Road and Transportation Research Association

Working Group Earthworks and Foundations

FGSV

Technical testing regulations for soil and rock in road construction

R 1

TP BF-StB

Part B 8.4

Calibration Rules for the Light and Medium Drop-Weight Tester

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Calibration Rules for the Light and Medium Drop-Weight Tester

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Preliminary remark:

The present part B 8.4 "Calibration Rules for the Light and Medium Drop-Weight Tester" of the Technical testing regulations for soil and rock in road construction ("TP BF-StB") was drafted by the Committee "Testing Equipment".

The calibration rules apply to the Light Drop-Weight Tester according to the "Technical testing regulations for soil and rock in road construction" (TP BF-StB), Part B 8.3, and to the Medium Drop-Weight Tester according to the "Technical testing regulations for aggregates in road construction" (TP Gestein-StB), Part 8.2.1 "Dynamic Plate Load Testing with the Medium Drop-Weight Tester".

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1 General

The loading mechanism and the settlement measuring instrument of the Light and Medium Drop-Weight Testers are to be calibrated prior to shipment ex works and after repair. The calibration is required at least annually.

The calibration may only take place at an authorized calibration institute (proofed by the BASt – Federal Highway Research Institute). The BASt keeps an overview of authorized calibration institutes (see www.bast.de > Qualitäts-bewertung > Straßenbau > Anerkennung).

The functionality of the device as well as the compliance of the specifications for the loading mechanism (tables 1 to 3) and the settlement measuring instrument (table 4) is proofed through calibration.

Table 1: Required values for impact force and impact duration

	Light Drop-Weight Tester	Medium Drop-Weight Tester
Required value of the maximum impact force	7.070 kN ± 1 %	14.140 kN ± 1 %
Maximum permissible standard deviation of the impact force	20 N	40 N
Required value of the impact duration	17 ms ± 1.5 ms	13 ms ± 1 ms

The calibration has to be durably affixed by a label on the loading mechanism and on the settlement measuring instrument. These labels have to show the name of the calibration institute and the validity period of the calibration.

The calibrated loading mechanism and the load plate with the calibrated settlement measuring instrument may only be used together and must be calibrated together. The load plate with the settlement measuring instrument and the loading mechanism have to be indicated by a label, so that the togetherness of these three parts is easily recognizable. They may not be exchanged by means of parts from other Drop-Weight Testers.

For the measurements described in the sections 2 and 3, the measurement results must be recorded with the resolution set out in tables 2 to 4 as a minimum, and must be stated with the number of decimal places stipulated below, for reasons of mathematical processing.

Note: So that the text is easier to read, and to avoid confusion, the empirical standard deviation of one measurement series will hereinafter not be designated with s, but with σ.
The maximum settlement for one measuring impact will be indicated as s_L, instead of $s_{max\,Light}$, for the Light Drop-Weight Tester and s_M, instead of $s_{max\,Medium}$, for the Medium Drop-Weight Tester.
Also, the maximum force for one measuring impact will be indicated as F_m, instead of F_{max} (see also list of abbreviations).

Table 2: Specifications for force measurement

				Light Drop-Weight Tester	Medium Drop-Weight Tester
1.	Resolution in force measurement $F_{m,ij}$:			≤ 5 N	
2.	Number of decimal places when indicating				
2.1	force $F_{m,ij}$ [N]:	none	e.g.	7,060 N	14,133 N
2.2	Average value $\overline{F_{m,i\bullet}}$: (GI-3)	one	e.g.	7,059.7 N	14,132.7 N
2.3	Average value $\overline{\overline{F_{m,\bullet\bullet}}}$: (GI-7)	two	e.g.	7,059.74 N	14,132.68 N
2.4	Standard deviation $\sigma_{F,i\bullet}$: (GI-5)	two	e.g.	1.96 N	3.92 N
2.5	Standard deviation $\sigma_{F,\bullet\bullet}$: (GI-8)	three	e.g.	1.958 N	3.917 N

Note: If in the index line there is a point (e.g. $\overline{F_{m,i\bullet}}$ calculated from equation (GI-3)) that means that addition was carried out by the parameter replacing the point (e.g. parameter j in (GI-3)).

Table 3: Specifications for impact duration measurement

				Light Drop-Weight Tester	Medium Drop-Weight Tester
1.	Resolution in impact duration measurement $t_{s,ij}$:			≤ 0.02 ms	
2.	Number of decimal places when indicating				
2.1	Impact duration $t_{s,ij}$:	two	e.g.	≤ 17.71 ms	≤ 12.92 ms
2.2	Average value $\overline{t_{s,i\bullet}}$: (GI-4)	three	e.g.	≤ 17.712 ms	≤ 12.883 ms
2.3	Standard deviation $\sigma_{t,i\bullet}$: (GI-6)	four	e.g.	≤ 0.0672 ms	
2.4	Test quantities T_{10}, T_1: (GI-1a/b), (GI-2a/b)	three	e.g.	2.123	

Table 4: Specifications for settlement measurement

				Light/Medium Drop-Weight Tester
1.	Resolution			
1.1	In settlement measurement with the Light Drop-Weight Tester $s_{L,ij}$ or Medium Drop-Weight Tester $s_{M,ij}$:			≤ 0.005 mm
1.2	in settlement measurement with inductive displacement transducers $s_{IND,ij}$:			≤ 0.002 mm
2.	Number of decimal places when indicating			
2.1	Single values, average values and differences of the settlements, measured with the Drop-Weight Tester or with inductive displacement transducers: $s^*_{M,ij}$, $s^*_{L,ij}$, $s_{M,ij}$, $s_{L,ij}$, $s_{IND,ij}$, $\Delta_{s,L,ij}$, $\Delta_{s,M,ij}$, $s_{A,ij}$, $s_{B,ij}$, $s_{C,ij}$	three	e.g.	0.524 mm
2.2	Average values and differences of the settlements, measured with the Drop-Weight Tester or with inductive displacement transducers: $\overline{s^*_{L,i\bullet}}$, $\overline{s^*_{M,i\bullet}}$, $\overline{s_{L,i\bullet}}$, $\overline{s_{M,i}}$, $\overline{s_{IND,i\bullet}}$, $\overline{\Delta_{s,L,i\bullet}}$, $\overline{\Delta_{s,M,i\bullet}}$	four	e.g.	0.5242 mm
2.3	Standard deviations $\sigma_{s,IND}$, $\sigma_{s,^*L}$ or $\sigma_{s,^*M}$, $\sigma_{s,L}$ or $\sigma_{s,M}$, σ_Δ: (Gl-13), (Gl-15), (Gl-23)	four	e.g.	0.0125
2.4	Test quantities $T_{\Delta,L}$ and $T_{\Delta,M}$: (Gl-24a), (Gl-24b)	three	e.g.	1.249
2.5	Test quantities $T_{Var,L}$ and $T_{Var,M}$: (Gl-25a), (Gl-25b)	three	e.g.	0.014
2.6	Test quantities T_1 and T_{10}: (Gl-9a/b/c), (Gl-10a/b/c)	three	e.g.	1.192
2.7	Calibration factor $c_{M,i}$ (Gl-16)	five	e.g.	1.02431
2.8	Average value of calibration factors $c_{M,i}$ (Gl-17)	six	e.g.	1.004567

