

The high-speed road deflection tester

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A new method for the measurement of road deflection under a rolling load has been tested using an experimental vehicle. The preliminary results are very promising and indicate that the method is worthy of further investigation for which purpose an especially designed measurement vehicle will be developed.

1. INTRODUCTION

In the early '70s, a search for an objective road surveying method that could replace the subjective methods in use at that time began at the Swedish Road and Traffic Research Institute (VTI), following a request by the Swedish Road Administration (VV). It was thought that an ideal measuring system should:

- cause minimal interference to surrounding traffic;
- be durable, reliable, and require minimal service;
- have the ability to collect information about all road characteristics used in the decision-making process regarding road maintenance;
- be capable of measuring several (and preferably all) relevant road characteristics simultaneously.

In 1981, the first Laser Road Surface Tester (Laser RST) was built at VTI, and it very nearly fulfilled all of these requirements. The Laser RST is a laser-based, computer-automated, non-contact road profilometer system with the ability to simultaneously collect and fully process data about the underlying road surface. Today it is used to measure roads in Sweden (about 65,000 km annually) and in fourteen other countries throughout the world.

Research and development aimed at maintaining the Laser RST's state-of-the-art status is presently being carried out by OPQ Systems AB (Linköping, Sweden) and the Laser Road Surface Research Group at VTI. The goal is to create a fully automated system that will be capable of inspecting all aspects of the surface and sub-surface structures of a road; such a system does not currently exist. OPQ systems and the research group at VTI are working with two of missing parameters of a fully automated road analysis system: (1) an automated road-surface distress analyzer for the detection and analysis of cracks and (2) a high-speed non-contact road deflection tester for the measurement of bearing capacity. This paper is concerned with the latter parameter.

2. HISTORY

The purposes of road maintenance are to preserve invested capital and provide the road user with an acceptable road standard. Bearing capacity is very important with regard to the preservation of invested capital, while vibration comfort of vehicle occupants is one of the earliest acceptance criteria considered by VV. The use of vibration comfort as a criterion for decisions about the need for road maintenance has a long international history, with decisions based largely on visual/sensitive information. To replace this subjective information with objective measurement data, it was necessary to separate the components of the road surface into categories or variables that were measurable and to find ways of measuring these variables.

One of the first attempts at VTI to correlate objective measurements with human subjective ratings was carried out in 1973. In this experiment, vibration comfort ratings were correlated with unevenness measures obtained from different types of meters (ref. 1). The results of this experiment convinced the researchers that measurement devices could be used to predict vibration comfort sensations and thus replace at least one part of subjective road surveys that were carried out routinely every three years.

A natural consequence of this was to consider the possibility of collecting several road surface parameters in only one run. One step in that direction was taken in 1975 with the development of the so-called BV11J, a friction meter BV11 with instrumentation for the simultaneous measurement of friction and unevenness. A brief consideration was then given to the idea of using a single tow vehicle, instrumented for the collection of measurement data from BV11J and a Dutch rut meter, which in two runs could give information about friction, unevenness, and rut depth. This idea was, however, abandoned in favour of the development of a multi-functional mechanical device, the Saab Road Surface Tester (Saab RST).

The Saab RST was based on the Saab Friction Tester,

which was essentially a Saab 900 with a friction meter BV11 incorporated in the rear axle. It was developed jointly by Saab Scania and VTI in close cooperation with VV and was capable of measuring friction, unevenness, crossprofile, crossfall, and curve radius. Two Saab RST's were built, and they were used in a road survey carried out by VV in 1980 (refs 2-5).

The latest link in this chain of road surface measuring devices was the development of the Laser RST, which began in 1980 and is presently continuing. In its original version, it was capable of measuring road unevenness and cross profile, while the ability to measure friction when towing a BV11 was foreseen (ref. 6). Later, the ability to measure crossfall and macro- and megatexture and to detect cracks were added to the system (refs 7-8). The current version of Laser RST is also capable of measuring horizontal and vertical curve radii (ref. 9, in press).

As mentioned above, research and development of the Laser RST is presently continuing. Some of the projects under development, in addition to the high-speed deflection tester, include (1) a method of accurately calculating cut and fill volumes of road work based on Laser RST measurements; (2) the use of the "Navigation Satellite Timing and Ranging Global Positioning System" (Navstar GPS) for various applications such as navigation, mapping, surveying, etc.; and (3) an improved method to detect, classify and rate the severity of road surface cracking using a combination of video and laser techniques.

