include any advice, reference for quality or proposal deducted from the measurement result!

ANNEX A

(normative)

Calibration of the light falling weight deflectometer

A.1 Factory calibration

The gauge sold by the manufacturer must be calibrated at least in the factory; the drop height must be equal to the value calculated on the basis of the mass of the falling weight and the spring constant. The setup parameters and the control values typifying the measuring unit and the relating tolerances must be stated in writing by the manufacturer.

A.2 Calibration procedure

The dynamic compactness and dynamic bearing capacity measuring gauge must be calibrated by a competent calibrating laboratory after it reaches the 10 000 measurements, but at least in every second year. Before calibration the gauge must be supervised in a professional service ~~workshop~~ appointed by the manufacturer, the necessary repairs must be executed and/or the components appointed by the manufacturer must be replaced (for example: the teflon bearing (slip ring) or the synthetic rubber spring element). If the spring element ~~cannot be replaced~~ no need exchange after this period, then it must be calibrated also with a procedure determined by the calibrating laboratory.

It is advantageous to apply long-life, expensive metal plate spring. If the spring element is made of plastic, ~~rubber or~~ it must be replaced during calibration according to the manufacturer's instruction, then the followings must be verified with a measurement executed in a special laboratory and/or an expertise: during the usage ~~replacement~~ period between 0 – 40 °C it is independent from temperature within 5 % tolerance; the accepted aging of *K* (N/m) spring resistance is smaller then 5% per year; and the change of its rigidity.

The accepted different owing to the change of the temperature must be verified with a loading of at least 500 mm/min on the new spring elements, at least up to 10 kN within 5 % tolerance; and at the end of the time period prescribed for the replacement of the spring element further 5 % tolerance can be permitted on the measured spring element.

If the deflectometer gauge must be repaired or any of its components must be replaced, then the deflectometer must be calibrated again.

During the calibration procedure the values measured and indicated by the deflectometer must be checked by a measuring system being independent from the deflectometer. The calibration data are at least the set-up drop height, and the mass of the falling weight. The calibration procedure must include at least the followings: dynamic load measured under the centring ball of the spring element, loading time, travel during the loading time, and their accuracy. The calibration must be executed in ~~an~~ the manufacturer designated ~~accredited~~ calibration laboratory, which requires the development and approval of a suitable calibration procedure. The calibration must be executed on the basis of the input data provided by the manufacturer and if necessary it must be corrected by modifying the drop height.

The calibration must include a force measuring being independent from the gauge and an independent deformation measuring. The independent calibration force measuring unit must be suitable for the measurement of the force running down during 18 ms and its maximum. The independent calibration deformation measuring unit must be suitable for the measurement of the deformation originating from a loading of 18 ms at measuring points placed in at least three segments (i.e. placed per 120°) – as detailed below, within the suitable range – for which the *continuous contact must be provided between the measuring plate and the deformation measuring on the opposite side* (from under) to the loading.

A calibration report must be issued. The report must include the deflectometer's ID data, the detailed calibration results and at least the manufacturer's data and the condition of the deflectometer (wearing, damage, free drop) and:

- the average of the measured dynamic loading force and ~~its dispersion~~ the standard deviation (A_{σ},σ_F)
- the average of the measured loading time and ~~its dispersion~~ the standard deviation ($A_T\sigma_T$)
- the average of the individual differences of deformation and ~~its dispersion~~ the standard deviation ($A_s\sigma_s$)

The conformity of the ~~depression~~ settlement amplitudes must be checked at least in the three following thickness (settlement) range:

- 0,02 – 0,60 mm
- 0,60 – 1,00 mm
- 1,00 – 1,50 mm

The individual ranges must be typified with at least 12 measurements, average and standard deviation ~~dispersion~~ and the difference measured fro the independent measuring unit must be determined also.

