STRUCTURAL PAVEMENT MONITORING WITH NON-DESTRUCTIVE MEASURING DEVICES AT TRAFFIC SPEED - CURRENT RESEARCH AND EXPERIENCE IN GERMANY

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ABSTRACT

As Germany's federal road network of 53,000 km has become the centre of transit road freight transport in Europe and a large part of the network is now about 30 to 50 years old, a systematic pavement and maintenance management becomes more and more essential for road authorities.

The existing pavement condition monitoring and assessment (Zustandserfassung und -bewertung ZEB) and Pavement Management System (PMS) focuses on measured surface characteristics like longitudinal and transverse profile, skid resistance and visual damages like cracking, spalling, patching, bleeding and is carried out in a four year cycle on the entire federal road network. A pavement condition rating based on these surface characteristics is calculated using a standardised procedure. No account is taken for structural bearing capacity and often there is only poor knowledge about the pavement structure, layers and thicknesses. As Falling Weight Deflectometer (FWD) deflection measurements and coring are suitable measures for project level assessments and require lane closures, there is growing demand for Non-Destructive-Testing (NDT) methods on network level at highway speed without traffic disruptions.

To overcome the lack of knowledge about structural pavement condition and the need to detect deteriorations like bottom-up fatigue cracking, debonding of layers, etc., i.e. a general loss of stiffness, the German Federal Highway Research Institute BASt performed a project where NDT systems operating at traffic speed of 80 km/h like the Ground Penetrating Radar (GPR) and the Danish High Speed Deflectograph (HSD) performed concerted measurements on selected highway sections which were supplemented by FWD measurements and core samples. An overview over the state-of-the-art in pavement condition monitoring in Germany and the results of NDT measurements will be given as well as an assessment of different structural parameters. The observed problems and shortcomings and the advantages and possibilities of the HSD are finally addressed and discussed.

1 INTRODUCTION

1.1 Pavement condition monitoring in Germany

The pavement condition monitoring and assessment on Germany's 12,000 km federal highways and 41,000 km trunk roads is carried out in a four year cycle with longitudinal and transverse profile, skid resistance and surface images being continuously recorded with measuring vehicles at traffic speed. Measurements are taken on all highway lanes and the right lanes of trunk roads. The German pavement condition monitoring and assessment (ZEB) is divided into four technical packages TP1 to TP4 which are carried out by consultants and control checked by BASt:

TP1: Longitudinal and transverse profile
TP2: Skid resistance
TP3: Surface imaging
TP4: Evaluation and assessment

Profile data is recorded every 1.0 m with longitudinal profile being measured in the right wheel track. A fictive water depth is then computed from the measured rut depth and the transverse slope for asphalt pavements. A spectral density analysis is performed on the longitudinal profile data resulting in the general unevenness index AUN (Allgemeiner Unebenheitsindex). Skid resistance is recorded by the SKM-device (Seitenkraftmessgerät) which is based on the SCRIM principle. A structural surface condition index is calculated from the visual image data on the basis of surface crack length and areas affected by damages like patches, spalling and ravelling per unit length or unit area.

The calculated values are then normalised and transformed into marks from 1 to 5, with 1 rating a very good and 5 rating a very poor pavement condition. These marks are then averaged to form homogeneous 100 m sections. The final result is a condition map showing the rating from 1 to 5 for each condition parameter in 100 m resolution for the entire federal highway network, serving as input for the PSM and the planning of maintenance measures.

1.2 High Speed Deflectograph HSD

The High Speed Deflectograph device was originally developed by the Danish company Greenwood in cooperation with the Danish Road Institute (DRI). The name was later changed to Traffic Speed Deflectograph (TSD) for public relation reasons. In the following, the device remains referred to as High Speed Deflectograph (HSD), the original name.

The HSD is a measuring vehicle comprising a single-, twin-tyred axle trailer carrying a container with measuring equipment town by a two axle prime mover. The HSD vehicle and the principle measurement system are shown in Figure 1.

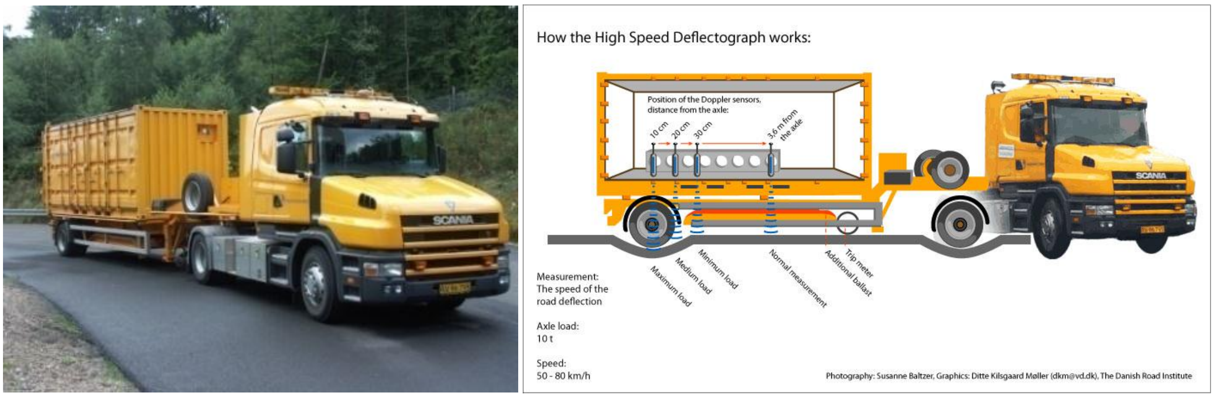

Figure 1: The Danish High Speed Deflectograph and the measuring principle.