Knowledge about bearing capacity is very important with regard to road maintenance. The combined information about road unevenness, cross profile, crossfall, and cracking gives some indication of the condition of the road, but information about road deflection under load is also needed for more detailed information about the bearing capacity of the road. The purpose of this report is to describe the working principle and the measurement results obtained to date with the new high-speed deflection tester currently being investigated at VTI.

3. MEASUREMENT METHOD

To find sections of road with low bearing capacity, stationary devices (e.g., the Benkelman Beam and the Lacroix Deflectograf) have been used for many years. However, because of the very low measurement speeds, only spot measurements have normally been carried out with the obvious risk of missing the weaker parts of the road. The purpose of the method under development at VTI is to make continuous road-deflection measurements at higher speeds possible, thus establishing a more reliable base for pavement management work. It will also use a loading method more akin to the actual load the road is exposed to from heavy vehicles.

The measurement method involves a heavy vehicle, a lorry or a bus, with a cross profilometer mounted in front of or behind a lightly loaded front axle and outside the deflection basin caused by this axle. There is a second

profilometer placed immediately behind the heavily loaded rear axle, which allows the measurement of the maximum deflection under the load. The front profilometer measures the cross profile of a section of road in an unloaded condition while the rear profilometer measures the same cross section when loaded. The difference between these profiles gives the deflection of the road surface. The cross profilometers are basically the same as those used by the Laser RST, but more laser units are distributed along the cross profilometer and in such a way as to make the recording of the shape of the deflection basin possible.

Figure 1 shows the experimental vehicle used for the initial testing of the method. The extension of the crossprofilometer on the left side of the vehicle permits the outermost laser to measure a spot 1.54 m to the left of the left rear wheel. This point is defined as the zero point of the cross profiles. On the right side of the vehicle, a laser angled 45° vertically out from the vehicle is used, giving a measurement width of 4.4 m.

When the vehicle is measuring, it is driven along the road at normal traffic speeds, and the distance between the different laser units and the road surface is sampled at a rate of 16 kHz. A mean distance value for each laser unit is calculated every 100 - 150 mm, thus filtering out the macrotexture effect on the readings, and a mean profile based on these mean values is determined for each cross profilometer.

Measurement results are presented in terms of "difference profiles", i.e. the difference between the profiles recorded by the two cross profilometers. The difference profile is calculated in this way:

1. the two cross profiles recorded at the same cross section of the road are found;
2. the cross profiles are arranged so that their end points coincide; and
3. the mean profile obtained by the front profilometer is subtracted from the mean profile obtained by the rear profilometer

In addition to measuring the bearing capacity, the

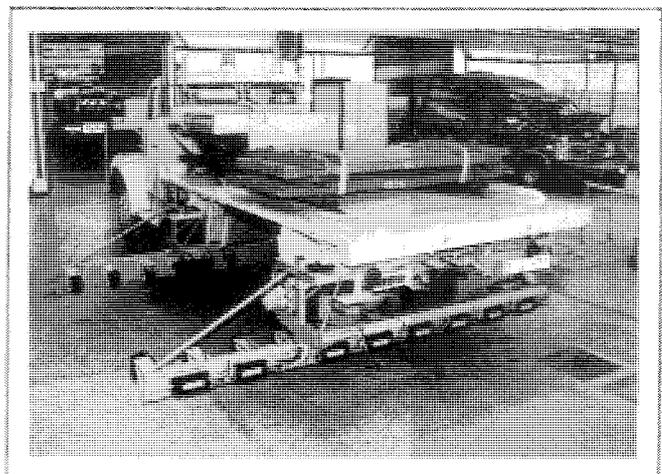


Figure 1 The experimental Road Deflection Tester (RDT)

Laser RDT will also measure the temperature of the road surface and the thickness of the different layers of the road structure using non-contact methods. Finally, the Laser RDT may also be used for surveying, giving a quick appreciation of the bearing capacity, an indication of if and where more detailed deflection studies are warranted, and deflection information for statistical purposes.

It is anticipated that at some point in the future, the Laser RDT and the Laser RST will be combined in one measurement vehicle, making it possible to measure road deflection and a number of surface variables simultaneously.

4. RESULTS

The results are presented in four parts: (1) the repeatability of the measurements, (2) the influence of axle load, (3) the influence of measurement speed, and (4) a comparison of the Laser RDT and a Falling Weight Deflectometer (FWD).

4.1 Repeatability

Figure 2 shows the results of two measurements at 5 km/h and constant axle loads carried out at Mantorp Park, a racing circuit used for drag-, truck-, car- and road racing. The difference profiles shown are the mean over a 400-m section, and the marked points on the profiles represent the lateral position of the lasers. The left rear wheel of the lorry is, as mentioned above, situated at 1.54 m while the right wheel is at 2.95 m from the zero point. As can be seen, the difference profiles end at 3.5 m instead of 4.4 as it should have been. The reason for this is that the angled laser on the right side did not work properly, so it sometimes had to be omitted in the calculation of the difference profile. Nevertheless, the figure shows very good repeatability of the measurement.

