Dynamic load plate tests – Calibration Procedure for test equipments in Germany

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ABSTRACT: In Germany the dynamic load plate test with the Light Falling Weight Deflectometer (LFWD) is, beside the static plate load test, standard for testing the bearing capacity of the subgrade. For testing the bearing capacity of subbase layers the Medium Falling Weight Deflectometer (MFWD) has been developed. For this several modifications of the LFWD have been systematically evaluated. The result of this research is an equipment with a bigger mass and a modified spring assembly. These small modifications allow to keep the main principle of the test procedure and the calibration procedure. For the calibration of the LFWD as well as the MFWD an updated calibration procedure has been developed. To verify this calibration procedure and to evaluate if the calibration centers can handle the calibration procedure a round robin test has been started in 2012.
The purpose of use related test device selection and its calibration procedure will guarantee high quality construction control and a wide acceptance.

KEY WORDS: Dynamic, Falling Weight, Deformation modulus

1 INTRODUCTION

The Light Falling Weight Deflectometer (LFWD) is an approved test method in Germany for many years. Due to the results of a round robin test in 1999, the test parameters and the calibration of the LFWD have been significantly changed. These modifications raised the level of trust on the client's side as well as the acceptance by the contractor. So the LFWD is fixed in the German standards for earthworks, equivalent to the classic static load test, as a test method for compaction control and an indirect criterion for density grade control.

But the application of the LFWD is limited to earthworks layers because of its load range. The application on unbound sublayers with higher deformations moduli is not possible. Therefore the Medium Falling Weight Deflectometer (MFWD) has been developed in the first decade of the 21st century.

An important part of this acceptance is due to the calibration procedure and the approval of calibration centers by the Federal Highway Research Institute BASt.

2 LIGHT FALLING WEIGHT DEFLECTOMETER

2.1 Equipment

The Light Falling Weight Deflectometer basically consists of a drop weight, mounted to a guide rod which allows giving a defined impulse via a loading plate to the tested ground, see figure 1. A defined spring assembly (disc springs), mounted between the drop weight and the loading plate, allows controlling the impact force and duration. A settlement sensor in the centre of the loading plate measures the vertical movement of the loading plate or of the tested ground respectively.

With the falling weight mass of 10 kg and a loading plate diameter of 300 mm an impact force of 7,07 kN or a normal stress of 0,1 MN/m² will be induced. The spring assembly has been configured to an impact duration of 17 ms. The impact force and duration are fixed parameters, controlled by periodically calibration. This assuming can be done, because the buffer is made of a steel spring assembly instead of rubber. With this, the load impact inducted to the loading plate is independent from the surrounding and equipment temperature. Therefore, compared to similar test equipments on the international market, the test equipment has no load cell.

With the known impact force and the measured maximum vertical deformation a dynamic deformation modulus of the tested ground will be calculated by using formula 1.

$$E_{vd} = 1{,}5 \cdot r \cdot \frac{\sigma_{max}}{\phi s_{max}} \quad (1)$$

with E_{vd} *= Dynamic deformation modulus [MN/m²]*
r *= Radius of the loading plate, fixed to 150 [mm]*
σ_{max} *= Maximum of normal stress under the loading plate, fixed to 0,1 for LFWD [MN/m²]*
$\varnothing s_{max}$ *= Medium of three measured maximum vertical deformations [mm]*

