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Continuous and Detailed Measurements Of Road Bearing Capacity at 80 km/h

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Abstract

It is well known that proper road structure and bearing capacity are important factors for a proper and long-lasting road.
For years the bearing capacity has been measured with Benkelman beams and Falling Wight Deflectometers (FWD). However, both the Benkelman beam and the FWD are point-measurements, which are relatively time consuming in man-hours and in actual measuring time. In addition, they are in this way obstructing the traffic and are a reason for accidents – and they are in their nature not making continuous measurements.

With the new Traffic Speed Deflectometer (TSD) it is now possible to make continuous and detailed bearing capacity measurements at 80 km/h and obtain structural indices as D_0, SCI 300, curvature etc. which are repeatable and comparable with the results achieved from the Benkelman beam and the FWD.

This paper presents the main principles of the TSD, shows new test-measuring examples and gives a short introduction to new research area.

Peer-review under responsibility of WORLD CONFERENCE ON TRANSPORT RESEARCH SOCIETY.

Keywords: Traffic Speed Deflectometer; TSD; road bearing capacity; road infrastructure maintenance; structural evaluation

1. Introduction

Papers as “Roadex Benefits and Savings” by Saarenketo et al. (2012) are showing possible savings in road maintenance work of up 10-80% when optimizing the work based on actual structural conditions.

Nevertheless, even though the original road design, the lifetime calculation etc. are based on bearing capacity data, many maintenance tasks are based on functional data. And in those cases where structural data have been used, they have traditionally been collected using the Benkelman beam or the FWD.

These traditional methods are time consuming and relatively slow compared to ordinary traffic. As the road network and the traffic density grows, it becomes increasingly expensive and disruptive to carry out the measurements in these ways.

The Traffic Speed Deflectometer has already proven a valuable and effective tool for structural evaluation and so far, the TSD is in operation in Europe, Australia, USA, and China.

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New development, where the number and locations of the Doppler lasers have shown important, has recently made it possible to improve the outcome from the TSD and to use the measured data for detailed project level decisions and for new research projects.

Following points can be highlighted for the TSD:

- Repeatable and accurate data as D_o, SCI300 etc., which are comparable to measurements with the FWD and Benkelman beam for use at project level.
- Continuous measurements from the TSD ensure accurate registration of weak points
- High measuring speed of the TSDs allows for
  - high productivity and low cost per measured kilometer
  - uniform and comparable data from all over the network
- The TSDs move at normal traffic speed and keep the risk of accidents at a minimum.

Nomenclature

D	Deflection
D_0	Maximum deflection
FWD	Falling Weight Deflectometer
GPR	Ground penetration radar
λ	Wavelength
SCI300	Structural Curve Index (or Surface Curvature Index)
TSD	Traffic Speed Deflectometer
V	Velocity
V_{dop}	Deflection velocity of pavement
V_0	Driving velocity of the truck

2. **The Traffic Speed Deflectometer**

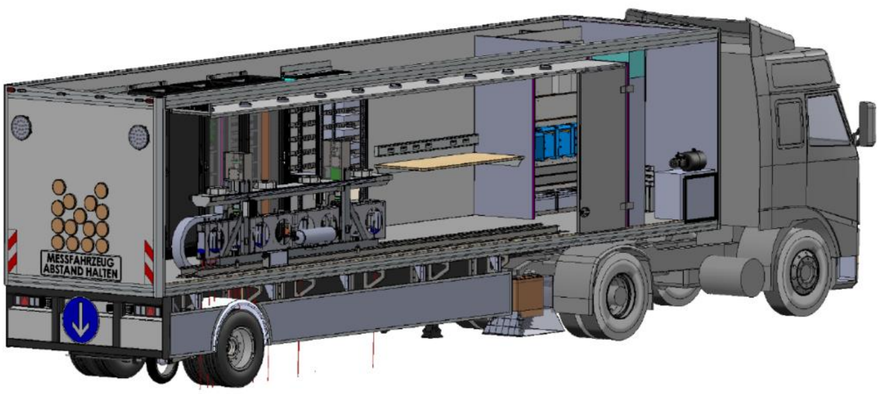

Fig. 1. Traffic Speed Deflectometer (TSD)

The Traffic Speed Deflectometer (see fig. 1) is designed to measure structural data by measuring pavement-motion created by a real driving truck, which is to be used in maintenance optimization at network level assessment and in project level decisions.