The calibration of the loading means a comparison with the average of the values read off from the gauge. The accepted difference from the average of the dynamic loading force measured with 12 sequences is the following:

- the average of the dynamic loading force is 7070N ± 2%, i.e. between 6928 – 7212 N with an accuracy of one decimal figure, so the next criteria more rigorous:
- ~~at the same time,~~ because the under-plate dynamic loading must be between 0,345 – 0,350 MPa owing to the compaction work ~~, T~~ the loading force needed for this is ~~approx. 7200 N,~~ 7056-7212 N, which ~~must~~ meets the previous criteria ~~condition~~ also. The under-plate loading needn't to be calibrated separately, it is enough to check the factory adjustment of the loading force
- the average of the loading time is between 16 – 20 ms with an accuracy of one decimal figure

The calibration of the deformation measurement means a comparison with the average of the values read off from the gauge. The accepted difference from the average of the dynamic loading force measured with 12 sequences is the following:

- maximum 0,08 mm in the 0,02 – 0,60 mm range
- maximum 0,10 mm in the 0,61 – 1,00 mm range
- maximum 0,15 mm in the 1,01 – 1,50 mm range

After the calibration the mechanical loading deflectometer and the electrical deflectometer (PC) forms a harmonized unit. The calibration data (set-up drop height, mass, calibration date) must be indicated in the deflectometer in a prominent position. For the calculation of the measuring ambiguity the standard deviation ~~dispersion~~ must be calculated from the $\sigma = \sqrt{\sigma_F^2 + \sigma_S^2}$ formula, where σ_S means the dispersion of the deformation range of 1 – 1,5 mm. (The dispersion of time is included in the measurement of deformation, it is needn't to be considered separately).

A.3 Own control

A.3.1 General

The own control must be executed by the user is in accordance with his/her own quality assurance system to check the operability of the gauge.

A.3.2 Control

The deflectometer must be assembled as introduced in 6.4.1. and switched into calibration mode, control test as written in 6.3.2. point. ~~own control function.~~ Check the default set-up values. Match the indication of the acceleration gauge with the individual values and tolerances stated by the manufacturer.

Control value (default): *K*1 = value stated by the manufacturer, with given ± Δ tolerance. After turning the loading disc around its horizontal axle with 180° (turn up) the indication of the control value in reversed position: *K*2 with ± Δ tolerance. If it is not met, the deflectometer is not operable. In this case run the ADM test in the measuring software.

Calibration factor: number adjusted during calibration, which the manufacturer determines in the operation instructions, and it must be stated in the calibration report also. If its value is different or its change exceeds the given tolerance value, then the gauge must be calibrated again. This may be inbuilt in the measuring software also.

A.3.3 Individual measurement for calibration

The deflectometer must be able to execute individual measurement also for calibration or qualification. This menu cannot differ from the measuring mode. After the drop of the falling weight the individual measurement values data must be indicated.

A.3.4 Reliability and accuracy of the measuring method

To determine the reliability and the accuracy the followings must be stated according to EN 5725-2 standard: reproducibility dispersion s_r, repeatability dispersion s_R values or in case of large number of samples the measurement reliability must be calculated by statistical methods. The accuracy of the measurement must be checked after every calibration and it must be stated in the suitable reference point of the test reports.

A.3.5 Reproducibility and repeatability, measurement result tolerance

The light falling weight measuring deflectometer is suitable for measurement according to the present regulation, if beside n ≥ 30 number of samples the amplitudes are the following:

- reproducibility deviation $s_r \leq 0{,}8$
- repeatability deviation $s_R \leq 1{,}2$

Result tolerance, the calculated measurement error

The measurement result error and tolerance must be determined from the deviation of the measured results per laboratory and per deflectometer. Its degree must be indicated in the test report.

If the accuracy of the measurement of the ~~depression~~ settlement amplitudes is 0,01 mm and the accuracy of the measurement of the dynamic loading force is 5 %, the measurement error is the ~~5,2~~ ± 2,6 % of the measured E_d dynamic modulus and is ± 1 ~~2,0~~ T_{rd}% of the measured ~~T_{rd}%~~ dynamic compactness rate. The error of the dynamic compactness rate regarding the properties determined during the Proctor-test in the present tolerance range is considered as charged with the errors of measurement of maximum ± 0,10 ~~0,15~~ g/cm^3, therefore in case of larger density variation the accuracy must be calculated again from large sample.