2 Calibration of the loading mechanism

2.1 Devices and application

The loading mechanism is calibrated by adjusting the impact and the impact duration to the required values. To do so, the drop height of the drop-weight and the pre-tension of the spring package are adjusted. The mass of the drop-weight may not be changed.
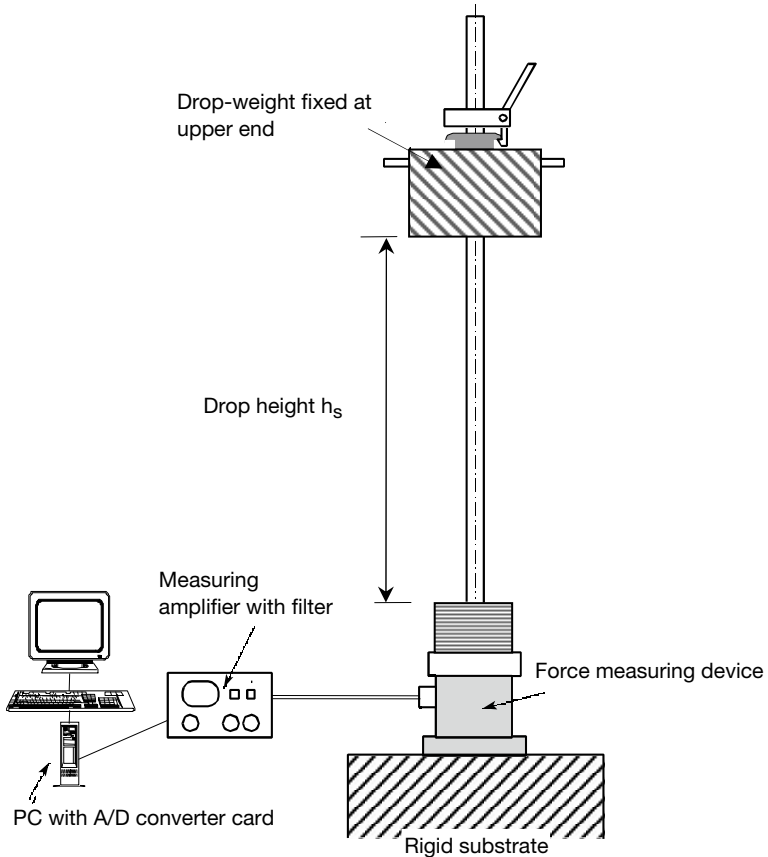
Before calibration new spring assemblies have to be preloaded with at least 100 impacts. After finishing the preloading impacts the calibration can begin at the earliest after one hour.

Requirements for calibration:

– Rigid substrate; the substrate has to be rigid and may not be stimulated due to the impact load to vibrations which disturb the force progression. As rigid substrate a concrete foundation has to be used with minimum dimensions (length x width x height) of 0.8 m x 0.8 m x 0.5 m. The surface of the concrete foundation has to be horizontal and flat.

– Drop-weight with guide rod and spring assembly

– Holder for vertical alignment of the rod

– Force measuring device with a nominal load of 50 kN and a spigot for the loading mechanism (bullet centring)

– Measuring amplifier with adjusted internal filter: 1000 Hz < upper limit frequency f_G < 2000 Hz

– PC with A/D converter card, at least 12 bit, sampling rate at least 19 kHz, signal filtration via software. Software parameters: low-pass filter 4th order with filter characteristics acc. to Butterworth, limit frequency 200 Hz/–3 dB, evaluation software for the complete force flow and displaying the maximum value of force and impact time, zero point determination after notching the drop mass.

For the measurement chain consisting of force measuring device and measuring amplifier a calibration proof according to DIN EN ISO 376 is necessary. The force measuring device has to be calibrated within the partial load range from 1 kN to 16 kN. Within this measuring range it has to fulfil class 1 according to DIN EN ISO 376. The calibration has to be realized by an institution which has traceable test equipment.

The calibration of the force measuring device has to take place annually.

Drop-weight fixed at upper end

Drop height h_s

Measuring amplifier with filter

Force measuring device

PC with A/D converter card

Rigid substrate

Figure 1: Outline sketch for calibration of the loading mechanism

The guide rod with the drop-weight has to be put on to the force measuring device. The measurement chain has to be made ready for measurement according to the operating instructions. The guide tube has to stay vertical during the measurement impacts. Therefore the guide tube has to be fixed at the upper end to a locking mechanism, which ensures a vertical positioning of the guide rod at each measurement impact.

The vertical movement of the rod must not be impeded. The guide rod has to be perfectly clean, so that the friction between guide rod and drop-weight is as low as possible.

After mounting the guide rod three preloading impacts have to be carried out. Their results are not registered.

Three measurement series (i = 1, 2, 3) each with 10 measurement impacts (j = 1, 2, ... 10) with the same drop height have to be carried out and thereby at each measurement impact the maximum impact force $F_{m,ij}$ and impact duration $t_{s,ij}$ has to be registered. The measurement results have to be entered in the calibration protocol or be documented in a computer printout. After each measurement series the guide rod has to be removed completely and put back in.

The measurement of the impact duration t_s begins at the moment when the force is 210 N and ends when the force again reaches 210 N.

2.2 Outlier test for a force measurement series

Prior to further evaluation of the measurement series, for each measurement series an outlier test with 10 impacts has to be carried out, whether or not based on subjective estimation an outlier exists or not. The subsequent test checks if either the highest or the lowest value of a measurement series with n = 10 measurement values has to be rejected as outlier.

From the highest value $F_{m,i(10)}$ respectively $t_{s,i(10)}$ in an ordered measurement series with n = 10 measurement values, the average value $\overline{F_{m,i\bullet}}$ (see GI-3) or $\overline{t_{s,i\bullet}}$ (see GI-4) and the standard deviation $\sigma_{F,i\bullet}$ (see GI-5) or $\sigma_{t,i\bullet}$ (see GI-6) the following test quantity has to be calculated:

$$T_{10,F} = \frac{t_{s,i,(10)} - \overline{t_{s,i\bullet}}}{\sigma_{t,i\bullet}} \qquad \text{(GI-1a)}$$

$$T_{10,t} = \frac{F_{m,i,(10)} - \overline{F_{m,i\bullet}}}{\sigma_{F,i\bullet}} \qquad \text{(GI-1b)}$$

From the lowest value $F_{m,i(1)}$ or $t_{s,i(1)}$ in an ordered measurement series the following test quantity has to be calculated:

$$T_{1,F} = \frac{\overline{F_{m,i\bullet}} - F_{m,i(1)}}{\sigma_{F,i\bullet}} \qquad \text{(GI-2a)}$$

$$T_{1,t} = \frac{\overline{t_{s,i\bullet}} - t_{s,i(1)}}{\sigma_{t,i\bullet}} \qquad \text{(GI-2b)}$$

If the test value $T_{10,F}$ respectively $T_{1,F}$ or $T_{10,t}$ respectively $T_{1,t}$ exceeds the threshold value of 2.410 (significance level 1 %), the measured value $F_{m,i(10)}$ respectively $F_{m,i(1)}$ or $t_{s,i(10)}$ respectively $t_{s,i(1)}$ has to be rejected as an outlier.

In this case a single new measurement impact has to be carried out additionally and its measurement result has to be used. That's why the guide rod should not yet be taken out of the holder at the end of a measurement series with 10 measurement impacts, so that in case of presence of an outlier an additional measurement impact can be carried out.