4.2 Influence of the Axle Loads

Figure 3 shows the results of repeated measurements using two different axle-load combinations. The upper curves are from measurements with a rear-axle load of 79 kN and front-axle load of 32 kN, while the bottom

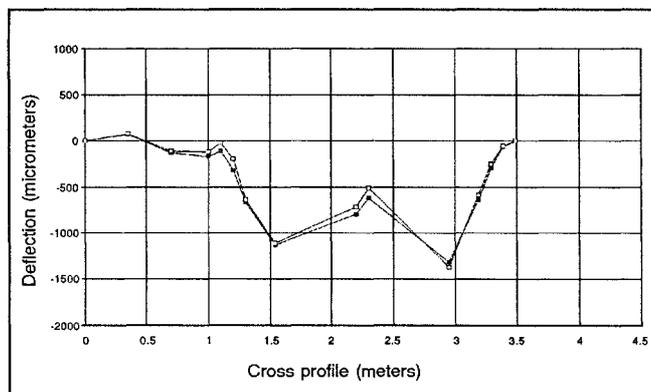


Figure 2 Repeatability test. Measurement speed 5 km/h, rear axle load 110 kN

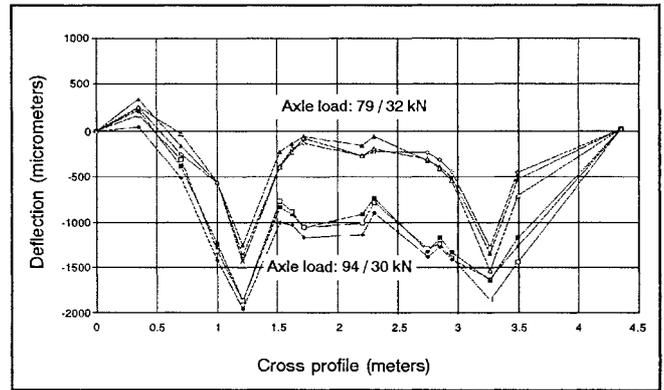


Figure 3 Repeated measurements at two different axle-load combinations. The first figure is the rear-axle load and the second the front-axle load

curves represent a rear-axle load of 94 kN and front-axle load of 30 kN. As can be seen, the increased axle load results in increased deflection, as would be expected.

4.3 Influence of Measurement Speed

Figure 4 shows the influence of speed on the deflection. The well-known fact that the stiffness of the bituminous materials increases with increasing velocity of load application is reflected in the result in that increasing measurement speed gives decreasing deflections. In Figure 4, the outer-most laser on the right side has been omitted for the reason described above, but it should not have any qualitative influence on the result.

4.4 Comparison of the Laser RDT and the Falling Weight Deflectometer (FWD)

To compare the Laser RDT with the Falling Weight Deflectometer (FWD), 13 road sections with different surface conditions and bearing capacity were identified. The sections measured were 100 m in length and rather homogeneous. Measurements with both devices were carried out at approximately the same time to avoid any difference in ambient conditions such as temperature and moisture.

Measurements with the FWD were carried out every

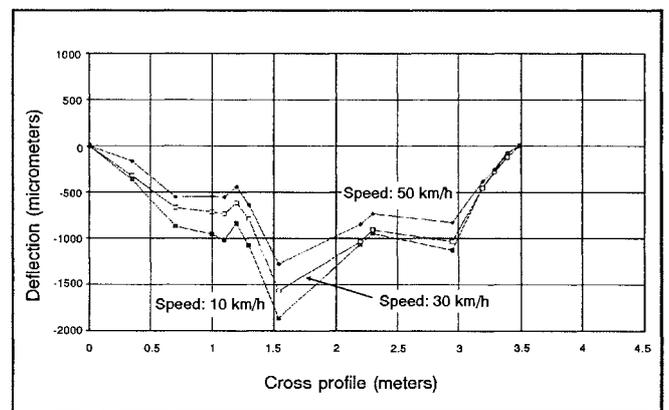


Figure 4 Result of measurements at three different speeds

10 m along a 100-m section. This was followed by a second series of measurements, again at 10-m intervals, but this time displaced 5 m from the first measurement. A total of 21 points along the road section was measured. At each measuring point the FWD did 2 - 5 drops, depending on the difference between the first drops. The deflection value obtained at the last drop at each measuring point was used in the calculation of the validity of the FWD. The load was approximately 50 kN, and the deflection was measured by six sensors placed from 0 to 1.5 m from the center with 0.3 m as the step value. The sensors were placed along the road in the left wheel track, in contrast to the Laser RDT, which measures across the road.