The static vertical wheel load of the trailer axle is about 10 t with 5 t on each wheel. Four Doppler laser sensors are installed on a rigid metal beam inside the container at an offset of 100, 200, 300 and 3600 mm in front of the vertical centre axis of the trailer axle. The three sensors at 100, 200 and 300 mm offset measure the velocity of the surface deflections caused by the vertical wheel load of the trailer axle while the sensor at 3600 mm offset works as reference sensor for compensating the vertical body movement, presuming no deflection occurs in this area due to ample spacing between the adjacent axles.

Finally, the centre deflection D0 and the Surface Curvature Index SCI300 are computed using a polynomial fit or an elastically bedded beam model. Additionally, air and road surface temperatures are measured and GPS signals can be recorded. The normal operating speed of the HSD is between 50 and 80 km/h, measurements at 40 km/h have also been conducted successfully.

More detailed information about the HSD can be found amongst others in Rasmussen, S. ; Krarup, J. A. ; Hildebrand, G. (2002), Rasmussen, S. (2008), Ferne, B. et al. (2009b), Hildebrand, G. ; Rasmussen, S. (2002).

1.3 Falling Weight Deflectometer FWD

The FWD is a best-known pavement surface deflection measurement device used for structural pavement analysis and thus only briefly described here. The BASt FWD used for the measurements has nine geophones and all measurements in the framework of this project were carried out with 50 kN vertical target load at 7.5 m distance on all nine test sections.

One common evaluation approach is to compute structural deflection bowl parameters from the measured values which are related to the structural strength of different layers. A selection of structural deflection bowl parameters is compiled and described in WSDOT (2005). In the framework of this project five structural deflection bowl parameters were computed, three of them were selected here to rate the structural strength of the upper asphalt layers of the pavement sections (D0, SCI300, Tz). The BASt FWD and selected deflection bowl parameters are shown in Figure 2 and briefly described in Table 1.

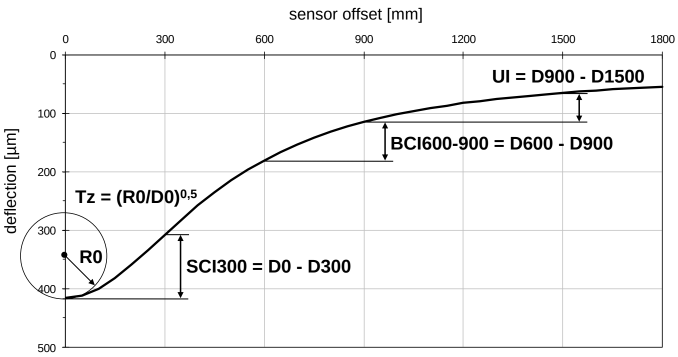

Figure 2: BASt Falling Weight Deflectometer FWD (left) and selected FWD deflection bowl parameters (right) for structural strength assessment of pavement structures.

Table 1: Selected FWD deflection bowl parameters and their characteristics.

deflection bowl parameter		characteristic
centre deflection D0	D0	high > low strength
bearing capacity index Tz	$Tz=(R0/D0)^{0.5}$	high > high strength
surface curvature index SCI300	D0-D300	high > low upper layers strength
base curvature index BCI600-900	D600-D900	high > low subgrade strength
subgrade bearing capacity index UI	D900-D1500	high > low subgrade/-base strength

1.4 Ground Penetrating Radar GPR

The Ground Penetrating Radar (GPR) is a measurement system which is mainly used in geophysics and geotechnical engineering. The system is based on the propagation of electromagnetic waves and the reflection at layer interfaces in earth, soil and pavements.

The measured propagation time can be related to the thickness of a layer inside a pavement structure by calibration. Sufficient knowledge and experience of the user presumed GPR enables the detection of structural defects like voids or debonding of layers and the identification of different layers as well as their thicknesses.

As the wave propagation time and the wave reflection depends on the dielectric constants of the materials it is principally easier and more reliable to distinguish between bound and unbound materials like asphalt on a granular base (different dialectical constants) than between layers of similar materials like asphalt base-, -binder- and -wearing course (nearly the same dialectical constants). In the framework of this project GPR measurements were performed to identify the different layers as far as possible and to continuously determine the total thickness of the bound layers as well as their variation in thickness. An important advantage of the GPR is that it can be operated non-destructively at traffic speed of up to 80 km/h with a high data acquisition rate providing a “continuous” image of a pavement structure.

More detailed background information on the GPR can be found amongst others in Saarenketo, T. (1997) and Saarenketo, T. ; Roimala, P. (1998). Figure 3 shows the BASt van-mounted GPR antenna and a detail of a radar diagram indicating the different layers and their interfaces of a measured pavement section of the B35 trunk road in the framework of this project.