2.3 Calculations from the measurement results

From $n = 10$ measurement impacts of a measurement series i the following have to be calculated:

Average value of the force from n measurement impacts:

$$\overline{F_{m,i\bullet}} = \frac{1}{n} * \sum_{j=1}^{n} F_{m,ij} \qquad \text{(GI-3)}$$

Average value of impact duration from n measurement impacts:

$$\overline{t_{s,i\bullet}} = \frac{1}{n} * \sum_{j=1}^{n} t_{s,ij} \qquad \text{(GI-4)}$$

Standard deviation of force from n measurement impacts:

$$\sigma_{F,i\bullet} = \sqrt{\frac{1}{n-1} * \sum_{j=1}^{n} \left(F_{m,ij} - \overline{F_{m,i\bullet}} \right)^2} \qquad \text{(GI-5)}$$

Standard deviation of impact duration from n measurement impacts:

$$\sigma_{t,i\bullet} = \sqrt{\frac{1}{n-1} * \sum_{j=1}^{n} \left(t_{s,ij} - \overline{t_{s,i\bullet}} \right)^2} \qquad \text{(GI-6)}$$

From the average values $\overline{F_{m,i\bullet}}$ of the three force measurement series i the following have to be calculated:

Average value of the 3 force measurement series:

$$\overline{\overline{F_{m,\bullet\bullet}}} = \frac{1}{3} * \sum_{i=1}^{3} \overline{F_{m,i\bullet}} \qquad \text{(GI-7)}$$

Standard deviation of the average values of the 3 force measurement series:

$$\sigma_{F,\bullet\bullet} = \sqrt{\frac{1}{3-1} * \sum_{i=1}^{3} \left(\overline{F_{m,i\bullet}} - \overline{\overline{F_{m,\bullet\bullet}}} \right)^2} \qquad \text{(GI-8)}$$

2.4 Result evaluation and consequences; decision-making rules

1. If an outlier exists, an additional measurement impact has to be carried out. If an outlier exists and processing another measurement impact should not be possible any more, alternatively the further calculations can be carried out with a measured value quantity of $n = 9$. When there is more than one outlier in one measurement series the measurement series has to be repeated completely.

2. If in the case of the Light Drop-Weight Tester $\sigma_{F,i\bullet} > 20$ N respectively in the case of the Medium Drop-Weight Tester $\sigma_{F,i\bullet} > 40$ N, the measurement series of $n = 10$ impacts must not be evaluated and has to be repeated completely.

3. If $\sigma_{t,i\bullet} > 0.1$ ms, the measurement series of $n = 10$ impacts must not be evaluated and has to be repeated completely.

4. If the average value $\overline{F_{m,i\bullet}}$ differs more than ±1 % from the required value of the impact force, the drop height has to be changed until the permitted tolerance of ±1 % is met. At each change of drop height the complete procedure of calibration of the loading mechanism has to be repeated.

5. If the measured impact duration $\overline{t_{s,i\bullet}}$ at the drop height hs differs by more than ±1.5 ms of the required impact duration in the case of the Light Drop-Weight and by more than ±1.0 ms in the case of the Medium Drop-Weight Tester, the disc spring has to be preloaded accordingly or a different spring assembly has to be used. With the replaced spring assembly the calibration has to be conducted completely new.

6. If $\sigma_{F\bullet\bullet} > 10$ N, all 3 measurement series have to be completely repeated. All 3 measurement series have to be conducted with the same drop height h_s.

The drop height h_s determined for the required impact force $F_{soll} = 7.070$ kN in the case of the Light Drop-Weight Tester or $F_{soll} = 14.140$ kN in the case of the Medium Drop-Weight Tester has to be recorded permanently on the loading mechanism. As drop height h_s the distance from the bottom of the drop-weight, which is suspended into the release device, to the impact face on the upper part of the spring assembly, has to be stated (see figure 1).

2.5 Recommended measuring technique for force measurement

For force measurement the following measuring technique is recommended, which corresponds to the specifications mentioned in section 2.1:

– Force measuring device: Type C4/50 kN from Hottinger-Baldwin-Messtechnik
– Measuring amplifier: MGC plus with single channel amplifier plug in e.g. type ML 55B from Hottinger-Baldwin-Messtechnik
– A/D converter card: with at least 12 bit resolution

With the stated measuring technique compliance with the requirements mentioned in section 1 is possible. Another measuring technique, based on a newer technical state, is also permitted as far as the requirements in section 1 are met.

3 Calibration of the settlement measuring instrument

3.1 Devices and application

The calibration of the settlement measuring instrument has to apply to the complete measuring range from 0.3 mm to 1.5 mm with the calibrated drop height h_s. In calibration of the settlement measuring instrument, the value s_L or s_M indicated by the settlement measuring instrument is compared with the average value s_{IND} of the settlements of three inductive displacement transducers. The set-up points A, B and C of the three inductive displacement transducers have to be as close as possible to the centre of the load plate and each has to be offset 120° (see figure 2).
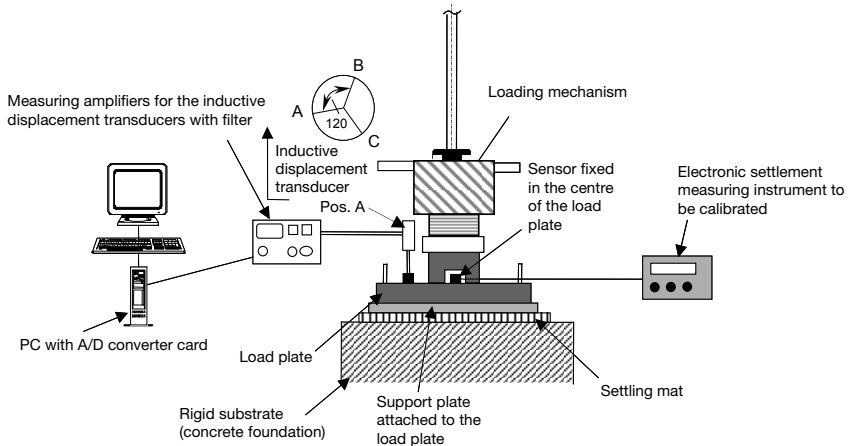
Figure 2: Outline sketch for calibration of the settlement measuring instrument

The following measuring equipment according to figure 2 is needed for the calibration:

– Rigid substrate; the substrate has to be rigid and may not be stimulated due to the impact load to vibrations which disturb the force progression. As rigid substrate a concrete foundation has to be used with minimum dimensions (length x width x height) of 0.8 m x 0.8 m x 0.5 m. The surface of the concrete foundation has to be horizontal and flat.

– Support plate of steel (diameter 340 mm, weight 30 kg ± 0.25 kg) as equivalent weight for the average resonant half-space weight of the soil. The load plate has to be fixed to the support plate for calibration by means of a quick release skewer. The weight of 30 kg ± 0.25 kg includes the weight of the quick release skewer.

– Holder for vertical alignment of the guide rod (without interference of the vertical movements of the drop mass along the guide rod)

– Three settlement mats with different thicknesses. The mats have to ensure the following settlements of the load plate at the calibrated impact force:
1. Settlement measuring range $i=1$ (soft substrate):
$\overline{s_{IND,i\bullet}} > 0.9000$ mm; the target value in the settlement measuring range 1 should be $\overline{s_{IND,i\bullet}} \approx 1.4000$ mm for the Light Drop-Weight Tester and $\overline{s_{IND,i\bullet}} \approx 1.2000$ mm for the Medium Drop-Weight Tester.
2. Settlement measuring range $i=2$ (medium-hard substrate):
$\overline{s_{IND,i\bullet}}$ between 0.4000 mm and 0.6000 mm; the target value should be within the settlement measuring range 2 for the Light Drop-Weight Tester and should be $\overline{s_{IND,i\bullet}} \approx 0.5000$ mm for the Medium Drop-Weight Tester.
3. Settlement measuring range $i=3$ (hard substrate):
0.2500 mm $< \overline{s_{IND,i\bullet}} < 0.4000$ mm; the target value should be within the settlement measuring range 3 for the Light Drop-Weight Tester and should be $\overline{s_{IND,i\bullet}} \approx 0.3000$ mm for the Medium Drop-Weight Tester.