The Laser RDT measured each section three times at 5 km/h and two times at 30 km/h. In the validity calculation (see below), the average of the three at 5 km/h was used. The axle loads were 94 kN on the real axle and 30 kN on the front axle. In order to increase the deflection, the rear axle carried only single types, and the distance between them was 2.05 m. Tire pressure was 850 kPa.

Based on these measurements, the reliability coefficient was calculated for the Laser RDT and for the FWD. Figure 5 shows the results for the Laser RDT, and the values shown are the mean deflection for each test section. The reliability coefficient is 0.88, and the intercept of the regression line is very close to zero. Figure 6 shows the reliability of the FWD, which appears to be excellent (reliability coefficient 0.997). However, it should be noted that this reliability is calculated from the mean of 21 measured points along each 100-m section, while in normal production measurements one or perhaps two points would be measured. It should thus be observed that the reliability when measuring at random on a fixed section (e.g., 100 m in length) will probably be rather poor on sections

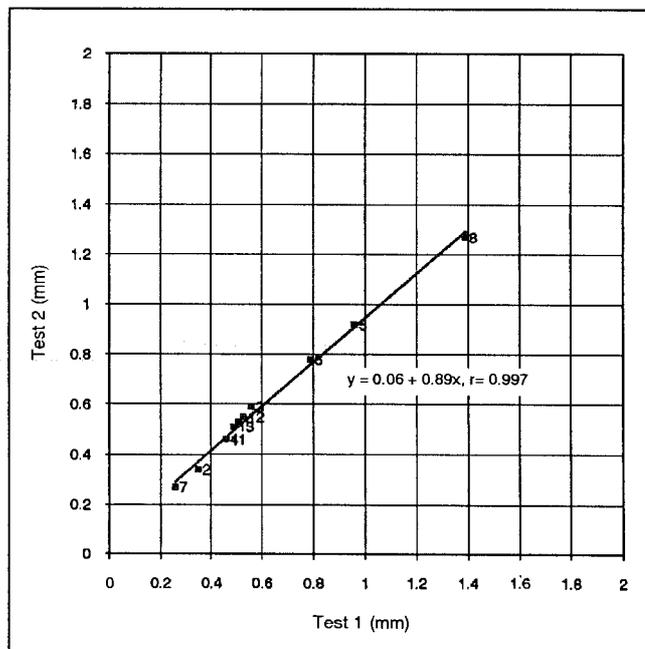


Figure 6 Reliability of the FWD

with varying bearing capacity, especially compared to measuring devices producing a measure based on measuring the entire section.

Figure 7 shows a comparison of the Laser RDT and the FWD. The agreement appears to be limited (correlation coefficient 0.52). However, it should be noted that when comparing these two completely different methods, the relationship between the two measures probably depends on the properties of the road. It is known that Road Section 4 differs from the other measured sections in that it has a very thick wearing