Annex B

(informative)

Informative requirements and examples for calculations

B.1 Technical requirements

Informative requirements of the design of the mechanical loading deflectometer:

- mass of the falling weight (including handle) — ~~10,5~~ 10,0kg ± 1,0 ~~0,5~~ kg
- total mass of guide rod (including the spring consisting of spring elements, transportation protection of the falling weight, triggering structure ~~and tilting protection~~) — ~~max.~~ 5 ± 0,5 kg
- dynamic loading — 0,35 ± 0,05 Mpa
- loading time — 18 ± 2ms

Drop height: *h* = according to calibration, but usually 72 ± 5 cm

Design requirements of the loading disc:

- diameter of the loading disc — 163 ± 1 ~~2~~ mm
- thickness of the loading disc — >~~min.~~20 mm
- total mass of the loading disc complete masse (including measuring cell for the sensor and handles) — 15 ± 1,0 kg

Fixed technical data of acceleration gauge applied for deformation measurement:

- measurement range of in-built acceleration gauge — 0 – 50 g

In case of applying other strain gauge and the acceleration gauge:

- measurement time — 18 ± 2ms
- processed measurement signal — min. 18 signals/18 ms
- reading accuracy of deformation — min. 0,01 mm
- quartz clock accuracy — maximum ± 1,5 s~~per~~ /day
- reading accuracy of deformation — minimum 0,01 mm

B.2 Formulas and expression applied in the calculations

The dynamic bearing capacity modulus must be calculated from the formula stated in 7.2.1.

~~Depression~~ Settlement amplitude measurement in case of applying acceleration gauge $s = \frac{1}{2} a t^2$ where:

a = the measured acceleration

t = the time measured by time measuring built-in in the processor with 0,005 s accuracy

The T_{rE}% on-site relative compactness, the T_{rw} moisture correction coefficient and the T_{rd}% dynamic compactness rate must be calculated as stated in 7.3.

B.3 Calculation and application of the moisture correction coefficient

The first result of the ~~on-site~~ dynamic compactness measurement is the on-site relative compactness (T_{rE}%) which shows what the compactness of the layer is like in comparison with the highest possible compactness reachable at the actual field water content. ~~The moisture correction coefficient is not needed for the on-site relative compactness measurement.~~ It is a new testing parameter which is in the evaluation of the efficiency of the compacting instruments important. If it is known, the decision can be made whether further compaction can be executed on the layer, by the given moisture content. *Accordingly, the T_{rE}% on-site relative compactness qualifies ~~typifies only~~ the rolling compaction work.* The moisture correction coefficient is not needed for the on-site relative compactness measurement.

For the calculation of the T_{rd}% dynamic compactness rate the measured T_{rE}% on-site relative compactness must be corrected depending on that the site water-content in what degree differs from the optimal. The rate, which is the quotient of the dry density determined by the Proctor-test in samples of different water-content and the maximal dry bulk density, is called as moisture correction coefficient:

$$T_{rwi} = \frac{\rho_{di}}{\rho_{\mathrm{dmax}}} \quad \text{where } T_{rw} < 1{,}00 \text{ except at } w_{\mathrm{opt}}, \text{ where } T_{rw} \equiv 1{,}00$$

Accordingly, the Proctor-test is necessary for the dynamic compactness inspection also, for the calculation of the $T_{rwi} - w_i$ moisture curve or the preliminary calculation of the table (expediently as the part of the control test). The T_{rwi} must be determined preliminary for the given material at least for the ± 5 % vicinity of w_{opt} per one-three percent, upward and downward from the optimal water-content also. The pre-calculated T_{rwi} values per material are enough to apply it for the dynamic compactness measurement with the measurement of the real water content. Accordingly, the T_{rw} moisture correction coefficient typifies the acceptability of the water content of the material and its compactibility.

For example: the calculation of the T_{rwi} from the data of the control test, in case of a selected fine-sand sample, if ρ_{dmax} = 1,85 g/cm^3 and w_{opt} = 6,9 %, is the following:

Dry branch					w_{opt}	**Wet branch**				
–5%	**–4%**	**–3%**	**–2%**	**–1%**		**+1%**	**+2%**	**+3%**	**+4%**	**+5%**
0,956	0,973	0,989	0,995	0,999	1,000	0,997	0,989	0,962	0,940	0,892

The T_{rw} moisture correction table must be determined with the modified Proctor compactibility measurement according to 7.4 of EN 13286-2, with four- five different water contents and ~~at least 5, but possibly rather with 6-8 Proctor points,~~ with Δw water-content-stages distributed uniformly up to the S = 0,9 saturation line. ~~The Proctor-curve must be determined with a second-degree approximation curve, by the check of the closeness of the regression and not by simply connecting the points.~~

From the equation of the got curve the ρ_{di} values must be determined per Δw = 1 % stage and the T_{rw} moisture correction coefficient value must be displayed in tabular form compared to ρ_{dmax}.

