TSD Evaluation in Germany

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Abstract
The assessment of the structural pavement condition plays a crucial role of the economic pavement maintenance management. The aging structure as well as the considerable increase of heavy-traffic load on Germany’s motorways and trunk roads encourages the use of innovative, sound and reliable methods for the structural assessment. The existing data base of the German Road Monitoring and Assessment ZEB provides a good basis, but it is limited to the evaluation of surface properties (evenness, surface texture, traction).

Bearing capacity measurements are therefore becoming more and more an important component, but they are rather used at the object level caused by the measuring velocity when using the established methods like FWD, Curviametro or Lacroix. Now the Traffic Speed Deflectometer TSD provides a method which can be applied on the highly stressed German network.

Therefore the applicability, the possibilities and limits of the TSD has been and will be tested in different projects right now.

Keywords: Traffic-Speed-Deflectometer, bearing-capacity, structural assessment, asphalt pavements

1. Introduction

Since nearly 2006 the German Federal Highway Research Institute BAS has evaluating the applicability of the Traffic-Speed-Deflectometer TSD. First tests have been made with the prototype owned by the Danish Road Institute. These tests have been conducted at the BAS indoor test track as well as on different sections of in situ pavements.

The test results with the prototype showed some room for improvements. Temperature control of the sensor holding steel beam and the missing control or monitoring of the dynamic axle load have been identified as critical points. As one conclusion a BAS developed system for the measurement of the dynamic axle load has been first time applied. Based on this, the TSD manufacture provides all its equipments on demand with this option.

The identified critical points have been eliminated and all improvements can be found at the 2nd generation TSD. Because of this, the data measured by the Danish 1st generation prototype (without applied modification) shouldn’t be used directly for further evaluation. This is why BAS is interested in the 2nd generation evaluation of the TSD.

The evaluation of the applicability of the TSD on German pavements will contain the following: general applicability, comparability, repeatability.

An important first step has been made by the Bavarian state in 2012. There 300 km of different road classifications have been measured by a 2nd generation TSD. BAS has supported and accompanied these measurements.
One of the further steps has been the organization and realization of comparative measurements with two 2\textsuperscript{nd} generation TSD on a motorway section in Germany. In addition a R&D project has just started to take a deeper look into repeatability and applicability of the system.

2. Structural assessment in Germany

At the moment the pavement assessment in Germany on network level is based on a write-down model in combination with surface characteristics data.

The write-down model works with only a few necessary data input and is therefore easy to apply on network level, see figure 1. By using time- and layer-depending factors the in situ thickness of the bound pavement structure will be decreased to an equivalent thickness of the pavement. This equivalent thickness will be compared to the necessary thickness, derived by pavement design calculations with the actual traffic load. Via scaling this comparison, a structural number between one and five will be presented.

![Figure 1. Deriving a structural number with the write-down model](image)

As mentioned before the advantage of this write-down model is that it uses easy to derive input data. The disadvantage is that individual in situ impacts like traffic, climate and material parameters, which will have an influence on the deterioration of the pavement, cannot be incorporated.

A linkage to the real condition of the pavement will be made with the data from the ‘Road Monitoring and Assessment’ system ZEB (\textit{Zustandserfassung und -bewertung}). Every fourth year the federal network will be monitored with high-speed non-destructive devices, see figure 2. These measurements include the longitudinal- and transversal-evenness, surface images and skid resistance. With the help of evenness and surface distress data a scaled structural number between one and five will be derived.
The advantage of the ZEB is that it is well implemented into the German pavement management for years and that it covers the whole federal network. The disadvantage is that it is based on surface distress and therefore only gives limited information about structural damages.

A nearly perfect data mix for the structural assessment should therefore include ‘real’ structural data as well as additional data about the maintenance history of the pavement. Figure 3 gives an overview of such a perfect data mix. It should be clear, that depending on the grade of deterioration of the pavement it is not economic and reasonable to collect all the data for the assessment. Therefore easy to derive data, like surface distress and age of the different layers, could help to make pre-decisions. This outlook becomes more and more realistic with the availability of a high-speed device for bearing-capacity measurements.
3. Applicability

Compared to many countries worldwide, pavements in Germany are very thick. This is one reason that the general applicability of the TSD device has to be taking into account at the evaluation.

The state of Bavaria organized in 2012 a TSD measurement campaign on 300 km of different road classification. Motorways (approx. 34 cm asphalt), federal highways (approx. 30 cm asphalt) and state highways (approx. down to 22 cm asphalt) have been taking into account. On some tracks, the TSD measurements have been supported by FWD, Deflectograph Lacroix or Curviameter measurements. A detailed description of this project can be found in [1].

The overall result of this project has been that the TSD gives valuable information and has the needed potentials. The advantage of the measurements seems to increase with decreasing road classification. The inspected 137 km of motorways don’t seem to have any bearing capacity problems. The comparison to the other devices has been satisfying, especially when comparing to rolling wheel devices, see also chapter 4.1. At the time of the measurements the used TSD was not equipped with a dynamic axle monitoring device. The combined evaluation of the TSD data, evenness data and front camera images shows, that the information about the actual applied axle load is crucial for the assessment of bearing capacity measurements with the TSD.

In 2014 a second measurement on a motorway has been organized by BASt, see also chapter 4.2. Even on this very stiff pavement, the TSD produces valuable and plausible results, which in this case helped to define homogenous sections for an intensive structural assessment with intrusive methods.

4. Comparability

When evaluating the comparability of the TSD two perspectives have to be taking into account:
- Comparability to other bearing capacity measuring devices like the FWD
- Comparability of one TSD to another

4.1 Comparability to the FWD

The first mentioned comparability has been evaluated in many international projects with different types of devices. Most mentioned comparisons have been done with the very popular Falling-Weight-Deflectometer FWD.