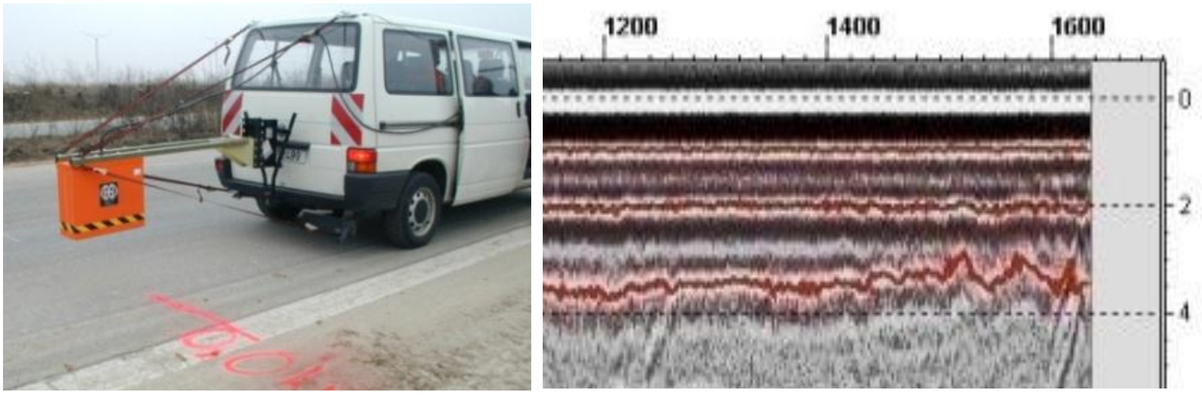

Figure 3: BASt van-mounted GPR antenna (left) and a radar diagram of the B35 trunk road indicating different pavement layers and their thicknesses (right).

2 CHARACTERISTICS OF THE SELECTED PAVEMENT SECTIONS

Four highway sections and five federal trunk road sections were chosen for the comparative measurements with FWD, HSD and GPR. The construction and layer thicknesses of the highway sections A3 and A70 were taken from a research report by Ressel, W. et al (2008) which contains evaluation of core samples. The layer thicknesses of the B7 trunk road were taken from supplied photos of cores. Additional core samples were taken in all sections of the B35 federal trunk road. A3 Fuerth and A3 Nuernberg are the oldest and most heavily trafficked sections resulting in the highest accumulated traffic loads of all sections. Due to technical problems with the device there is no GPR data available for B7 and no HSD data is available for A70 due to a wet surface. No reliable traffic data was available for the B7 trunk road but it is assumed that it is the less trafficked section of all.

Table 2 summarizes the basic data of all nine pavement sections selected for this project.

Table 2: Characteristics of the selected pavement sections and structures.

test section basic data	A3 Wies-baden	A3 Fuerth	A3 Nuern-berg	A70 Stadel-hofen	B7 West-uffeln	B35 Illingen 1	B35 Illingen 2	B35 Illingen 3	B35 Illingen 4
from station [km]	145.0	389.0	395.5	101.0	1.885	3.750	3.350	2.950	2.550
to station [km]	145.5	388.5	395.0	101.5	2.285	3.350	2.950	2.550	2.150
measurement length [m]	500	500	500	500	400	400	400	400	400
year of construction	1987	1980	1980	1992	n.a.	2007	2007	2007	2007
construction class (RStO)	SV	SV	SV	II	II[1]	II	IV[2]	III[2]	III[2]
direct asphalt underlay[3]	SOB	HGT	HGT	SOB	SOB	SOB	SOB	SOB	SOB
E_{v2} granular base [MPa]	220/350	n.a.	n.a.	300/270	n.a.	220[4]	195[4]	230[4]	205[4]
max ESALs (design) [mio]	> 32	> 32	> 32	10	10	10	0.8	3	3
heavy vehicle share [%]	18.3	18.9	17.8	19.0	n.a.	17.7	17.7	17.7	17.7
$AADT_{HV}$ [HV/24h]	5620[5]	7626[5]	8590[5]	3331[5]	n.a.	8371[6]	8371[6]	8371[6]	8371[6]
$AADT_{HV}$ [HV/24h]	9049[7]	15556[7]	17523[7]	4254[7]	n.a.	n.a.	n.a.	n.a.	n.a.
GPR data	x	x	x	x	n.a.	x	x	x	x
FWD data	x	x	x	x	x	x	x	x	x
HSD data	x	x	x	n.a.	x	x	x	x	x
core data	x	x	x	x	x	x	x	x	x

[1] construction class resulting from multiple asphalt overlay
[2] analytically designed, corresponding RStO 01 construction class
[3] SOB: granular base, HGT: cement bound base
[4] assumed value for the analytic design procedure
[5] year of construction
[6] traffic count 2000
[7] calculated value for 2004

The layer thickness of each asphalt layer was determined on cores. The total thickness of the asphalt layers and the thickness of the cement bound layers were also determined by GPR measurements.

Table 3 summarizes the layers and thicknesses for all test sections and contains the mean values of the GPR measurements per section as well as the assumed design thickness. Except for the A70 the GPR total asphalt thickness matches very well with the core thickness.