The Proctor-curve may be determined according to precedent, or from the 6th degree polynomial curve (suggestion Fleming-Gilbert) or from the Proctor points by hand-drowned curve. The measured Proctor points can be completed with two fictive (virtual) points from the S=0,95 saturation line. By this method the moisture correction curve calculated from the modified Proctor inspection can be calculated for the whole water-contents and it can be stated preliminary.

Several theoretical implications of the dynamic compactness measurement are suitable for such pre-estimation, which cannot be executed with other method, and which typifies the expected behaviour of the layer to be compacted during the mechanical compacting. Such are the following: highest compactness rate, which can be reached beside given water-content, the measurement of the efficiency of the compacting work, or the selection and pre-estimation of the compacting method.

- At on-site relative compactness measured as T_{rE}% = 100 % the T_{rw} values exactly represent the dynamic compactness rate/100 values, i.e. with the maximal T_{rE} = 100 % compacting beside w_{opt} + 5 % site water content – in the present example – maximum 100 x 0,892 = 89,2 % compactness rate (T_{rd}) can be reached.

- If at w_{opt} – 5% site water content the measured on-site relative compactness for example was not $T_{rE} = 100\%$, but for example: $T_{rE} = 96{,}2\%$ and T_{rw}=0,956, then the dynamic compactness rate will be T_{rd} = 0,956 x 96,2 = 92,0%.

- The ~~mechanical~~ machine (roll) compacting is considerably harder above the optimal water-content in the wet branch, which the T_{rw} - values represent well and they can be calculated preliminary.

- In the wet branch another problem can be the air-content needed for the compacting, which can be shown from the rate of the air-content / optimal air-content and the < ~~1%~~ S=1,0 saturation, which can be calculated from the control test, if the ρ_s is known. The saturation line must be calculated every time.

- It must be checked before all dynamic measurements that the measured site water-content what saturation represents on the basis of the control test. Above S > 0,95 no dynamic measurement gives realistic result, while it is unrealistic owing to the incompressibility of the water (during the loading time), i.e. it measures smaller compression than the real compression. Therefore above S > 0,95 saturation no dynamic measurement result is acceptable and prohibited to roll the layer also (un-compactable).

- The relative on-site compactness rate to be necessarily reached during construction can be calculated from the limit value prescribed for the compactness rate. In such cases, it is enough to try to reach this value with the mechanical compacting. If for example: we measured w_{opt} – 3% site water-content and the qualifying requirement is $T_{r\rho} = T_{rd} \geq 95{,}0\%$ compactness rate, then to meet it (calculated from the above example) the $\frac{T_{rd}}{T_{rw}} = \frac{95{,}0}{0{,}989} \geq T_{rE} = 96{,}1\%$ value must be met. If during the construction it is ensured with rolling, then the qualifying compactness tests will be acceptable also!

- The *expected efficiency of the compacting work* can be pre-estimated, if the T_{rw} moisture correction coefficient is known. If the site water-content (w_t) – applying the above example – is w_{opt} + 4%, then beside T_{rE} = 100% (i.e. the mechanical compacting gives the maximal on-site relative compactness) we can reach maximum 100%*0,940 = 94,0% = T_{rd} compactness rate only, i.e. 95% in no case can be reached! In such cases to reach the prescribed 95 % compactness a new material type must be selected, or the water-content must be decreased. Accordingly, the in-building technology must be selected on the basis of the control test already.

The application of the dynamic compactness measuring method and the moisture correction coefficient help the correct selection of the compacting method during construction; and the applicability of the material can be evaluated already during the preliminary laboratory control test, therefore it is the efficient instrument for the quality control. For this beside the laboratory Proctor-test (which is necessary on every account) only the delivery water-content of the site material must be known. From this the curve of the moisture correction coefficient can be calculated preliminary and simply.

The dynamic compactness rate (T_{rd} %) is equivalent with the compactness rates determined with the ~~isotopic~~ density-ratio measurements, so the relating conventional qualifying requirements must be considered as limit value.

NOTE The measuring method and its theory help in forming and spreading a new contractor aspect, while it flashes the very importance of the moisture content of the applied granular materials and the maximal compactibility, which can be reached by the work of rolling, and which can be checked easily. The applicability of the dynamic compactness measuring deflectometer is helped by its small size and easy handling. Owing to its environmental protection and health aspects it must be highlighted that this method can be used without isotope (nuclear) source in an environment-friendly way.