For the settlement mats, mats of type Aclacell from Acla-Werke GmbH, Cologne, with the pressures listed in table 5, should be used. The mats are provided by the BASt, or can be obtained through the BASt.

Table 5: Settlement mats to be used for calibration

1	2	3	4	5	6	7
			Light Drop-Weight Tester		Medium Drop-Weight Tester	
Settlement measuring range	from to [mm]	Target value [mm]	Relevant modulus of deformation $E_{vd,LFG}$ at target value [MN/m²]	Thickness of settlement mat for Light Drop-Weight Tester calibration [mm]	Relevant modulus of deformation $E_{vd,MFG}$ at target value [MN/m2]	Thickness of settlement mat for Medium Drop-Weight Tester calibration [mm]
3	0.2500 – 0.4000	0.3	75	6	150	2
2	0.4000 – 0.6000	0.5	45	10	90	4
1	> 0.9000	1.4 (LFG)/ 1.2 (MFG)	16	23	37.5	10

Note on table 5: The target values of the settlement measuring ranges (column 3) for the calibration are set so that with the three settlement measuring ranges calibration is carried out at the edges and in the middle of the entire permissible measuring range for the Light Drop-Weight Tester (15 MN/m² to 75 MN/m²) and for the Medium Drop-Weight Tester (30 MN/m² to 150 MN/m²). To attain the target values (column 3), the settlement mat thicknesses listed in columns 5 and 7 are recommended. But since the target value of the settlements cannot always be precisely attained with the specified thicknesses, a calibration is also valid provided the settlement in the respective settlement measuring range meets the condition in column 2 of table 5.

- Three inductive displacement transducers, with immersion rod or probe, suitable for impact measurements; attachment of immersion rods to load plate (see below); measuring range at least ± 5 mm.
- The inductive displacement transducers have to be calibrated for a measuring range of ± 2 mm around the zero point position. Within this measuring range they have to be adequate to accuracy class 0.5 according to DIN EN ISO 9513.
- Bridge or tripod for displacement transducer
- Measuring amplifier with adjusted internal filter:
  1000 Hz < upper limit frequency fG < 2000 Hz
- PC with A/D converter card, at least 12 bit, sampling rate at least 19 kHz, signal filtration via software.
  Software parameters: low-pass filter 4th order with filter characteristics acc. to Butterworth, limit frequency 200 Hz/−3 dB, evaluation software for the complete course of settlement and displaying the maximum value of the settlement, zero point determination after notching the drop mass.

For the measurement chain, consisting of the inductive displacement transducers and the associated measuring amplifier, a calibration proof according to DIN EN ISO 9513 is necessary. The calibration of the path measurement chain with calibration proof for the 3 path measurement channels has to be conducted by a calibration institute which has re-conducted inspection equipment at its disposal. The calibration of the inductive displacement transducers has to be yearly together with the measuring amplifiers.

The support plate is put on the settlement mat for the measuring range > 0.9 mm (soft substrate, corresponding to settlement measuring range $i = 1$) and the load plate is fixed to the support plate.

The measuring bridge or the tripod has to be supported thus far away from the load plate centre to a solid substrate, that no disturbing vibrations can be transferred. The inductive displacement transducers are put on the load plate at the points A, B and C. The immersion rods have to be permanently connected on the load plate using adhesive glue, or pressed onto the load plate by a spring-reinforced probe, or fixed on the load plate by a magnet. The measurement applies within the average measuring range of the inductive displacement transducers.

For performing the calibration the loading mechanism has to be mounted to the centre of the load plate and the measuring chain has to be made ready for measurement according to the operating instructions.

After mounting the guide rod three preloading impacts have to be carried out. Their results are not registered.

Afterwards $n = 10$ measuring impacts ($j = 1, 2, ... 10$) with the drop-weight are performed from the drop height h_s defined according to section 2. On each impact, the settlements $s^*_{L,ij}$ are measured with the settlement measuring instrument belonging to the Light Drop-Weight Tester, or the settlements $s^*_{M,ij}$ with the settlement measuring instrument belonging to the Light Drop-Weight Tester, and the settlements $s_{IND,ij}$ are measured with the inductive displacement transducers. The settlements $s_{IND,ij}$ correspond to the average value of the settlements $s_{A,ij}$, $s_{B,ij}$ and $s_{C,ij}$ measured at the measuring points A, B and C (see Gl-11). The measurement results have to be entered in the calibration protocol or be documented in a computer printout.

Then a further 10 measurements are performed using the settlement mats for the settlement measuring range 2 (settlement in the range from 0.4 mm to 0.6 mm) and for the settlement measuring range 3 (settlement in the range of < 0.4 mm), similarly to the measurements in the settlement measuring range 1.

3.2 Outlier test for a settlement measurement series

Prior to further evaluation of the measurement series, for each of the below mentioned measurement series an outlier test with $n = 10$ measurement impacts has to be carried out, whether or not based on subjective estimation an outlier exists or not.

1. Measurement series $s^*_{L,ij}$ respectively $s^*_{M,ij}$ of the settlements measured with the settlement measuring instrument of the Light or Medium Drop-Weight Tester
2. Measurement series $s_{IND,ij}$ of the settlements measured with the inductive displacement transducers $s_{A,ij}$, $s_{B,ij}$ and $s_{C,ij}$
3. Measurement series $\Delta_{s,ij}$ of the differences from the settlement measured with settlement measuring instrument of the Light or Medium Drop-Weight Tester and the settlement measured with the inductive displacement transducers

The subsequent test checks if either the highest or the lowest value of a measurement series with $n = 10$ measurement values has to be rejected as outlier.

The outlier test and the calculations from the measurement results in section 3.3 are presented in the following by way of example for the measurement series $s^*_{M,ij}$ of the settlements measured with the Medium Drop-Weight Tester.

For the measurement series $s^*_{L,ij}$ of the settlements measured with the Light Drop-Weight Tester the procedure is the same.

From the highest value $s_{IND,i,(10)}$ respectively $s^*_{M,i,(10)}$ respectively $\Delta_{s,M,i,(10)}$ in an ordered measurement series with $n = 10$ measuring values, the average value $\overline{s_{IND,i\bullet}}$ (see GI-12) or $\overline{s_{M,i\bullet}}$ (see GI-14) or $\overline{\Delta_{s,M,i\bullet}}$ (see GI-22) and the standard deviation $\sigma_{s,IND,i\bullet}$ (see GI-13) or $\sigma^*_{s,M,i\bullet}$ (see GI-15) or $\sigma_{\Delta,M,i\bullet}$ (see GI-23) the following test quantities have to be calculated:

$$T_{10,IND} = \frac{s_{IND,i,(10)} - \overline{s_{IND,i\bullet}}}{\sigma_{s,IND,i\bullet}} \tag{GI-9a}$$

$$T_{10,M} = \frac{s^*_{M,i,(10)} - \overline{s_{M,i\bullet}}}{\sigma_{s,M,i\bullet}} \tag{GI-9b}$$

$$T_{10,\Delta} = \frac{\Delta_{s,M,i,(10)} - \overline{\Delta_{s,M,i\bullet}}}{\sigma_{\Delta,M,i\bullet}} \tag{GI-9c}$$

From the lowest value $s_{IND,i,(1)}$ respectively $s^*_{M,i,(1)}$ respectively $\Delta_{s,M,i,(1)}$ in an ordered measurement series the following test quantities sgimilarly have to be calculated:

$$T_{1,IND} = \frac{\overline{s_{IND,i\bullet}} - s_{IND,i,(1)}}{\sigma_{s,IND,i\bullet}} \tag{GI-10a}$$

$$T_{1,M} = \frac{\overline{s^*_{M,i\bullet}} - s^*_{M,i,(1)}}{\sigma_{s,M,i\bullet}} \tag{GI-10b}$$

$$T_{1,\Delta} = \frac{\overline{\Delta_{s,M,i\bullet}} - \Delta_{s,M,i,(1)}}{\sigma_{\Delta,M,i\bullet}} \tag{GI-10c}$$

If the test value T_{10} respectively T_1 exceeds the threshold value of 2.410 (significance level 1 %), the measured value $s_{IND,i,(10)}$ respectively $s^*_{M,i,(10)}$ respectively $\Delta_{s,M,i,(10)}$ or $s_{IND,i,(1)}$ respectively $s^*_{M,i,(1)}$ respectively $\Delta_{s,M,i,(1)}$ has to be rejected as an outlier.