Table 3: Layer thicknesses based on core samples and GPR-measurements (mean values per section) and design thicknesses of all test sections.

layer thickness [cm]	A3 Wies-baden	A3 Fuerth	A3 Nuern-berg	A70 Stadel-hofen	B7 West-uffeln	B35 Illingen 1	B35 Illingen 2	B35 Illingen 3	B35 Illingen 4
AD (core)	4,0	4,0	4,0	4,0	4,7[1]	4,0	4,3	4,5	4,1
ABI (core)	8,0	4,0	7,0	9,0	5,0[1]	7,5	-	8,2	8,0
AB (core)	22,0	17,5	24,5	14,0	3,6[1]	10,3	10,5	9,1	8,2
HGT (assumed design)	-	15,0	15,0	-	-	-	-	-	-
sum asphalt (core)	34,0	25,5	35,5	27,0	26,0[1]	21,8	14,8	21,8	20,3
sum asphalt (core)+HGT	-	40,5	50,5	-	-	-	-	-	-
mean asphalt (GPR)	34,2	25,7	33,8	32,6	-	20,4	14,7	20,2	
mean HGT (GPR)	-	12,2	17,3	-	-	-	-	-	
mean asphalt+HGT (GPR)	-	38,0	51,1	-	-	-	-	-	
asphalt (design)	34,0	26,0	26,0	26,0	-	22,0	15,0	20,0	
HGT (design)	-	15,0	15,0	-	-	-	-	-	

[1] asphalt pavement comprises seven layers, only three layers are shown

3 RESULTS OF THE DIFFERENT MEASUREMENT SYSTEMS

3.1 GPR measurements

The main objective of the GPR measurements is the continuous identification of structural layers and the determination of the total asphalt thickness and the thickness of the cement bound base courses underneath if present.

Figure 4 shows a typical radar diagram of the four different sections on the B35 trunk road with layer interfaces marked on the basis of the wave reflection at the layer interfaces. Due to the strong reflection, the layer interfaces between asphalt and granular base could have been determined with reasonable accuracy and correspond well with the core data.

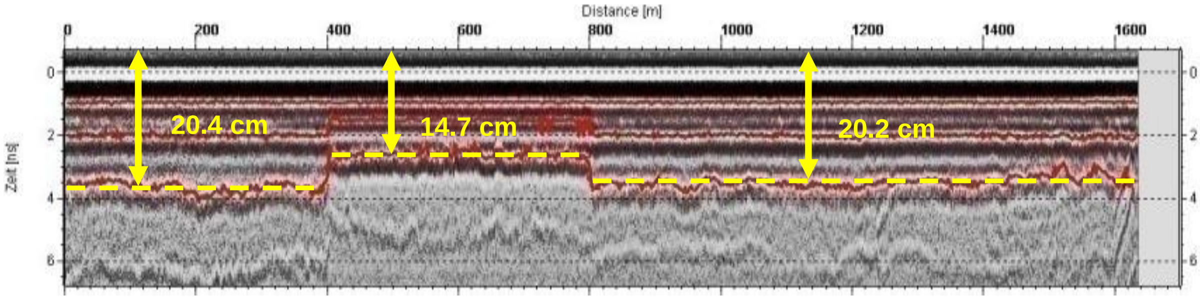

Figure 4: GPR radar-diagram of the four different asphalt pavement sections of the B35 trunk road at Illingen indicating the asphalt thickness (mean value) and the layer interfaces.

3.2 FWD measurements

FWD measurements were taken at intervals of 7.5 m on all test sections. Figure 5 shows the mean values of the FWD D0 and FWD SCI300 calculated from the FWD deflection bowl including the 5 % and 95 % -quantile per section, the total asphalt thickness determined on cores and the average surface temperature during the measurements.