B.4 Presentation of Calculations

B.4.1 Calculations

Beside the proposed PC processing hereby we introduce the procedure of a calculation for the determination of the dynamic compactness- and bearing capacity measurement results. The downloaded (or PC stored) data originating form the measurement are the followings (see Table 2):

- serial number of the gauge (Gauge Nº)
- number of measurement (Measurement Nº)
- time of measurement (Date)
- ID of measuring personnel (ID)
- type of measurement (S=small-plate, B=bearing capacity, BC=bearing capacity and compactness rate, BCP= bearing capacity and compactness rate, "primitive" short cut solution) (SB / SBC / SBCP)
- Boussinesq plate multiplier (Model rigid c=π/2, flexible c=2)
- applied Poisson-coefficient (μ)
- entered value of T_{rw} moisture correction coefficient applied at site
- dynamic loading force *N*
- radius of plate ~~*cm*~~ *mm*
- $s_{01} - s_{53}$ ~~depression~~ settlement amplitudes originating from the measurement (x 100, in mm dimension)
- $v_{01} - v_{53}$ speeds of plate ~~depression~~ settlement originating from the measurement (x 100, in mm dimension)

B.4.2 Calculation of the dynamic modulus

On the basis of the data of Table 2: μ = 0,3 (Poisson) and c = π/2 (Model), r = 81,5 mm (Radius)

$C\mu = \pi/2 \cdot (1-\mu^2) \cdot p_{dyn} \cdot r = 40{,}8$

From this: $E_d = \frac{C\mu}{s_{1a}}$, where $C\mu = 40{,}8$ and $s_{1a} = \frac{(0{,}54 + 0{,}47 + 0{,}40)}{3} = 0{,}47$, i.e.

$$E_d = \frac{40{,}8}{0{,}47} = 86{,}8 \text{ MPa}$$

The same way: $E_{dend} = \frac{C\mu}{s_{5a}} = \frac{40{,}8}{0{,}31} = 131{,}6 \text{ MPa}$, where $s_{5a} = \left(\frac{0{,}34 + 0{,}31 + 0{,}29}{3}\right) = 0{,}31$ mm

The saturation value belonging to w_t = 4,0% is S=0,87 < 0,95, so the saturation does not limit the representatively of the measured dynamic modulus.

STX			
Gauge	Nr =	4080408	
Measure	Nr =	140	
2005. 01. 19	13:56:24		
User	ID =	1	
Type	=	BC	
Model	=	1,571	
Poisson	=	0,3	
Trw	=	0,998	
Fdin	=	7200	
Radius	=	81,5	
s01=	257	V01=	409
s02=	75	V02=	181
s03=	68	V03=	157
s11=	54	V11=	152
s12=	47	V12=	135
s13=	40	V13=	124
s21=	38	V21=	129
s22=	38	V22=	124
s23=	35	V23=	118
s31=	33	V31=	116
s32=	31	V32=	124
s33=	38	V33=	126
s41=	32	V41=	124
s42=	32	V42=	106
s43=	35	V43=	113
s51=	34	V51=	115
s52=	31	V52=	123
s53=	29	V53=	119
ETX			

Table 2 – *data stored on PC or downloaded from the measurement control unit~~, downloaded to the PC~~*

B.4.3 Calculation of the moisture correction coefficient (T_{rw} or T_{rwK})

The water-content measured in laboratory or at site with pre-calibrated gauge: w_t = 4,0 m%

$T_{rw} = \frac{\rho_{di}}{\rho_{d\max}} = \frac{1,862}{1,90} = 0,980$ calculated from the Proctor curve, where, the ρ_d is the bulk density belonging to w = 4,0 m%. If the T_{rw}-curve (table) is prepared previously, then we simply can read off the T_{rw} = 0,980 value belonging to $w = 4{,}0\%$, and w_{opt} = 9,0 m%

B.4.4 Calculation of the on-site relative compactness rate, and standard compactness rate

The stored data are the hundred-fold values of the ~~depression~~ settlement amplitudes. The ~~depression~~ settlement amplitudes must be corrected after the calculation of the dynamic modulus, for the calculation of the dynamic compactness rate, i.e.