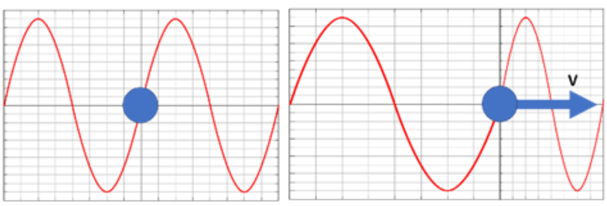

Fig. 2. Doppler effect; change in wavelength as the source moves with the velocity V.

To measure the pavement-motion the TSD uses Doppler lasers and the principle from the Doppler effect where the movement of a source is creating a change in the wavelength as illustrated in fig 2. In the TSDs the Doppler lasers are sending downwards a laser beam with a wavelength of 633 nm, which when reflected from the moving pavement has changed depending on the pavement velocity.

$\Delta\lambda = F(V_{dop})$ The change in wavelength is a function of the deflection velocity of the pavement (1)

To combine the pavement-motion created by a real truck with high pression laser measurements, the TSD is built as a standard truck with an axle load of 10 tons and with a number of Doppler lasers mounted on a moveable beam inside the trailer, right over the wheel path. In a target point each Doppler laser is registering the change in wavelength $\Delta\lambda$ from which, the velocity V_{dop} is calculated as the TSD drives with normal traffic speed.

In the same time, a high precision odometer measures the driving speed of the truck (V_0). Combining these two velocities the deflection slope of the bowl is calculated (see fig. 3)

$$\text{Slope} = V_{dop}/V_0 \quad (2)$$

For new TSDs, 10 or more Doppler lasers are mounted in front of and behind the load wheel (one of them being the reference laser not shown on figure 4) giving the deflection slope in all the point as shown in fig 4.

The deflection curve (fig 5) is fitted to the slope measurements shown in fig. 4.