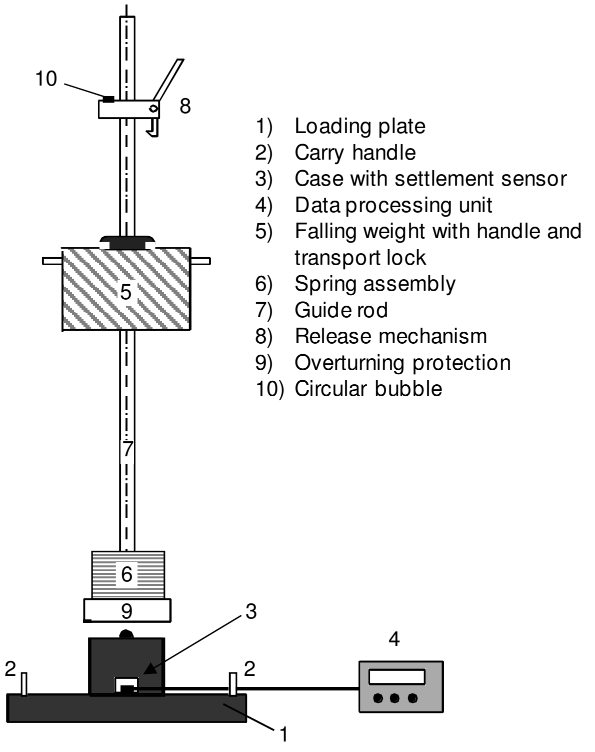

Figure 1: Schematic diagram of LFWD (FGSV, 2003)

In addition to the maximum deformation the whole deformation timeline of a drop will be recorded and given the user as plot. With the help of this plot, the quality of the measurement can be evaluated. For example irregular settlement, tilting or jumping of the loading plate can be identified by reviewing the plot, see figure 2.