We reorder the data line ~~them~~ in $s_{ij} \geq s_{ij-1}$ form. In this example it is unchanged up to s_{32}, and then its value is 31 between $s_{33} - s_{52}$. With this method we filter out the waiving of data line, caused by the over-compacting.

After then the ~~depression~~ settlement differences are calculated one after the other by the $\Delta s_i = s_{ij} - s_{ij+1}$ formula:

As we can see ~~on~~ from diagram 2 the ordered ~~data~~ differences data-line will be 182, 7, 14, 7, 7, 2, 0, 3, 2, 2, 0, 0, 0, 0, 0, 0, 2.

While the Φ linear coefficient value of the linear regression analysis of the ΔV_{mm} - T_{rg}% relation calculated from the G_d = constant model of the Proctor-test corresponds to the 0,380 ± 0,20 ~~0,365 ± 0,25~~ general condition, we can calculate with it.
We apply the T_{rE} = 100 – 1,25·0,380 ~~0,365~~*D_m value to simplify the calculation.
D_m value is the sum of the summed data weighted with the drops in the number of the drops:
D_m=[1·(182)+2·(182+7)+3·(182+7+14)+4·(182+7+14+7)+5·(182+7+14+7+7)+6·(182+7+14+7+7+2)+ …+ ~~18~~ 17·(182+7+14+7+7+2+0+3+2+2+0+0+0+0+0+0+2)] / ~~18000~~ 17000=2,01 mm

From this the on-site relative compactness is

$$T_{rE} = 100 - 1{,}25 \cdot \Phi_0 \cdot D_m = 100 - 1{,}25 \cdot 3{,}80 \cdot 2{,}01 = 90{,}5\%$$

~~$T_{rd}\% = T_{rw} \cdot T_{rE}$ = 0,980 · 93,1% = 91,2%~~

The calculated dynamic compactness rate:

a.) without the controlling of measure compating work, and if T_{rw}=0,98:

$$T_{rd}, \% = T_{rw} \cdot T_{rE} = 0{,}980 \cdot 90{,}5\% = 88{,}7\%$$

so the on-site compactness rate (one result) is 88,7%

b.) with controlling the measure compacting work based on regulation 6.5.3. point, i.e. $T_{rE2}\%$=97% (without mooving the plate) and CWC=97/100=0,97

$$T_{rwK} = CWC \cdot T_{rw} = 0{,}97 \cdot 0{,}98 = 0{,}95$$

$$T_{rd}, \% = T_{rwK} \cdot T_{rE} = 0{,}95 \cdot 90{,}5\% = 86{,}0\%$$

so the on-site compactness rate (one result) is 86,0%

For a standard dynamic compactness rate result at least we must average two measurement results calculated in this way.
In case of qualifying tests the mathematical average of two dynamic compactness rates measured within one metre can be calculated and the value of the standard dynamic compactness rate.

a.) sample T_{rd} = 88,7% and the (supposed) second result is T_{rd}= 90,2% average value 89,5%, difference 90,2-88,7= 1,5% < 3% allowed value, two result sufficient
Result must be stated rounded to integral number T_{rdM}=90%

b.) sample T_{rd} = 86,0% and the (supposed) second result is T_{rd}= 95,1% average 90,6%, difference 95,1-90,6= 4,5% > 3% allowed value, two result is not enough. The 3. measure gives 89,2% i.e. so the average of three is 90,1%
Result must be stated rounded to integral number T_{rdM}=90%

B.4.5 Conversions and relationships

The regression from analyzes of the compactness and dynamic load measurement data aggregation in great number provide useful information. Deduction in the literature can be found.

Value of static bearing capacity E_{2V} modulus: E_{2V}=0,94E_d (R^2=0,93) Exaple: calculated in the general example E_d=86,8MPa, conversion E_2=0,94*86,8=**81,6Mpa** namely $E_2 \approx E_d$ (different less than 10%)

CBR% value: $CBR_5=5,43/s_{0a}$;$CBR_{2,5}=4,07/s_{1a}$;and the end CBR% is weighted average of this two. ~~Choosen~~Chosen of CBR% is different from the habitual, because the loading curve is different in case of static method and the dynamic one.
Example: $CBR_5=5,43/1,33=4,1\%$;$CBR_{2,5}=4,07/0,47=8,7\%$;
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 $1-(s_{0a}/(s_{1a}+s_{0a}))=0,231$; the weighted of $CBR2,_5$ is $1-(s_{1a}/(s_{1a}+s_{0a}))=0,739$. The sum of the weight-values equal 1.
$s_{0a}=1,33$mm , $s_{1a}=0,47$mm , and $(s_{1a}+s_{0a})=1,80$ in this example.
From this, the CBR%=4,1·0,231+8,7·0,739=**CBR%=7,5%**
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 (Subert).