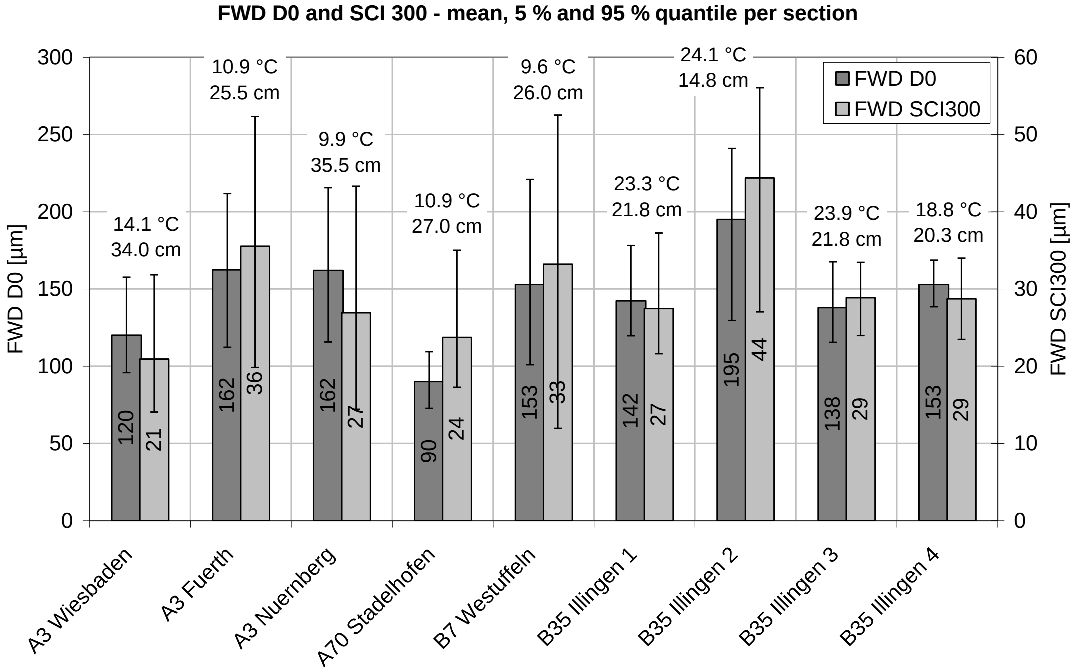

Figure 5: FWD D0 and SCI300 values (mean, 5 % and 95 % -quantile) with total asphalt thickness determined on cores and average surface temperature for each section.

Both, FWD D0 and FWD SCI300 values show a relatively high scatter of stiffness in almost any section except the B35 sections 1, 3 and 4 while the scatter of the FWD D0 values is generally less than that of the FWD SCI300 values. The deflection values are not compensated for temperature. It should be mentioned that the surface temperature during the measurements on the B35 is about 11 °C higher than in the other sections and therefore the strength of the B35 sections based on the FWD deflection values might be slightly underrated.

Both parameters indicate a similar strength ranking for all test sections. According to these values the A70 highway section and the A3 section at Wiesbaden are rated the strongest pavements although both constructions do not comprise any cement bound base underneath the asphalt as the A3 Fuerth and A3 Nuernberg sections. Due to the high scatter there are some overlaps in the range of values between pavement sections of different mean strength and construction class. B35 section 2 shows the highest deflection values.

3.3 HSD measurements

All HSD measurements are generally characterized by very high scatter of the calculated HSD SCI300 parameter. The Danish Road Institute also noticed an offset and a drift of the HSD data on the B35 due to an uneven warming up and bending of the measurement beam inside the container because of a warming up of the lasers according to Baltzer, S. (2011). Thus, the B35 measurements have to be treated with caution and are not fully evaluable.

All measurements also produced a high amount of negative HSD SCI300 values. Negative HSD SCI300 values can theoretically be explained by measurements on a pavement stiffer than the pavement the calibration of the HSD lasers was carried out on as mentioned in Ferne, B. et al. (2009a). In the present case, negative SCI300 values occur even on a relatively weak pavement as the B35 section 2 with only ca. 15 cm of total asphalt thickness. However, the reasons for the high amount of negative HSD SCI300 values are still unknown.

Figure 6 shows the HSD SCI300 values of all four B35 sections with 0.1 m resolution and 0.1 m reporting interval. Slightly higher HSD SCI300 values due to a lower asphalt thickness (~15 cm in section 2 compared to ~20-21 cm in section 1, 3 and 4) can be noticed in section 2.

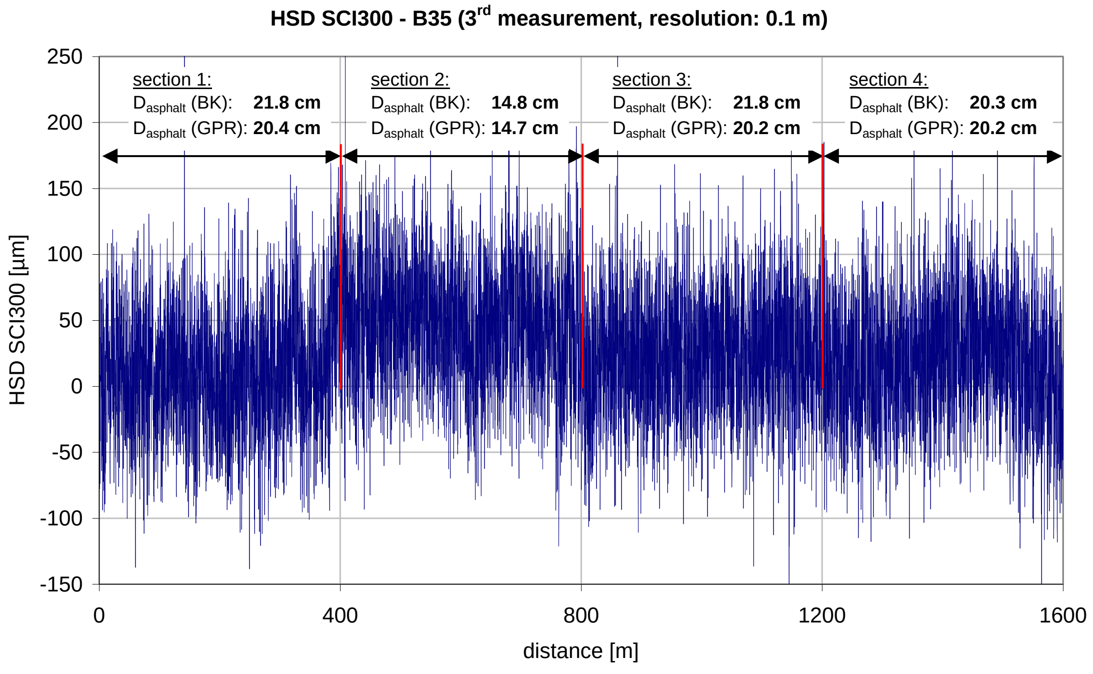

Figure 6: HSD SCI300 values of all four sections of the B35 Illingen federal trunk road (3rd measurement with 0.1 m resolution at an average surface temperature of 16.3 °C.