In this case a single new measurement impact has to be carried out additionally and its measurement result has to be used. That's why the test set-up should not be removed at the end of one measurement series with 10 measuring impacts, so that, if there is an outlier, an additional measuring impact can take place.

3.3 Calculations from the measurement results

From the measurement results the following value are calculated.

The average value of the settlements measured by the 3 inductive displacement transducers:

$$s_{IND,ij} = \frac{1}{3} * \left(s_{A,ij} + s_{B,ij} + s_{C,ij} \right)$$ (GI-11)

The average value of the settlements measured by the inductive displacement transducers from $n = 10$ measuring impacts:

$$\overline{s_{IND,i\bullet}} = \frac{1}{n} * \sum_{j=1}^{n} s_{IND,ij}$$ GI-12)

Standard deviation of the settlements measured by the inductive displacement transducers from $n = 10$ measuring impacts:

$$\sigma_{s,IND,i\bullet} = \sqrt{\frac{1}{n-1} * \sum_{j=1}^{n} \left(s_{IND,ij} - \overline{s_{IND,i\bullet}} \right)^2}$$ (GI-13)

Average value of the settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester from $n = 10$ measuring impacts:

$$\overline{s_{M,i\bullet}^*} = \frac{1}{n} * \sum_{j=1}^{n} s_{M,ij}^*$$ (GI-14)

Standard deviation of the settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester from $n = 10$ measuring impacts:

$$\sigma_{s,M,i\bullet}^* = \sqrt{\frac{1}{n-1} * \sum_{j=1}^{n} \left(s_{M,ij}^* - \overline{s_{M,i\bullet}^*} \right)^2}$$ (GI-15)

Calibration factor of the measurement series i :

$$c_{M,i} = \frac{\overline{s_{IND,i\bullet}}}{\overline{s_{M,i\bullet}^*}}$$ (GI-16)

Average value of the calibration factors of the measuring ranges $i = 1$ to 3:

$$\overline{c_{M\bullet}} = \frac{1}{3} * \sum_{i=1}^{3} c_{M,i}$$ (GI-17)

Calibrated settlements of the settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester $s_{M,ij}^*$

$$s_{M,ij} = \overline{c_{M\bullet}} * \overline{s_{M,ij}^*}$$ (GI-18)

Note: The calculations (GI-16, GI-17, GI-18) are to carried out when the calibration of the settlement measuring instrument is performed by way of a calibration factor. Alternatively, a calibration function can also be used instead of the calibration factor. The calibration factor or calibration function does not necessarily have to be calculated however. In this case: $s_{M,ij} = s_{M,ij}^*$ respectively $s_{L,ij} = s_{L,ij}^*$.

Average value of the calibrated settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester from $n = 10$ measuring impacts:

$$\overline{s_{M,i\bullet}} = \frac{1}{n}*\sum_{j=1}^{n} s_{M,ij} \qquad \text{(GI-19)}$$

Standard deviation of the calibrated settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester from $n = 10$ measuring impacts:

$$\sigma_{s,M,i\bullet} = \sqrt{\frac{1}{n-1}*\sum_{j=1}^{n}\left(s_{M,ij} - \overline{s_{M,i\bullet}}\right)^2} \qquad \text{(GI-20)}$$

Differences of the calibrated settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester from the settlements measured with the inductive displacement transducers:

$$\Delta_{s,M,ij} = s_{M,ij} - s_{IND,ij} \qquad \text{(GI-21)}$$

Average value of the differences from 10 measuring impacts of the calibrated settlements measured with the settlement measuring instrument of the respective Drop-Weight Tester and the settlements measured with the inductive displacement transducers in the settlement measuring range i:

$$\overline{\Delta_{s,M,i\bullet}} = \frac{1}{n}*\sum_{j=1}^{n}\Delta_{s,M,ij} \qquad \text{(GI-22)}$$

Standard deviation from 10 measuring impacts of the calibrated settlements measured with the settlement measuring instrument of the respective Drop-Weight Tester and the settlements measured with the inductive displacement transducers in the settlement measuring range i:

$$\sigma_{\Delta,M,i\bullet} = \sqrt{\frac{1}{n-1}*\sum_{j=1}^{n}\left(\Delta_{s,M,ij} - \overline{\Delta_{s,M,i\bullet}}\right)^2} \qquad \text{(GI-23)}$$

3.4 Result evaluation and consequences; decision-making rules

1. If an outlier exists, an additional measurement impact has to be carried out. If an outlier exists and processing another measurement impact should not be possible any more, alternatively the further calculations can be carried out with a measured value quantity of $n = 9$.
   When there is more than one outlier in one measurement series the measurement series has to be repeated completely.

2. The amount of the average value of the differences or from 10 measuring impacts of the calibrated settlements measured with the settlement measuring instrument of the respective Drop-Weight Tester and the settlements with inductive displacement transducers measured in the settlement measuring range i must not exceed the maximum permissible deviations If the

value is exceeded, the relevant settlement measuring instrument must be adjusted according to the manufacturer's operating instructions and the calibration must be repeated with 10 measuring impacts.

Table 6: Maximum permissible deviation of the average value of the settlement measurements measured with the settlement measuring instrument of the relevant Drop-Weight Tester from the average value of the settlement measurements with inductive displacement transducers

Settlement measuring range	$\overline{s_{IND,i\bullet}}$	$\Delta_{s,i,zul}$
$i = 1$	> 0.6000 mm	0.0150 mm
$i = 2$ and 3	≤ 0.6000 mm	0.0100 mm

3. The test quantity must be formed from the amount of the average value $|\overline{\Delta_{s,L,i\bullet}}|$ respectively $|\overline{\Delta_{s,M,i\bullet}}|$ and the standard deviation $\sigma_{\Delta,L,i\bullet}$ or $\sigma_{\Delta,M,i\bullet}$.

$$T_{\Delta,L} = \frac{\left(|\overline{\Delta_{s,L,i\bullet}}| - \Delta_{s,i,zul}\right) * \sqrt{10}}{\sigma_{\Delta,L,i\bullet}} \text{ (for Light Drop-Weight Tester) or} \qquad \text{(GI-24a)}$$

$$T_{\Delta,M} = \frac{\left(|\overline{\Delta_{s,M,i\bullet}}| - \Delta_{s,i,zul}\right) * \sqrt{10}}{\sigma_{\Delta,M,i\bullet}} \text{ (for Medium Drop-Weight Tester)} \qquad \text{(GI-24b)}$$

For $\Delta_{s,i,zul}$ the values specified in table 6 are to be used in the calculation.