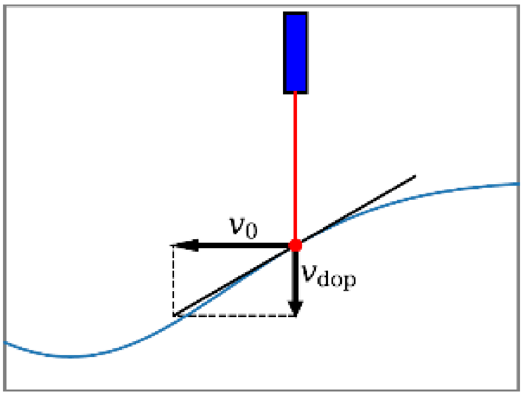

Fig 3 Deflection slope in one target point

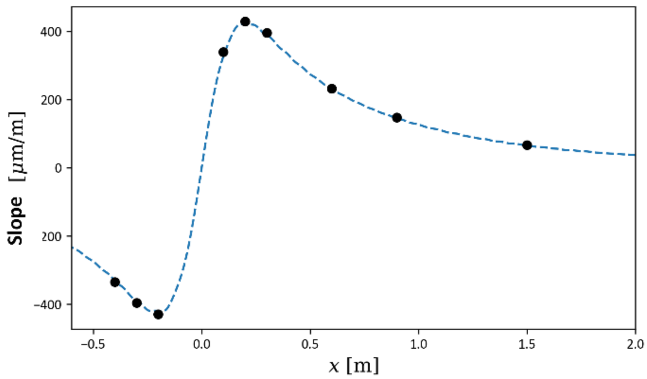

Fig 4 Deflection slope in all target points relative to the load

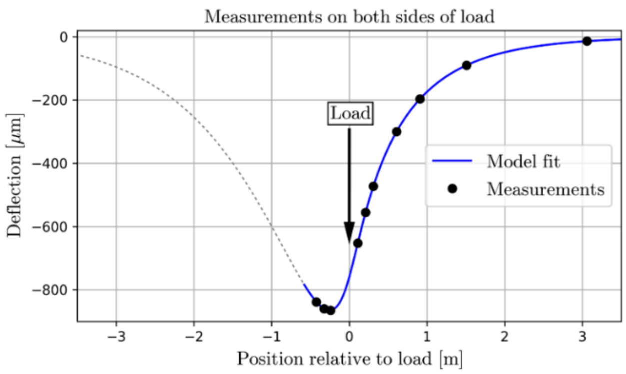

Fig 5 Deflection curve fitted to the slopes

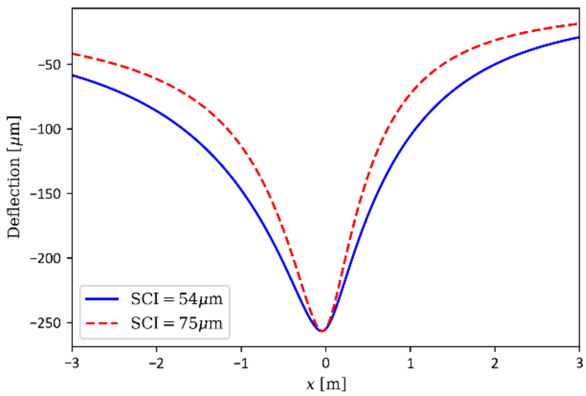

Fig 6 Deflection curves from two locations with (blue) stiff surface soft base and (red) soft surface and stiff base.

Measurements show that different road structures may have same maximum deflection D_0 but different SCI300 values with the same traffic load as shown in fig. 6 which for the maintenance planning is noted to give different fatigue-situations and different residual lifetimes.

2.1. TSD operation

Evaluating and comparing the TSD data in the next chapter it is worth noting that the TSD is operated by two persons only – a driver and a co-driver. There is no need for personnel or equipment for closing traffic lanes, setting up special warning signs or the like as the TSD drives and measures at normal traffic speed. This raises both productivity and efficiency compared to the traditional FWD.

The driver concentrates on the traffic and the co-driver follows the measurements in real time on the computer screen as in fig. 7 and fig. 8, where it is possible to make notes as needed and conduct quality control.

Fig. 7 Co-driver in position in the TSD

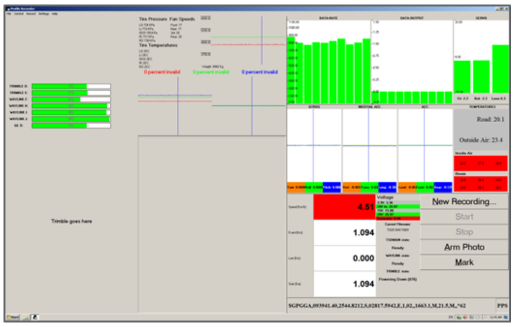

Fig 8 Main screen

3. Test measurements

In general, minimum requirements for good measurements are that they are repeatable and accurate. In this regard, several tests have been performed to analyze the values from the TSD-measurements, of which some examples are shown below.

Test example 1; repeatability:

Measurements from international highway E47 in southern part of Denmark with TSD 7.

With three separate runs the bearing capacity is measured and is here expressed as SCI 300 in fig 9 and enlarged with focus on the weaker part of the road in fig. 10. From fig. 9 is seen the same trend of the three measurements for the whole distance. For the weaker part of the road in fig 10 is seen a clear picture of the weakest spots with maximum variation in a single measuring point around 25 µm.