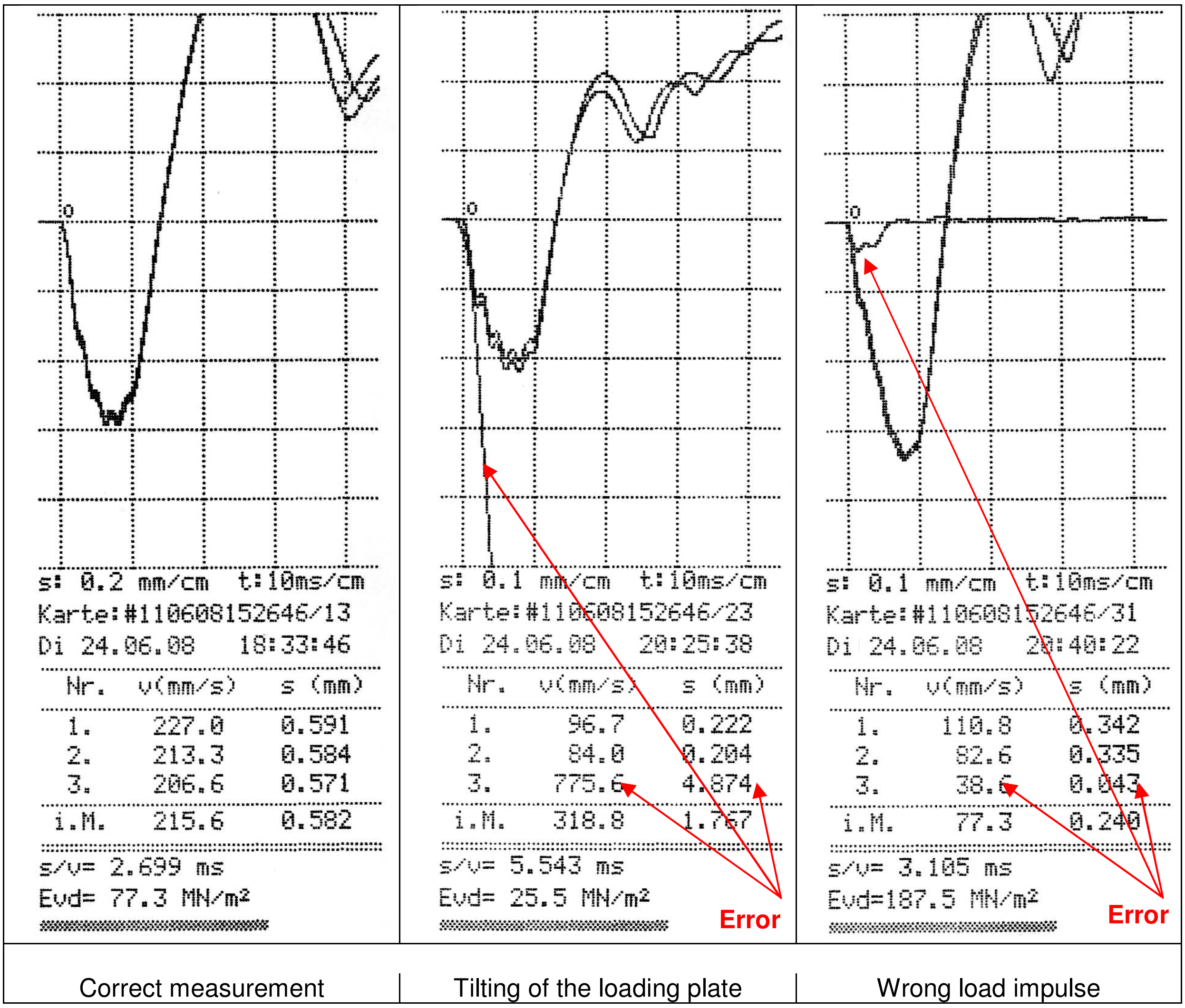

Figure 2: Examples for the evaluation of the deformation timeline (FGSV, 2012)

2.2 Scope of application

Due to the impact force and stress as well as to the in build sensor, the measurements with the LFWD are limited to deformations in between a range of 0,3 to 1,5 mm. Using formula 1 this means that the measurements are limited for testing grounds with a deformation modulus between 15 and 75 MN/m². Therefore the LFWD can be primarily used for the quality control of earthworks.

The usage of the LFWD is implemented in the German standards for earthworks (FGSV, 2009) which are part of the construction contract in case of road constructions for a public contracting body. Therefore the LFWD can be used for the control of the deformation modulus and as an indirect test for the grade of density of a compacted surface. The application is limited to non-cohesive soils or non-frost susceptible subsoil and subgrade.

In this case the minimum dynamic deformation modulus is 65 MN/m² for high volume roads and 50 MN/m² for low volume roads. Comparing to the well known static plate load test (PLT), this is intended to be equivalent to E_{v2} values of 120 MN/m² and 100 MN/m² respectively. When using the LFWD as an indirect test method for the grade of density of coarse-grained soils, the minimum E_{vd} values have to be 50 MN/m² for a minimum Proctor density of 100 % and 40 MN/m² for a minimum Proctor density of 98 %. If the LFWD will be used instead of the PLT, the necessary number of testing points for the needs of quality control has to be doubled.

3 MEDIUM FALLING WEIGHT DEFLECTOMETER

3.1 Development of a new test equipment

Due to the mentioned limitations the LFWD is not suitable for measurements on subbase layers and layers with higher deformation modulus respectively. On the other hand the easy and fast usage of the test equipment demands for expanding the field of application. Therefore a research project has been initiated in the year 2004 (Bräu and Vogt 2008) with the objective to develop a test equipment for subbase layers quite similar to the LFWD.

This new test equipment should therefore use the approved measurement technique with modifications to the falling weight mass or to the loading plate diameter. To achieve an economic solution it should be possible to transform a LFWD into a MFWD by changing the loading gear or the loading plate. The changing of the parameters mentioned in table 1 have been discussed.

Table 1: Possible modifications for the development of the MFWD, on the basis of (Bräu and Vogt 2008)

Parameter	Pro	Contra
Increasing the falling weight mass	Easy to realize: no large modifications of the LFWD needed	Limitations to user-friendliness: mass over 20 kg can only be used with the help of additional equipment
Increasing the drop height	Easy to realize: no large modifications of the LFWD needed	High limitations to user-friendliness: drop height over 90 cm can only be used with the help of additional equipment
Downsizing the loading plate	Easy to realize: no modifications of the loading gear and spring assembly	Reduction of measuring depth; higher influence of inhomogeneous testing ground
Increasing the impact speed (tensioning of the spring assembly)	No modifications of the falling weight and drop height (can poss. be reduced)	Complex technical modification
Increasing the requirements of the existing principle, which is based on velocity measurement	No changes of the construction principle necessary	Requires a new and severe calibration procedure; poss. usage of high priced sensors and electronic needed
Changing the whole principle	Poss. reduction of needs for calibration	Changes of whole construction necessary; versatile testing of new principle necessary