If the value $T_\Delta > 2.262$, the settlement measuring instrument has to be adjusted according to the instruction manual of the manufacturer and the calibration has to be repeated completely.

4. The standard deviation $\sigma_{s,L,i\bullet}$ respectively $\sigma_{s,M,i\bullet}$ may not exceed a value of 0.0200 mm with a measurement travel $\overline{s_{M,i\bullet}}$ > 0.6000 mm, and with a measurement travel $\overline{s_{M,i\bullet}}$ ≤ 0.6000 mm may not exceed a value of 0.0100 mm. If the value is exceeded, the settlement measurement series with 10 measuring impacts has to be repeated.

Note 1: If also after several repeated measurements the standard deviation $\sigma_{s,L,i\bullet}$ respectively $\sigma_{s,M,i\bullet}$ exceeds the required value, the settlement measuring instrument of the respective Drop-Weight Tester will not supply stable measurement values, so that the repeat standard deviation in the measurement series is too high.

5. The standard deviation $\sigma_{s,IND,i\bullet}$ may not exceed a value of 0.0200 mm with a measurement travel $\overline{s_{IND,i\bullet}}$ > 0.6000 mm, and with a measurement travel $\overline{s_{IND,i\bullet}}$ ≤ 0.6000 mm may not exceed a value of 0.0100 mm. If the value is exceeded, the settlement measurement series with 10 measuring impacts has to be repeated.

Note 2: If also after several repeated measurements the standard deviation $\sigma_{s,IND,i\bullet}$ exceeds the required value, this may be due to the following causes:
1. *The measurement chain of the inductive displacement transducers possibly provides incorrect values.*
2. *An error occurred on the fixture of the inductive displacement transducers.*
3. *The rubber mat significantly compresses during the measurement series. Then it has to be renewed.*

6. When using the settlement mat for the lowest draught < 0.4000 mm (and only for this one!) additionally the test value T_{Var} has to be calculated as follows from the measurement results:

$$T_{Var,L} = \frac{\sigma_{s,L,3\bullet}}{s_{L,3\bullet}} \text{ (for Light Drop-Weight Tester) or} \qquad \text{(GI-25a)}$$

$$T_{Var,M} = \frac{\sigma_{s,M,3\bullet}}{s_{M,3\bullet}} \text{ (for Medium Drop-Weight Tester)} \qquad \text{(GI-25b)}$$

If $T_{Var,L}$ respectively $T_{Var,M}$ is higher than 0.021, then the variation coefficient is significantly higher than 0.015. If the value is exceeded, the settlement measurement series with 10 measuring impacts has to be repeated.

Concerning the conclusions the notes 1 and 2 within points 4 and 5 apply analogously.

3.5 Recommended measurement equipment for settlement measurements

For settlement measurement the following measuring technique is recommended, which corresponds to the specifications mentioned in section 3.1:

Inductive displacement transducer: Type K-WA-L-O50W (immersion anchor) from Hottinger-Baldwin-Messtechnik

Measuring amplifier: MGC plus with single channel amplifier plug in e.g. type ML 55B or type MC 55 S6 from Hottinger-Baldwin-Messtechnik

A/D converter card: with at least 12 bit resolution

With the stated measuring technique compliance with the requirements is possible. Another measuring technique, based on a newer technical state, is also permitted as far as the requirements are met.

4 Symbols and Abbreviations

Relating to force

$F_{m,ij}$ Maximum impact force in measurement series Nr. i in test Nr. j

F_{Soll} Required value of the impact force

$\overline{F_{m,i\bullet}}$ Average value of the force in measurement series Nr. i from 10 measuring impacts

$\overline{\overline{F_{m\bullet\bullet}}}$ Average value of the force from 3 measurement series

$\sigma_{F,i\bullet}$ Standard deviation of the force in measurement series Nr. i from 10 measuring impacts

$\sigma_{F\bullet\bullet}$ Standard deviation of the average values of the 3 force measurement series

$\sigma_{F,zul}$ Maximum permissible standard deviation of the force

h_s Set (or to set) drop height under impact (measured from the bottom edge of the fixed drop-weight to the top edge of the spring assembly)

Relating to impact duration

$t_{s,ij}$ Impact duration in measurement series Nr. i in test Nr. j

$t_{s,\,Soll}$ Required value of the impact duration

$\overline{t_{s,i\bullet}}$ Average value of the impact duration from 10 measuring impacts of measurement series Nr. i

$\sigma_{t,i\bullet}$ Standard deviation of the impact duration from 10 measuring impacts of measurement series Nr. i

Relating to settlement

$s_{M,ij}^{*}$ Maximum settlement in the settlement measuring range i in test Nr. j, measured with the settlement measuring instrument of the Medium Drop-Weight Tester

$s_{L,ij}^{*}$ Maximum settlement in the settlement measuring range i in test Nr. j, measured with the settlement measuring instrument of the Light Drop-Weight Tester

$s_{M,ij}$ Calibrated maximum settlement $s_{M,ij}^{*}$

$s_{L,ij}$ Calibrated maximum settlement $s_{L,ij}^{*}$

$\overline{s_{M,i\bullet}^{*}}$ Average value of the settlement $s_{M,ij}^{*}$ in the settlement measuring range i from 10 measuring impacts, measured with the settlement measuring instrument of the Medium Drop-Weight Tester (see GI-14)

$\overline{s_{L,i\bullet}^{*}}$ Average value of the settlement $s_{L,ij}^{*}$ in the settlement measuring range i from 10 measuring impacts, measured with the settlement measuring instrument of the Light Drop-Weight Tester

$\overline{s_{M,i\bullet}}$ Average value of the calibrated settlement $s_{M,ij}$ in the settlement measuring range i from 10 measuring impacts, measured with the settlement measuring instrument of the Medium Drop-Weight Tester

$\overline{s_{L,i\bullet}}$ Average value of the calibrated settlement $s_{L,ij}$ in the settlement measuring range i from 10 measuring impacts, measured with the settlement measuring instrument of the Light Drop-Weight Tester

$\sigma^*_{s,M,i\bullet}$ Standard deviation of the settlement $s^*_{M,ij}$ in the settlement measuring range i from 10 measuring impacts, measured with the settlement measuring instrument of the Medium Drop-Weight Tester

$\sigma^*_{s,L,i\bullet}$ Standard deviation of the settlement $s^*_{L,ij}$ in the settlement measuring range i from 10 measuring impacts, measured with the settlement measuring instrument of the Light Drop-Weight Tester

$\sigma_{s,M,i\bullet}$ Standard deviation of the calibrated settlement $s_{M,ij}$ in the settlement measuring range i from 10 measuring impacts, measured with the settlement measuring instrument of the Medium Drop-Weight Tester

$\sigma_{s,L,i\bullet}$ Standard deviation of the calibrated settlement $s_{L,ij}$ in the settlement measuring range i from 10 measuring impacts, measured with the settlement measuring instrument of the Light Drop-Weight Tester

$\sigma_{s,zul}$ Maximum permissible standard deviation of the settlement

$s_{A,ij}$, $s_{B,ij}$, $s_{C,ij}$ maximum settlement, measured with the inductive displacement transducers at points A, B and C on the load plate in the settlement measuring range i in test Nr. j

$s_{IND,ij}$ Average value of the settlement measured with the three inductive displacement transducers in the settlement measuring range i in test Nr. j

$\overline{s_{IND,i\bullet}}$ Average value of the settlement from 10 measuring impacts, measured with the inductive displacement transducers

$\sigma_{s,IND,i\bullet}$ Standard deviation of the settlement from 10 measuring impacts, measured with the inductive displacement transducers