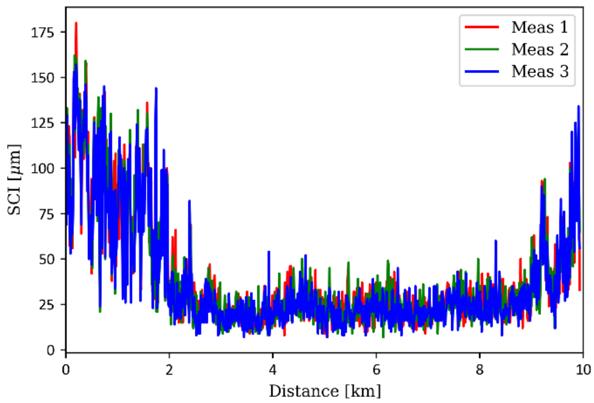

Fig. 9 SCI 300 data from highway E47 with driven distance

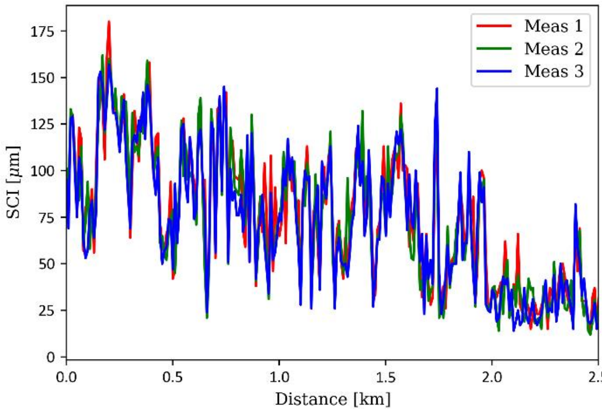

Fig. 10 SCI 300 data from highway E47, zoomed in on the weaker part.

Test example 2; accuracy:

For the same highway E47 as above is also made a comparison between bearing capacity measurements with a FWD (owned by the Danish Road Directorate, under the Ministry of Transport) and TSD 7 expressed as total deflection D_o in fig. 12. With the blue spots representing the 50 m interval point measurements from the FWD and the red line representing the continuous measurements from the TSD is seen a very high degree of identical readings and high accuracy when comparing the TSD to the FWD.

It is noted that even with a relatively short interval of 50 m there is a significant risk of weak spots between the FWD point measurements.

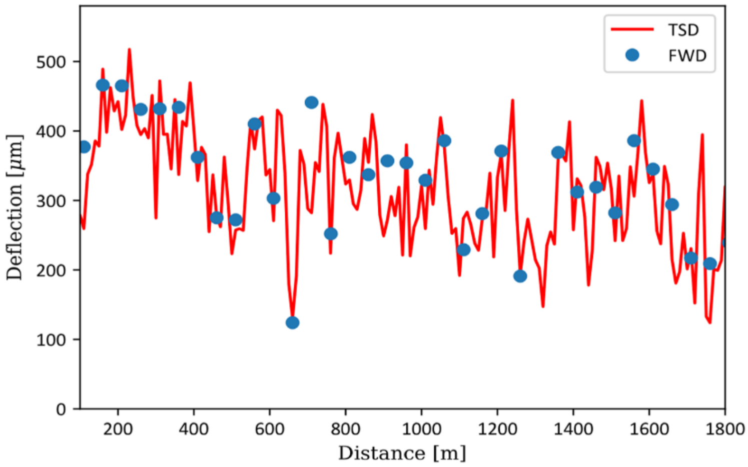

Fig. 12 D_0-data from highway E47 measured with FWD and with TSD 7

Test example 3; repeatability and accuracy

On an app. 10 km mixed road stretch including a part of main road 211 into Copenhagen, a part through a residential area and a part through a forest area is made three bearing capacity measurements marked with green, blue and red dots and expressed as slopes in the laser target points as shown in fig. 13 – fig. 15.

Only a little variation is seen between the three measurements, and in many target points it is difficult to distinguish one measured value from another.

Further, a total picture is seen with a relatively stiff main road 211 with maximum slopes values at 200 µm/m, a little softer road in the residential area with maximum slope values of 600 µm/m and an even softer road in the forest area with slope values as high as 900 µm/m, which is all very much confirming expectations.