Despite of the obvious difficulties a pragmatic evaluation approach of the HSD SCI300 data was performed by computing the mean values of each measurement run per section which are shown in Figure 7, additionally indicating the average surface temperature and the total asphalt thickness determined on cores. The data has not been compensated for temperature.

The results show an adequate repeatability of the measurements only on the A3 Fuerth, the A3 Nuernberg and the B7 section. All other sections are characterised by an increase of the HSD SCI300 mean value for each run, indicating the aforementioned problem with the warming up and bending of the beam which causes erroneous results.

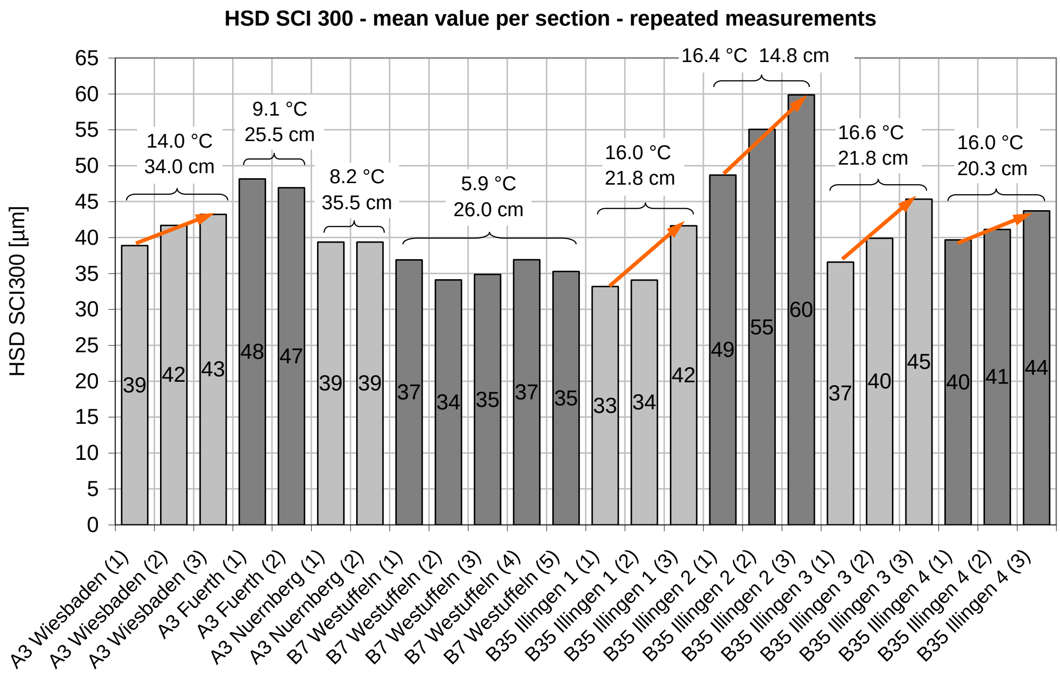

Figure 7: HSD SCI300 mean values and average surface temperatures per section and measurement (arrows indicate an increase of values due to uneven warming-up of the measurement beam).

4 COMPARISON OF HSD AND FWD VALUES AND PAVEMENT STRENGTH RATING BASED ON DEFLECTION PARAMETERS

For a final strength rating of the pavement sections the deflection parameters FWD D0, FWD SCI300 and FWD load bearing capacity index Tz as well as the HSD SCI300 value are compared. For each parameter the mean value along each test section is computed. Due to their different loading FWD SCI300 and HSD SCI300 are different in nature.

The HSD SCI300 is calculated as mean value of up to three repetitive measurements along each test section with only positive SCI300 values being considered while unreasonable negative values are deleted. To simplify the comparison between the different pavement sections and the measurement devices neither homogeneous sections regarding thickness or deflection values within each test section nor the effect of different surface temperatures at the time of measurement are considered. The GPR measurements show that the construction in all sections remains the same along the test length and does not show significant variations in layer thickness so all sections are considered homogenous regarding their construction.

The FWD SCI300 and the HSD SCI300 are compared in Figure 8, including the average surface temperature and the total asphalt thickness determined on cores.