In the context of the mentioned research project several of the modifications have been tested. Parallel to this a theoretical model has been developed to evaluate the effects of changing the parameters. The modification of the load gear, including the spring assembly, and the loading plate diameter have been in focus of all activities. The result of these activities has been that there is more than one preferable possibility to change a LFWD to a MFWD without changing the main principle. Out of these possibilities one has been chosen by an expert group. The chosen possibility includes a higher falling weight mass in combination with a small modification of the spring assembly. Table 2 shows the modifications, compared to the LFWD specifications. The schematic diagram of the MFWD is the same as for the LFWD, see figure 1 and 3.

Table 2: Specifications of the LFWD and MFWD

Parameter	LFWD	MFWD
Normal stress [MN/m²]	0,1	0,2
Mass of falling weight [kg]	10,0 ± 0,100	15,0 ± 0,150
Mass of guide rod [kg]	5,0 ± 0,100	5,5 ± 0,100
Max. impact force [kN]	7,07 ± 1%	14,14 ± 1%
Impact duration [ms]	17 ± 1,5	13 ± 1,0
Number of disc springs	17	
Dimension of spring assembly (D_e x D_i x t) [mm]	63 x 31 x 2,5	63 x 31 x 3,5
Diameter of loading plate [mm]	300 ± 0,5	
Thickness of loading plate [mm]	20 ± 0,2	
Mass of loading plate [kg]	15 ± 0,25	
Frequency range of settlement sensor [Hz]	8 – 100	
Measuring range of settlement sensor [mm]	0,3 – 1,5	

Figure 3: LFWD (left) and MFWD (right) load gear, loading plate and data processing unit

3.2 Scope of application

Due to the impact force and stress as well as to the built-in sensor, the measurements with the MFWD are possible on surfaces with a dynamic deformation modulus up to 150 MN/m².

An ongoing research project is assessing requirement values for the dynamic deformation values measured by the MFWD. The overall objective is to implement the usage of the MFWD in the German standard for unbound pavement layers, similar to what is done with LFWD for earthworks. As a first step for bringing the MFWD to the market the technical test specifications (FGSV, 2012) which describe the equipment and its usage have already been published in 2012.

4 CALIBRATION

An essential element for trusting the results of a test equipment is a high quality, periodic and well documented calibration procedure. In the first decade of the 21st century a new system for calibration of the LFWD has been set up and will be, with a small update, also valid for the calibration of the MFWD.

The calibration of the test equipment has to be done once a year by an approved calibration centre. The calibration also has to be done for new equipments and after fixing an equipment. The procedure and requirements for the calibration are described in technical test specifications for calibration (FGSV AA 5.7, 2012)

4.1 Calibration stand

For the calibration of the LFWD and MFWD a calibration stand is needed. The calibration procedure is divided into the calibration of the load gear and calibration of the settlement sensor. Both calibrations can be done on the same calibration stand, see figure 4 and 5.