Depending on several parameters like type, thickness and evenness of pavement, the direct comparison of FWD and TSD fits or does not. In most cases it can be seen, that there is a shift of the values derived with the two different devices. When taking a closer look to the principle of applying the load to the pavement and the principles of measuring the pavements response it is clear that this comparison is not so easy at it seems.
The FWD simulates a truck wheel passing a fixed point A with a velocity of about 60 km/h. For this, the FWD load impulse has a length between 25 and 30 ms and the load peak is normally set to 50 kN, which corresponds to a standard 10 to truck axle.

When looking at a simplified elastostatic case and calculating (Boussinesq equation, see [2]) the time and distance depending influence line of a rolling wheel device like the TSD and an impulse loading device like the FWD, it can be seen, that a direct comparison can be difficult. Figure 4 shows the influence line of a truck wheel passing a fixed point A (passed at distance = 0 m) with 80 km/h. It can be seen, that an influence, here deformation, to point A already exists when the wheel is more than 400 cm away. At 80 km/h this is about 200 ms before the load arrives at point A. Compared to the FWD load impulse, the FWD only simulate a loading which suddenly appears 30 cm (15 ms) before it reaches its peak at point A.

![Figure 4. Influence line of a rolling wheel and FWD loading time](image_url)

Taking into account that asphalt has a complex viscoelastic behavior, which is therefore also dependent to load frequency, it is obvious, that a direct comparison of an impulse load and a rolling wheel load can be different. Tests with an impulse generator and a rolling wheel device (Mobile-Load-Simulator MLS10) at the fully instrumented asphalt test road of BASt validate the above mentioned theoretical analysis. Figure 5 shows some results of the strain and pressure measurements at the asphalt bottom side under these different loadings.
Figure 5. Results from measurements of compression stress (left) in the unbound layer and strain (right) at the asphalt bottom side underneath a rolling wheel (black line) and an impulse generator (grey line).

Another reason for differing results when comparing TSD and FWD is, that none of these devices measures deflections, although both gave this back as an output to the user.

The TSD measures a deflection velocity which is transferred into a slope value and then will be fitted to a deflection with the help of a complex algorithm, see figure 6.

However the FWD measures the velocity at several points which will be transformed to a deflection. But the hereby derived well known deflection bowl is not really measured, because it is a combined product of the measured peaks at different positions of the surface wave which is emitted from the impulse load at the loading centre, see figure 7.
Even if FWD and TSD do not give comparable results in some cases, they both characterize the pavements respond due to a real loading. Therefore it is more a task of bringing the different results to a comparable scale than ‘fixing’ the one measurement device that it fits to the other.

### 4.2 Comparison of two TSD

In 2014 a comparative testing of two in service TSD has been organized and performed on an old but stiff motorway pavement (30 cm asphalt on 15 cm cement stabilization) in northern Germany. Both 2nd generation TSD devices have been manufactured by Greenwood Engineering and had the same specifications. Several runs on a total length of 50 km (25 km north- and 25 km southbound) have been made. One TSD was driving in front, the second followed directly in the same line as good as the driver of the second could do, see figure 8. The data has been analyzed afterwards by BASt. The full results can be found in [4].

![Figure 8. Impression from the measurements](image_url)
The data analysis showed that in general the measurements are comparable. At some data a shift could be observed (see figure 9) that could be lead back to the calibration procedure which needs some improvements, especially when measuring on stiff asphalt pavements. Additionally it has been observed, that the algorithm to derive deflection values out of slope values has its weak points, particularly when small deflections will be expected, see figure 10.

![Figure 9. Comparison of the measured slope value of the two TSD](image)

![Figure 10. Example for drop out of the algorithm for deflection calculation](image)

As a result of these measurements some improvements and recalibration have been made and the manufacture reconsidered the calibration method. Even knowledge groups like the FEHRL (Federal European Highway Research Laboratories) group BeCaTS (Bearing Capacity at Traffic Speed) started intensive discussions about calibration issues. It is clear, that one of the best quality assurance tools is and will be direct comparisons of devices. In case of the TSD the problem is the minor number of available devices and their worldwide distribution. But for example for Europe future comparative tests can be possible, as the number of available devices will possible rise in the next few years.

### 5. Repeatability

When looking at the repeatability of in situ pavement measurements the challenging question is how to differ between the changes which have happened at the measurement device and the changes of the pavement itself. In particular bearing capacity measurements are very sensitive to environment impacts like the changing temperature over a day. Every kind of temperature normalization or other ‘post-processed data fixing’ induces an inaccuracy to the raw data.

Taking this premise into account a R&D project, funded by BASt, has started in summer of 2015. This project aims to the short time repeatability of the TSD. Therefore repeatedly TSD measurements will be made at different types of asphalt pavements within a day and also at
different seasons. The (interim) results will be published at future related conferences and journals.

6. Conclusion and outlook

With the existence of the Traffic-Speed-Deflectometer (TSD) an important step has been made towards the structural assessment of pavements, especially on network level. The results of international as well as national studies show the high potential of the TSD. But there are also uncertainties left, which can have an impact to the quality of the results and the hereby derived pavement assessment. Operators, scientists as well as the manufacturer are working together on solving these issues.

Another big challenge is the derivation of assessment procedures of the measurement results and the implementation of these into pavement management procedures. R&D programs like the German ‘Innovation Program’ (hosted by BASt) are facing this challenge.

BASt is evaluating the development of the TSD since nearly 2006. After evaluating the current status of the 2\textsuperscript{nd} generation TSD at several projects on German roads and taking also the international existent experiences into account, the next step will be to obtain a device for intensive R&D work towards the structural assessment of pavements structure, even for concrete roads.

References