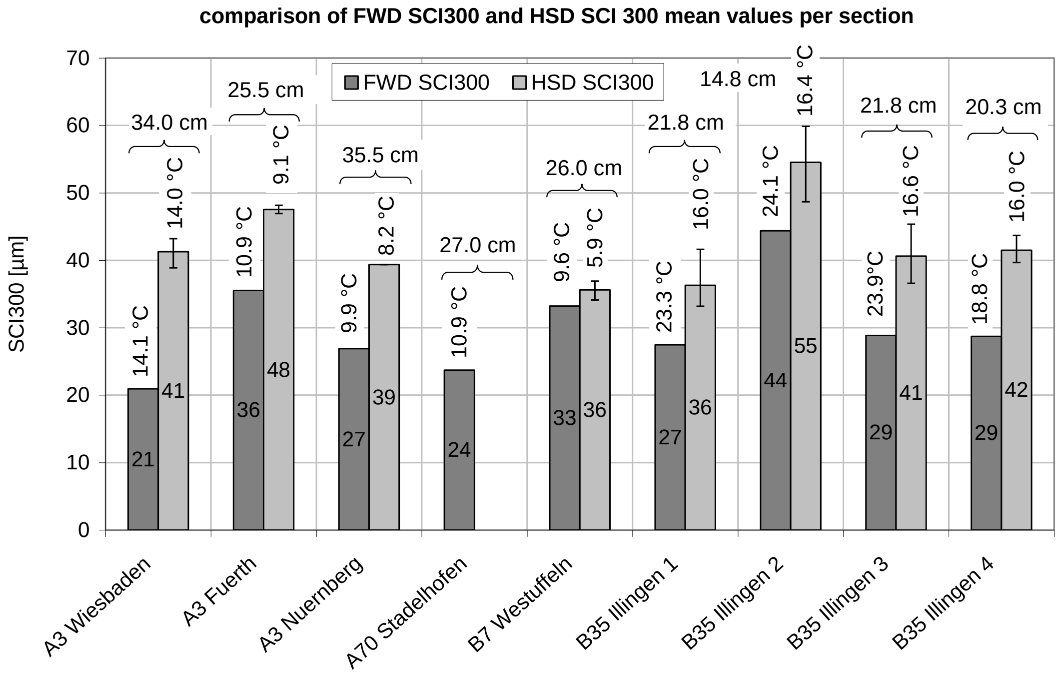

Figure 8: Comparison of FWD SCI300 and HSD SCI300 mean values, average surface temperatures and total asphalt thickness per section (minimum and maximum values of all repetitive HSD-measurements are indicated).

Firstly, it can clearly be seen that the HSD SCI300 mean values are generally higher than the FWD SCI300 values for all sections. Secondly, the HSD SCI300 values indicate a different structural strength ranking than the FWD SCI300 values. Note that both values are not directly comparable due to their different nature. A rating of the structural pavement strength for each deflection bowl parameter and the FWD and HSD is shown in Table 4.

Table 4: Strength rating of all test sections by selected characteristic FWD and HSD deflection parameters (mean values along test length and repeated HSD measurements).

	No.	FWD D0 [µm]		FWD SCI300 [µm]		HSD SCI300 [µm]		FWD Tz [-]	
strong	1	A70 Stadelhofen	90	A3 Wiesbaden	21	B35 Illingen 1	36	A3 Wiesbaden	6,5
	2	A3 Wiesbaden	120	A70 Stadelhofen	24	B7 Westuffeln	36	A70 Stadelhofen	5,4
	3	B35 Illingen 3	138	B35 Illingen 1	27	A3 Nuernberg	39	A3 Nuernberg	4,8
	4	B35 Illingen 1	142	A3 Nuernberg	27	B35 Illingen 3	41	B7 Westuffeln	4,8
	5	B35 Illingen 4	153	B35 Illingen 3	29	B35 Illingen 4	42	B35 Illingen 1	3,5
	6	B7 Westuffeln	153	B35 Illingen 4	29	A3 Wiesbaden	44	A3 Fuerth	3,5
	7	A3 Nuernberg	162	B7 Westuffeln	33	A3 Fuerth	48	B35 Illingen 3	3,3
	8	A3 Fuerth	162	A3 Fuerth	36	B35 Illingen 2	55	B35 Illingen 4	3,2
weak	9	B35 Illingen 2	195	B35 Illingen 2	44			B35 Illingen 2	2,1

On the basis of these values the test sections show a different strength rating for each parameter and measuring device. The FWD parameters show a similar strength rating of the sections, identifying A 70 Stadelhofen and A3 Wiesbaden as the strongest, B35 Illingen, section 2 as the weakest (obviously, because of the lowest asphalt thickness) and the remaining as mid-strength pavements. Contrary to this, the HSD SCI300 rated B35 section 1 and B7 Westuffeln as strongest pavements. B35 Illingen section 2 and A3 Fuerth were rated as the weakest sections in accordance with the FWD D0 and SCI300 values. Note that the HSD surface temperatures on B7 and B35 are much lower than those of the FWD measurements meaning that these pavement sections might be slightly overrated. Contrary to their strong asphalt package on cement bound layers, the A3 Furth and Nuernberg sections show higher deflection values than sections with lower asphalt thickness.

The evaluation generally shows the difficulties in accurate pavement strength rating based solely on deflection parameters. A distinction between pavements of various strengths seems to be possible with FWD measurements. The assessment based on the present HSD SCI300 values has to be treated with high caution due to high scatter, implausible negative values and drift of the values due to temperature effects during the measurements on the B35.