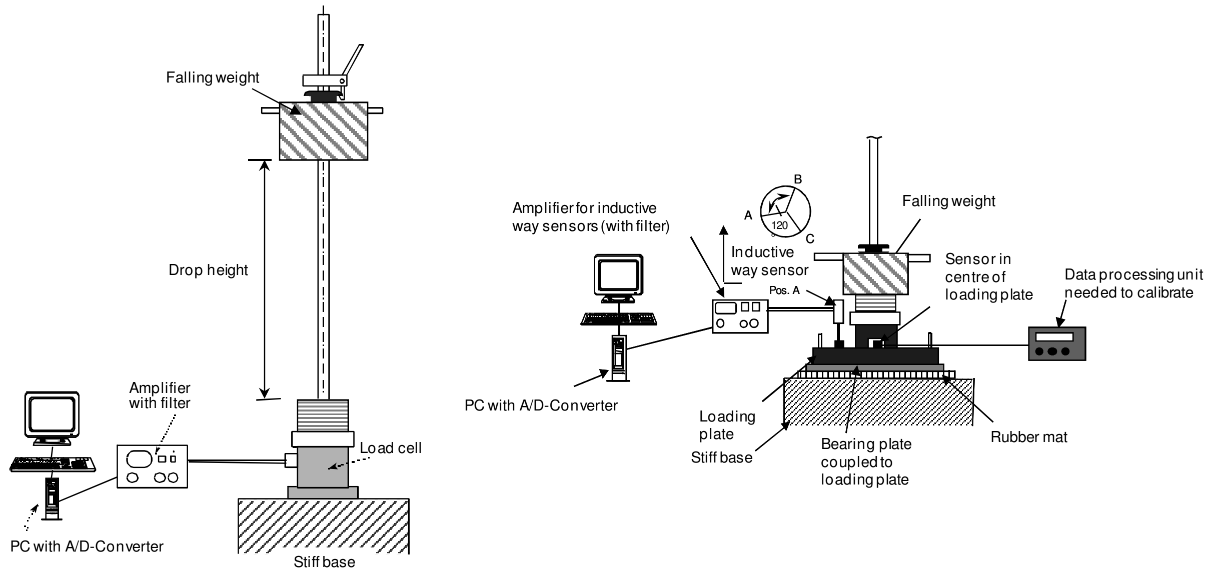

Figure 4: Calibration stand setup for load gear calibration (left) and calibration of the settlement sensor (right) (FGSVAA 5.7, 2012)

The calibration stand consist of a stiff base, preferably a concrete block with at least dimensions of 80 x 80 x 50 cm, three inductive way sensors which are decoupled from the concrete block, and a PC with signal amplifier.

When calibrating the load gear, the falling weight with the guide rod and spring assembly will be mounted on a calibrated load cell. The impact load measured by the load cell will be compared to the requirements.

When calibrating the settlement sensor, the whole equipment (calibrated load gear with loading plate) will be mounted to the calibration stand. On top of the loading plate three inductive sensors will be fixed. The measured settlement of the settlement sensor of the test equipment and the inductive sensors will then be compared at different deformation levels. The deformation levels are simulated by using rubber mats with different thicknesses.

Figure 5: Photos of calibration stand setup for load gear calibration (left) and calibration of the settlement sensor (right)

Figure 6: Decoupled formwork for concrete block (left) and rubber mats for calibration (right)

4.2 Calibration center approval

In 2012 there were seven approved calibration centers in Germany. An additional calibration stand is placed at the Federal Highway Research Institute of Germany (BASt). This calibration stand will only be used as reference for the approval of the calibration centers.

The approval has to be made by BASt. The calibration center has to proof the qualification of the affected staff and the presence of the necessary technical equipment. For the approval the calibration center will be visited by BASt staff. During this visit all significant elements of the calibration stand will be examined and documented. Then a Reference-LFWD, Reference-MFWD respectively (calibrated at the BASt reference calibration stand) will be tested on the calibration stand. The calibration of this reference equipment has to be successful without changing any parameters at the reference equipment. Then a second test equipment (LFWD, MFWD), delivered and manipulated by BASt, has to be calibrated by the calibration center staff.

If the calibration center fulfills all criteria and is able to calibrate successfully the equipment manipulated by BASt it will then be listed as approved calibration center and gets a certificate.

4.3 Calibration procedure

For the calibration the full test equipment, consisting of load gear and loading plate, has to be at the calibration center. The calibration staff has to check if the different parts belong to each other.

4.3.1 Load calibration

The test equipment is not outfitted with a load cell, hence the annual load calibration plays a very important par.

First the load calibration will be done. The load gear will be mounted on a load cell of the calibration center, see figure 4. The guide rod will be vertical fixed at the top. Then three pre-load drops have to be made. Afterwards three series consisting of 10 drops each have to be made. After completing each series, the load gear has to be dismounted and then mounted again.