$c_{M,i}$ Calibration factor of the settlement measuring range i corresponds to the ratio of the average value of the settlement $\overline{s_{IND,i\bullet}}$ measured with inductive displacement transducers to the average value of the settlement $\overline{s^*_{M,i\bullet}}$ measured with the settlement measuring instrument of the Medium Drop-Weight Tester

$c_{L,i}$ Calibration factor of the settlement measuring range i corresponds to the ratio of the average value of the settlement $\overline{s_{IND,i\bullet}}$ measured with inductive displacement transducers to the average value of the settlement $\overline{s^*_{L,i\bullet}}$ measured with the settlement measuring instrument of the Light Drop-Weight Tester

$\overline{c_{M\bullet}}$	Average value of the individual calibration factors $c_{M,i}$ of the settlement measuring ranges i = 1 to 3 (= total calibration factor for the settlement measuring instrument of the Medium Drop-Weight Tester)
$\overline{c_{L\bullet}}$	Average value of the individual calibration factors $c_{L,i}$ of the settlement measuring ranges i = 1 to 3 (= total calibration factor for the settlement measuring instrument of the Light Drop-Weight Tester)
$\Delta_{s,zul}$	Maximum permissible deviation of the average value from 10 settlement measurements measured with the settlement measuring instrument of the relevant Drop-Weight Tester from the average value of the settlements measured with the inductive displacement transducers
$\Delta_{s,L,ij}$	Difference of the calibrated settlements measured with the settlement measuring instrument of the Light Drop-Weight Tester and the settlements measured with the inductive displacement transducers in the settlement measuring range i in test Nr. j
$\Delta_{s,M,ij}$	Difference of the calibrated settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester and the settlements measured with the inductive displacement transducers in the settlement measuring range i in test Nr. j
$\overline{\Delta_{s,L,i\bullet}}$	Average value of the differences from 10 measuring impacts of the calibrated settlements measured with the settlement measuring instrument of the Light Drop-Weight Tester and the settlements measured with the inductive displacement transducers in the settlement measuring range i
$\overline{\Delta_{s,M,i\bullet}}$	Average value of the differences from 10 measuring impacts of the calibrated settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester and the settlements measured with the inductive displacement transducers in the settlement measuring range i
$\sigma_{\Delta,L,i\bullet}$	Standard deviation of the differences from 10 measuring impacts of the calibrated settlements measured with the settlement measuring instrument of the Light Drop-Weight Tester and the settlements measured with the inductive displacement transducers in the settlement measuring range i
$\sigma_{\Delta,M,i\bullet}$	Standard deviation of the differences from 10 measuring impacts of the calibrated settlements measured with the settlement measuring instrument of the Medium Drop-Weight Tester and the settlements measured with the inductive displacement transducers in the settlement measuring range i
$T_{\Delta,L}$	or $T_{\Delta,M}$ Test quantities (see Gl-24a or Gl-24b)
$T_{Var,L}$	or $T_{Var,M}$ Test quantities (see Gl-25a or Gl-25b)

Indices

i	Running variable for impact force measurement series and settlement measuring ranges
j	Running variable of the measuring impacts (measuring impact number in a measurement series)
n	Sample size
F	Force
s	Settlement
t	Impact duration
m	Maximum
M	Medium Drop-Weight Tester
L	Light Drop-Weight Tester
IND	Inductive displacement transducer

5 Technical Regulations

DIN	DIN EN ISO 376	Metallic materials – Calibration of force-proving instruments used for the verification of uniaxial testing machines	[1]
	DIN EN ISO 9513	Metallic materials – Calibration of extensometer systems used in uniaxial testing	[1]
FGSV	TP BF-StB, Part B 8.3	Technical testing regulations for soil and rock in road construction Part: Dynamic Plate Load Testing with the Light Drop-Weight Tester (FGSV 591/B 8.3)	[2]
	TP Gestein-StB, Part 8.2.1	Technical testing regulations for aggregates in road construction Part: Dynamic Plate Load Testing with the Medium Drop-Weight Tester (FGSV 610)	[2]

Reference sources

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Appendix: Example of a calibration protocol for a Medium Drop-Weight Tester

Calibration protocol
for the Medium Drop-Weight Tester
Required values: Force [N] = 14,140   Impact duration [ms] = 13

Device no.: ....   Date: ....

Manufacturer: ....   Carried out by: ....

Device type: ....   Test number: ....

Year of manufacture: ....   Air temperature: ....

Drop height of 15 kg – drop-weight h_s = **71.0 cm**

1. Calibration of loading mechanism (impact force):						
Check measurements of impact force and impact duration of the loading mechanism						
Measurement series	$i = 1$		$i = 2$		$i = 3$	
Measuring impact Nr. j	Impact force [N]	Impact duration [ms]	Impact force [N]	Impact duration [ms]	Impact force [N]	Impact duration [ms]
1	14,157	12.91	14,163	12.94	14,156	12.92
2	14,140	12.91	14,169	12.93	14,163	12.92
3	14,161	12.92	14,163	12.92	14,162	12.93
4	14,153	12.93	14,179	12.93	14,158	12.92
5	14,167	12.92	14,155	12.92	14,159	12.93
6	14,147	12.91	14,167	12.93	14,167	12.93
7	14,151	12.91	14,152	12.92	14,156	12.92
8	14,148	12.91	14,162	12.93	14,162	12.92
9	14,155	12.91	14,153	12.93	14,170	12.93
10	14,148	12.91	14,168	12.93	14,164	12.92
Average values	14,152.7	12.914	14,163.1	12.928	14,161.7	12.924
Rod w. σ	7.73	0.0070	8.29	0.0063	4.60	0.0052
T_{10}	1.850	2.286	1.918	1.905	1.804	1.154
T_1	1.643	0.571	1.339	1.270	1.239	0.769
Average value dev.	0.09 %	0.086	0.16 %	0.072	0.15 %	0.076
Decision-making rules						
1a) $T_{10} < 2.410$	Yes	Yes	Yes	Yes	Yes	Yes
1b) $T_1 < 2.410$	Yes	Yes	Yes	Yes	Yes	Yes
2) $\sigma_{F,i\bullet} < 40$ N	Yes		Yes		Yes	
3) $\sigma_{t,i\bullet} < 0.1$ ms		Yes		Yes		Yes
4) $|\Delta F| < 1$ %	Yes		Yes		Yes	
5) $|\Delta t| < 1.0$ ms		Yes		Yes		Yes
Average value of the force from 3 measurement series $\overline{\overline{F_{m\bullet\bullet}}}$ 14,159.17						
Standard deviation $\sigma_{F\bullet\bullet}$ 5.644						
6) $\sigma_{F\bullet\bullet} < 10$ N Yes						
all decision-making rules fulfilled: **Yes**						
Loading mechanism correctly calibrated; drop height correctly set.						