Dynamic bedding coefficient value: $C_d=0,0761/s_{0a}$ (N/mm^3)
Example: 0,0761/1,33mm=**0,06N/mm^3**

Expected settlement of surface: determined on 25cm layer thickness is) $\Delta S=\Delta T_{rd}\%/4,75$ ~~10·D~~$_{m}$
Example: In case of $\Delta T_{rd}\%=10\%$ the settlement is 10/(1,25*0,38)=2.1mm/25cm. This means ~~D_m=2,01, Smm=10·2,01=20,1mm/25cm, 8cm / 1m in case~~4*2.1mm*8m=6,7cm of a ~~refill trench~~8m height embankment.

Evib value (CCC method)=$0,5·E_d+57$ ($R^2=0,93$) Example: if E_d=86,8MPa then **E_{vib}=100,4Mpa**

German LFWD E_{vd} value: $E_{vd}=0,42·E_{dEnd}$ ($R^2=0,91$), or $E_{vd}=0,69·E_d$ ($R^2=0,90$) the smallest of two. Example: $E_{vd}=0,42·E_{dvég}=0,42·131,6=55,3$MPa; $E_{vd}=0,69·E_d=0,69·86,8=59,9$MPa; smallest value:**$E_{vd}$=55,3MPa**

Bearing Capcity Correction because of high density material (blast furnace slag):
$E_{dCorr}=K·E_d$, where $K=1,766/((\rho_{dmax}·(1/1+w_{opt}))$ where 1,766 means the base material is silty-Sand (Subert)
Example: $\rho_{dmax}=2,28$; $w_{opt}=12,2$; K=1,766/2,032=0,87
if E_d=86,6 then E_{dCorr}=0,87·86,8=**75,5MPa** (smaller value then the measured one)

Bearing Capcity and Compactness-rate Correction (fly ash) used the impulse-law (Subert):
Calculation: $\varsigma_E = \dfrac{\rho_1(1+w_1)}{\rho_2(1+w_2)} \cdot \dfrac{100}{T_{rE}\%}$; *m=0,986$T_{rEmeasured}$%–98.7 and* $T_{rECalc}\%=100+m·\zeta$
Example:
Measured values: **E_d=18,9MPa, T_{rE}%=91,7%**, w_t=38,3%. Wet density 1,26 g/cm^3, Proctor dry density ρ_{dmax}=0,91 g/cm^3, w_{opt}=26%, T_{rw}=0,985.
The measured static load result on this place was E_{2V}=37MPa, E_{2V}/E_{1V}=1,6 Compactness rate determined by tube-test $T_{r\square}$=98,3%.
Modification of the compactness rate:
ζ= (0,91·1,26)/(1,65·1,07)=1,147/1,766=0,649; m=($T_{rEmeasured}$%·0,986)–98,7=-8,3
T_{rECalc}%=100-8,3·0,649=94,6% és T_{rw}=0,985 → **T_{rdCORR}%=**$T_{rw}·T_{rE}$%=0,985·94,6=**93,2%**
Modification of Bearing Capacity
E_{dkorr}=$E_d·(1/\zeta)·(100/T_{rd}\%)$=18,9·(1/0,649)·(100/93,2)=18,9·1,54·1,07=**31,1MPa** (E_2=29,2MPa)
this means that E modulus is much higher than the original measured value, because of low density of fly ash.

Convert Compactness-rate to simplified (standard) Proctor rate (Subert)
T_{rd}% standard= T_{rd}%· (1/β) where $\beta=(\rho_{dmaxSt}/\rho_{dmaxMod})$;
Example: **$T_{rd\%}$=95%**; ρ_{dmaxSt}=1,82 and w_{optSt}=13,5%; $\rho_{dmaxMod}$=1,96 and w_{optMod}=13,5%;

Formázott: Betűszín: Vörös

Formázott: Betűszín: Vörös

β=0,943
$T_{rdStandard}\%$ = 1/0,943·95%=**101%**

* * *

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