A statistical analysis on the measured load impacts has to be done for each series beginning with the evaluation of outliers. If there were any outliers, the series has to be repeated. If there is no outlier, the mean value and the standard deviation will be calculated. These calculated values have to fulfill certain criteria. If the criteria are not fulfilled, the drop height or the tensioning of the spring assembly has to be adjusted. Afterwards the calibration procedure has to be repeated.

4.3.2 Settlement sensor calibration

Second the settlement sensor will be calibrated. For this, the full equipment (load calibrated) has to be mounted onto the calibration stand. Then three inductive way sensors have to be fixed at the top of the loading plate. The loading plate itself has to be coupled to a steel-made bearing plate. Between this bearing plate and the stiff base (concrete block) lies a rubber mat with a defined thickness, see figure 4.

After three pre-load drops one series with 10 drops has to be made. The signals from the inductive way sensors and the settlement sensor of the equipment were recorded. After a statistical analysis (outlier, mean value, standard deviation) the values of the two sensor types have to be compared and with this a calibration factor has to be calculated.

Then the full equipment has to be dismounted, the rubber mat has to be changed and the above described procedure has to be repeated.

This has to be done with three different rubber mats. These rubber mats simulate three different deformation moduli within the measuring range of the equipment. Table 3 shows the specification of the rubber mats. Because of the new added calibration of the MFWD and an update of the calibration procedure, the suitability of these rubber mats will be verified in a round robin test, see chapter 5.

Table 3: Specifications of rubber mats for the calibration

		LFWD		MFWD	
Measuring range	from - to [mm]	Deformation Modulus [MN/m²]	Thickness of rubber mat [mm]	Deformation Modulus [MN/m²]	Thickness of rubber mat [mm]
3	< 0,4	< 56	6	< 112	2
2	0,4 – 0,7	56 – 32	10	112 – 64	4
1	> 0,9	> 25	23	> 50	10
Rubber mat type: Aclacell 2435, Acla-Werke GmbH, Cologne					

The last step of the settlement sensor calibration is to calculate one calibration factor out of the single calibration factors from each series. The data processing unit of the test equipment will then be updated with this calibration factor.

5 ROUND ROBIN TEST

As mentioned before, the calibration procedure has been updated. Modifications to the rubber mat thicknesses and to the statistical analyses have been made and the calibration of the MFWD has been added. To verify the updated calibration procedure and its precision requirements and to check if the calibration centers can handle the modifications, a round robin test has been started in 2012 and will be finished in 2013. All approved calibration centers as well as the reference calibration stand at BASt have to participate.

For the round robin test three LFWD and three MFWD will be used. The LFWD and MFWD have been delivered by three German manufactures. The six test equipments will be sent from one calibration center to the next. Each calibration center has to calibrate each of the test equipments without changing the drop height and without changing the calibration factor. The calibration has to be done according to the regular calibration procedure, but the number of series will be doubled in each part of the calibration.

The results of the round robin test will lead into advices for the new calibration procedure and for the calibration centers.

6 CONCLUSION

The use of the LFWD is a regular method for bearing capacity measurements at earthworks. It is implemented into the German standards for earthworks an widely distributed. The easy and fast use of this test equipment asked for a similar test equipment for the use on subbase layers. So the MFWD has been developed on the basis of the LFWD. A just 50% higher mass of the falling weight and a modification of the spring assembly offers the possibility to double the normal stress. So the MFWD is as user-friendly as the LFWD and it is cost efficient, because the same loading plate can be used for both load gear devices.

An ongoing research project will asses requirement values for the new MFWD test equipment. The standards for subbase construction will then be updated with these values, so that the MFWD will find its way to the market.

A periodic and precise calibration procedure at approved calibration centers guarantees high quality results and the wide acceptance of the test method on the contractor’s side as even on the client’s side. To hold this high level the calibration procedure has been updated and will now be tested in a round robin test.

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