5 SUMMARY, CONCLUSIONS AND OUTLOOK

Following results can be derived from the concerted HSD, FWD and GPR measurements carried out by BASt on selected highway sections in Germany up to now:

- The HSD features a high data resolution (data points all 10 cm at 80 km/h), facilitating a quasi-continuous registration of pavement strength along a road section, ideally together with GPR measurements which also provide continuous information.
- Compared to almost all HSD-measurements in external studies the HSD-measurements in Germany were performed on relatively thick and therefore stiff pavements. Thus, the resulting values are very low and problems occurred when processing these values. Additionally, the validity of the applied theoretical models for calculating characteristic deflection values like D0 and SCI300 seems questionable.
- During the measurements in Germany the DRI detected that a warming up of the lasers produced a temperature gradient in the beam causing the beam to bend and resulting in a drift of the measured values. According to the DRI the container was later equipped with an air condition unit and fans to eliminate this problem.
- The high scatter of the HSD values as well as the implausible negative HSD SCI300 is considered critical. An adequate reliable distinction between stronger and weaker pavement sections does not seem possible on the basis of the measurements performed in Germany in the framework of this project.
- The comparison of deflections and the total thicknesses of the bound upper layers show that positions with lower deflections match with positions with higher layer thickness and vice versa. For an assessment of the structural strength, mainly expressed by the stiffness of the materials, the thickness of the bound upper layers has to be taken into account when evaluating deflections. It is therefore recommended, that continuous deflection measurements with the HSD should always be combined with continuous determination of layers thickness, ideally with GPR.
- Vertical dynamic wheel loads due to vehicle body and axle movements induced by longitudinal unevenness as well as lane change manoeuvres and driving in curves may produce vertical wheel loads significantly higher or lower than the static wheel loads assumed to act during HSD-measurements. Deviations of up to 50 % from the static wheel load are not negligible as they produce deviations of the deflection values of the same magnitude according to Rabe, R. (2011) and Rabe, R. (2012). A continuous measurement of the vertical dynamic HSD wheel load (e.g. with strain gauges on the axle profile) is considered a must. Deflection parameters could then be normalised to a “standard” static wheel load with reasonable good accuracy.
- The SCI300 value of the FWD and the HSD are not directly comparable because FWD and HSD have different load configurations and are computed using different

methods. The evaluation of measurements in Germany does not show any correlation between FWD SCI300 and HSD SCI300.
- The review of external projects confirmed a good short-term repeatability of the HSD data as stated in Kelley, J. ; Moffatt, M. (2012). No sufficient data is available to confirm a good long-term repeatability. The evaluation of measurements in Germany could not confirm a good short-term repeatability due to non-quantifiable effects. Other research also indicates that numerous influences like speed or surface properties are not fully quantified yet as stated in Ferne, B. et al. (2009b).
- The assessment of the structural strength of a pavement structure based solely on deflection values without any more information on the structure is naturally not possible. Additional information about the structure, the layers and the thicknesses are required. Therefore an assessment of the bearing capacity based on deflection values is best combined with GPR measurements or at least with information on the as-built layers and thicknesses documented in the control checks - as far as available.
- Based on this evaluation, a bearing capacity index derived from HSD measurements for integration into a PMS requires more investigation into the influence factors, the data quality and reliability and evaluation methods.

Under consideration of the results of completed projects including HSD measurements and review of literature it can be finally stated that the HSD is potentially capable to non-destructively and efficiently detect variations in pavement strength of asphalt pavement structures at traffic speed, especially when combined with GPR-measurements.

The measurements in Germany however showed that the system seems yet not fully capable to provide reliable data for a structural assessment of pavement strength for the implementation into a PMS under any condition. Before further measurements are performed, the influences of temperature, wheel load, surface properties, calibration, evaluation and processing etc. have to be thoroughly examined, quantified and improved under consideration of the German conditions.

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ABBREVIATIONS

$AADT_{HV}$	Annual average daily traffic (heavy vehicles)
ABI	Asphalt binder course
AD	Asphaltdeckschicht (asphalt wearing course)
AT	Asphalt base course
AUN	Allgemeiner Unebenheitsindex (general unevenness index)
BCI 600-900	Base curvature index 600-900
E_{v2}	Elastic surface modulus (static plate load bearing test)
FWD	Falling Weight Deflectometer
GPR	Ground Penetrating Radar
GPS	Global Positioning System
HGT	Hydraulisch gebundene Tragschicht (cement bound base)
HSD	High Speed Deflectograph
PMS	Pavement Management System
RStO	Richtlinen für die Standardisierung des Oberbaues von Verkehrsflächen (German pavement design guide)
SCI300	Surface curvature index 300
SCRIM	Sideways Force Coefficient Routine Investigation Machine
SKM	Seitenkraftmessgerät (based on the SCRIM-device)
SOB	Schicht ohne Bindemittel (Unbound granular base)
TSD	Traffic Speed Deflectograph
Tz	Tragfähigkeitszahl (Bearing capacity index)
UI	Untergrundindikator (Subgrade bearing capacity index)
ZEB	Zustandserfassung und -bewertung (Condition monitoring and assessment)