				2.1 Calibration of the settlement measuring instrument:			

Comparison measurements of settlement amplitudes [mm] between inductive displacement transducer (reference $s_{IND,1,j}$) and electronic settlement measuring instrument of Medium Drop-Weight Tester (tester $s_{M,1,j}$)

Settlement measuring range > 0.9 mm (soft substrate) $i = 1$							
Measuring impact Nr. j	Reference A [mm]	Reference B [mm]	Reference C [mm]	Ref. i.M. $s_{IND,1,j}$ [mm]	Tester $s^*_{M,1,j}$ [mm]	Tester $s_{M,1,j}$ [mm]	Difference $\Delta_{s,1,j}$ [mm]
1	0.977	1.111	1.061	1.050	1.028	1.055	0.005
2	0.979	1.112	1.067	1.053	1.026	1.053	0.000
3	0.980	1.112	1.068	1.053	1.028	1.055	0.002
4	0.971	1.111	1.071	1.051	1.026	1.053	0.002
5	0.982	1.105	1.066	1.051	1.026	1.053	0.002
6	0.982	1.109	1.071	1.054	1.027	1.054	0.000
7	0.982	1.109	1.071	1.054	1.031	1.058	0.004
8	0.976	1.117	1.072	1.055	1.029	1.056	0.001
9	0.985	1.111	1.170	1.055	1.028	1.055	0.000
10	0.975	1.113	1.069	1.052	1.023	1.050	−0.002
Average values				1.0528	1.0272	1.0542	0.0014
Calibration factor $c_{M,1}$				1.025			
Standard deviations σ				0.0018	0.0021	0.0021	0.0021
Test quantity T_{10}				1.222	1.810		1.714
Test quantity T_1				1.556	2.000		1.619
Test quantity T_Δ							−20.480
Decision-making rules							
1a) $T_{10} < 2.410$				Yes	Yes		Yes
1b) $T_1 < 2.410$				Yes	Yes		Yes
3) $T_\Delta < 2.262$				Yes			
4), 5) $\sigma < 0.0200$				Yes	Yes		
All decision-making rules fulfilled: **Yes,**							
settlement measuring instrument correctly calibrated on soft substrate.							
Summary for all three settlement measuring ranges							
Total calibration factor for the settlement amplitude =				**1.026**			
Settlement measuring range $j =$				1	2	3	
Plate substrate =				soft	medium-hard	hard	
Calibrated average settlement difference [mm] =				0.0014	−0.0022	0.0011	
2) Absolute value of permissible difference Δ_{zul} [mm] =				0.0150	0.0100	0.0100	
Requirement for all settlement measuring ranges $i = 1$ to 3 met.							

2.2 Calibration of the settlement measuring instrument:							
Comparison measurements of settlement amplitudes [mm] between inductive displacement transducer (reference $s_{IND,2,j}$) and electronic settlement measuring instrument of Medium Drop-Weight Tester (tester $s_{M,2,j}$)							
Settlement measuring range 0.4 mm to 0.6 mm (medium-hard substrate) $i = 2$							
Measuring impact Nr. j	Reference A [mm]	Reference B [mm]	Reference C [mm]	Ref. i.M. $s_{IND,2,j}$ [mm]	Tester $s^*_{M,2,j}$ [mm]	Tester $s_{M,2,j}$ [mm]	Difference $\Delta_{s,2,j}$ [mm]
1	0.483	0.506	0.511	0.500	0.489	0.502	0.002
2	0.488	0.497	0.516	0.500	0.488	0.501	0.001
3	0.487	0.501	0.515	0.501	0.486	0.499	−0.002
4	0.489	0.495	0.518	0.501	0.485	0.498	−0.003
5	0.489	0.500	0.514	0.501	0.483	0.496	−0.005
6	0.489	0.505	0.510	0.501	0.484	0.497	−0.004
7	0.491	0.502	0.510	0.501	0.482	0.495	−0.006
8	0.488	0.501	0.510	0.500	0.486	0.499	−0.001
9	0.485	0.508	0.513	0.502	0.486	0.499	−0.003
10	0.482	0.502	0.517	0.500	0.486	0.499	−0.001
Average values				0.5007	0.4855	0.4985	−0.0022
Calibration factor $c_{M,2}$				1.031			
Standard deviations σ				0.0007	0.0021	0.0021	0.0025
Test quantity T_{10}				1.857	1.667		1.680
Test quantity T_1				1.000	1.667		1.520
Test quantity T_Δ							−9.866
Decision-making rules							
1a) $T_{10} < 2.410$				Yes	Yes		Yes
1b) $T_1 < 2.410$				Yes	Yes		Yes
3) $T_\Delta < 2.262$							Yes
4), 5) $\sigma < 0.0100$				Yes	Yes	Yes	
All decision-making rules fulfilled: **Yes,**							
settlement measuring instrument correctly calibrated on medium-hard substrate.							

2.3 Calibration of the settlement measuring instrument:
Comparison measurements of settlement amplitudes [mm] between inductive displacement transducer (reference $s_{IND,3,j}$) and electronic settlement measuring instrument of Light or Medium Drop-Weight Tester (tester $s_{M,3,j}$)
Settlement measuring range < 0.4 mm (hard substrate) $i = 3$
Measuring impact Nr. j	Reference A [mm]	Reference B [mm]	Reference C [mm]	Ref. i.M. $s_{IND,3,j}$ [mm]	Tester $s^*_{M,3,j}$ [mm]	Tester $s_{M,3,j}$ [mm]	Difference $\Delta_{s,3,j}$ [mm]
1	0.294	0.340	0.298	0.311	0.302	0.310	−0.001
2	0.294	0.337	0.299	0.310	0.305	0.313	0.003
3	0.294	0.339	0.300	0.311	0.303	0.311	0.000
4	0.294	0.336	0.303	0.311	0.304	0.312	0.001
5	0.294	0.337	0.302	0.311	0.306	0.314	0.003
6	0.291	0.340	0.301	0.311	0.302	0.310	−0.001
7	0.293	0.338	0.301	0.311	0.302	0.310	−0.001
8	0.294	0.338	0.301	0.311	0.304	0.312	0.001
9	0.291	0.338	0.303	0.311	0.306	0.314	0.003
10	0.290	0.339	0.302	0.310	0.305	0.313	0.003
	Average values	0.3108	0.3039	0.3118	0.0011
	Calibration factor $c_{M,3}$		1.023		
	Standard deviations σ	0.0004	0.0016	0.0016	0.0018
	Test quantity T_{10}	0.500	1.312		1.056
	Test quantity T_1	2.000	1.188		1.167
	Test quantity T_Δ				−15.636
	Test quantity T_{var}			0.005	
Decision-making rules
	1a) $T_{10} < 2.410$	Yes	Yes		Yes
	1b) $T_1 < 2.410$	Yes	Yes		Yes
	3) $T_\Delta < 2.262$				Yes
	4), 5) $\sigma < 0.0100$	Yes	Yes	Yes	
	6) $T_{var} < 0.021$			Yes	
All decision-making rules fulfilled: **Yes,**
settlement measuring instrument correctly calibrated on hard substrate.

Remarks on the system of technical publications of the FGSV

R stands for regulations:
These publications either specify the technical design or realization (R1) or give recommendations on the technical design or realization (R2).

W stands for information documents:
These publications represent the current state-of-the-art knowledge and define how a technical issue shall be practicably dealt with or has already been successfully dealt with.

Category R1 indicates 1st category regulations:
R1-publications contain the contractual basis (Additional Technical Conditions of Contract and Guidelines, Technical Conditions of Delivery and Technical Test Specifications) as well as guidelines. They are always coordinated within the FGSV. R1-publications – in particular if agreed on as integral part of the contract – have a high binding force.

Category R2 indicates 2nd category regulations:
R2-publications contain information sheets and recommendations. They are always coordinated within the FGSV. Their application as state-of-the-art technology is recommended by the FGSV.

Category W1 indicates 1st category documents of knowledge:
W1-publications contain references. They are always coordinated within the FGSV but not with external parties. They represent current state-of-the-art knowledge within the respective responsible boards of the FGSV.

Category W2 indicates 2nd category documents of knowledge:
W2-publications contain working papers. These may include preliminary results, supplementary information and guidance. They are not coordinated within the FGSV and represent the conception of an individual board of the FGSV.

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