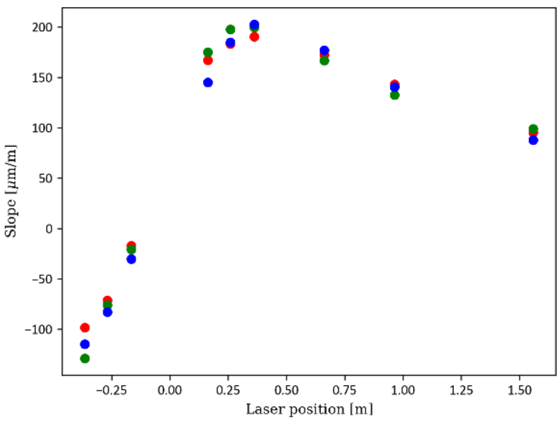

Fig. 12 Three measurements of slope on main road 211

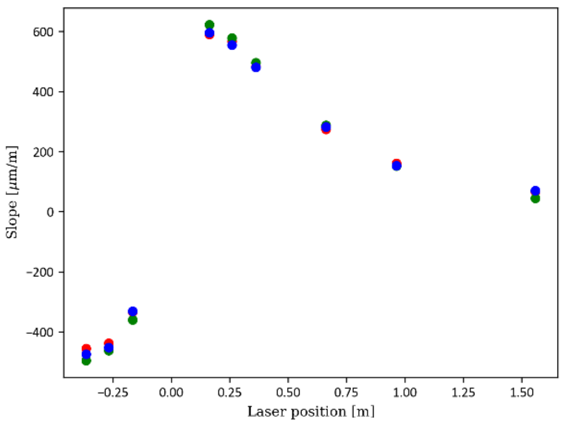

Fig. 13 Three measurements of slope on road in residential area

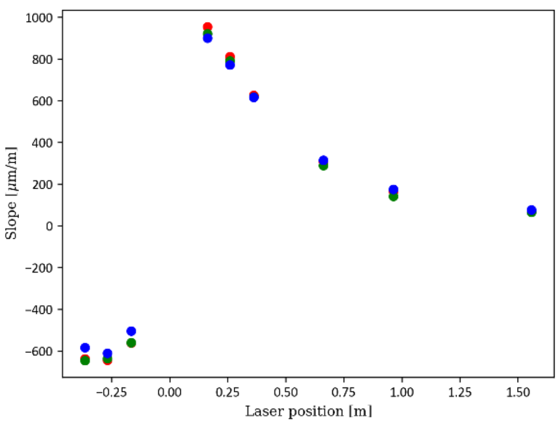

Fig. 14 Three measurements of slope on road in forest area

4. New research and test areas

Greenwood Engineering continues the research and development in cooperation with partners and customers around the world and is currently active within new areas as:

- Ground Penetration Radar measurements and bearing capacity measurements combined in one sequence with the TSD. This is a solution, which has already been delivered to the first customer in Germany and will be available from now on.
- Back-calculated e-moduli and strains for different structural layers based on TSD measurements with GPR. This is seen as an important aspect for more accurate description of the actual structural strength and for predicting the development of functional values as rutting, cracking etc.
- Rolling resistance models for trucks based on road deflections curves measured with the TSD. This is a research project in cooperation with Roskilde University Centre, which can have significant influence on future road construction and CO2 reduction from trucks.
- Viscos-elastic pavement values measured with the TSD and how they can be used for actual road design in the future.

5. Conclusion

The paper has gone through the basic principles of the TSD using Doppler laser technique.

With continuous measurements at traffic speed and with a requirement of only two personnel, the use of the TSD gives some advantages as:

- Full picture of the bearing capacity at the whole length of the measured track
- High productivity
- High efficiency
- Minimum traffic disturbance

Actual test results show a high degree of repeatable measurements and a high accuracy, which makes it possible to use the TSD for both network level assessments and for project level decision, where the data are fully comparable with data from the FWD.

Even the TSD has been on the market for some years Greenwood Engineering is still working on new research topics and developing the TSD further for broader use to be presented in more detail in the future.

References

Timo Saarenketo, Ron Munro, Annele Matintube 2012, Roadex Benefits and Savings. https://www.roadex.org/services/knowledge-center/publications/