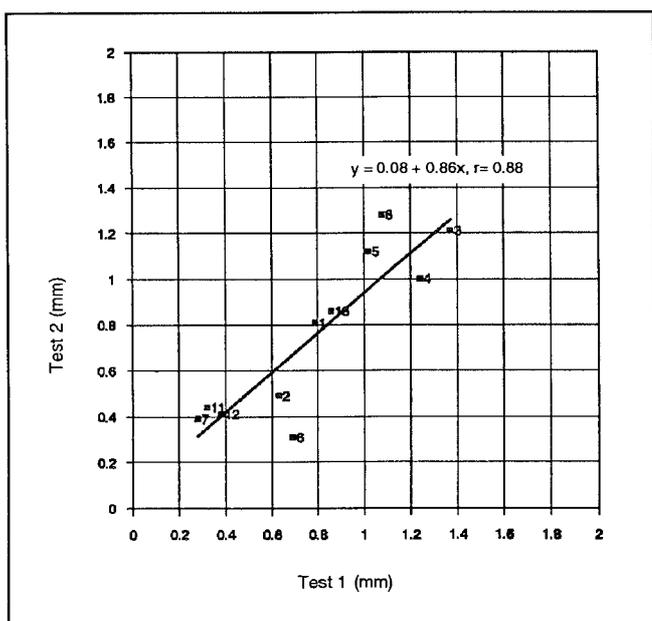


Figure 5 Reliability of the Laser RDT

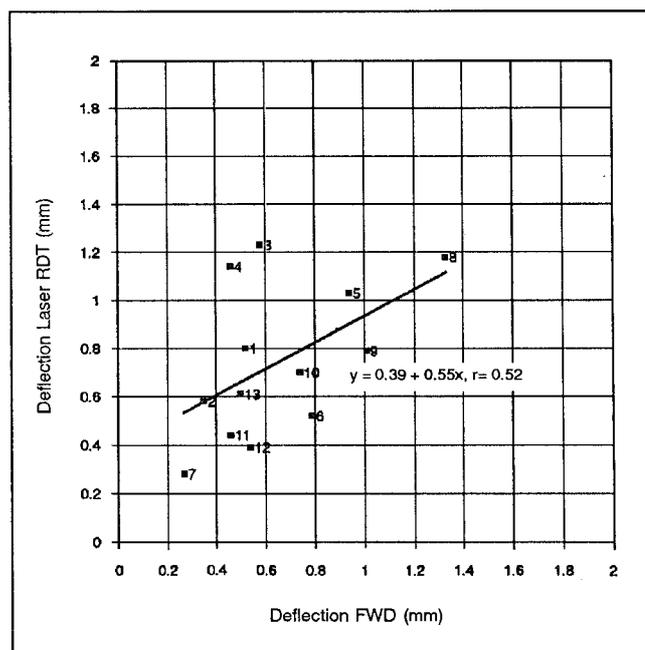


Figure 7 Comparison between maximum deflections as measured by the Laser RDT and the FWD

course as a result of repeated overlays. Road Section 3 is on a very narrow and dwindling road where measuring is very difficult, and at the evaluation of the second measurement it was observed that the vehicle was driven partly with the outermost laser outside of the road edge. If those two sections are deleted, the correlation coefficient increases to 0.88 (Figure 8).

Operating a vehicle with the laser carrying extension shown in Figure 1 will of course cause problems in normal traffic, especially on narrow and dwindling roads, and necessitate the use of special traffic safety measures such as a follower vehicle to warn other road users about the oncoming wide vehicle. To investigate the possibility of measuring without any extensions, a second evaluation of the Laser RDT measurements was carried out. The measurement used was the deflection under the rear wheels in reference in a line connecting the two nearest lasers on each side of the wheel. This measurement was compared to the deflection measured 300 mm from the center of the spot struck by the weight of the FWD. Figure 9 shows that Road Section 4 is still an "outlier" while Road Section 3 is now very close to the regression line. This illustrates that the problem with the narrow road has been solved by this type of evaluation. The correlation coefficient is 0.68. If Road Section 4 is again removed, the correlation coefficient increases to 0.82 (figure 10).

5. DISCUSSION

The results look very promising so far, although quite a bit of work remains before this method can be used in real production measurements. Especially interesting is the observation that deflection measured based only on the deflection within 300 mm on each side of the tire

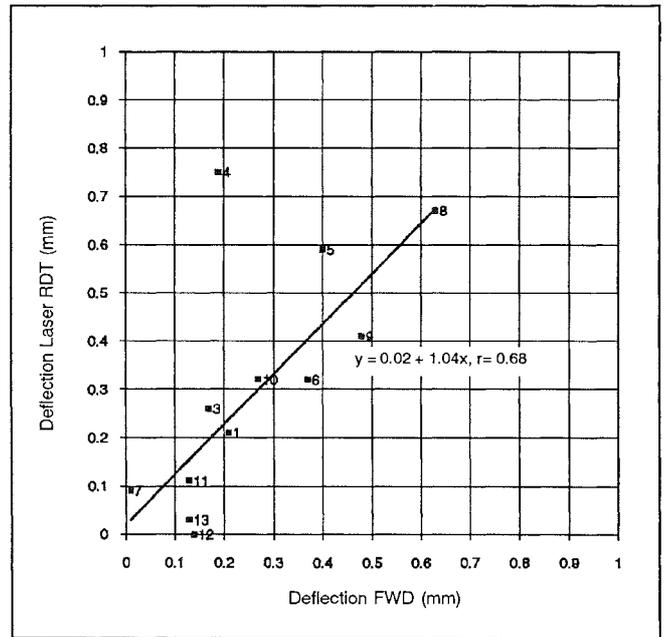


Figure 9 Comparison of deflections within a 300-mm radius around the center of the load as measured by the Laser RDT and the FWD

show good correlation with the FWD.

Work to be done includes the construction of a new measurement vehicle that is a combination of the Laser RDT and Laser RST. In all probability, this will be a 2.5-m wide bus (measuring at least 1 m out from the tires using angled lasers). The deflection will be calculated on-line in the bus together with all other road surface variables currently measured by the Laser RST.

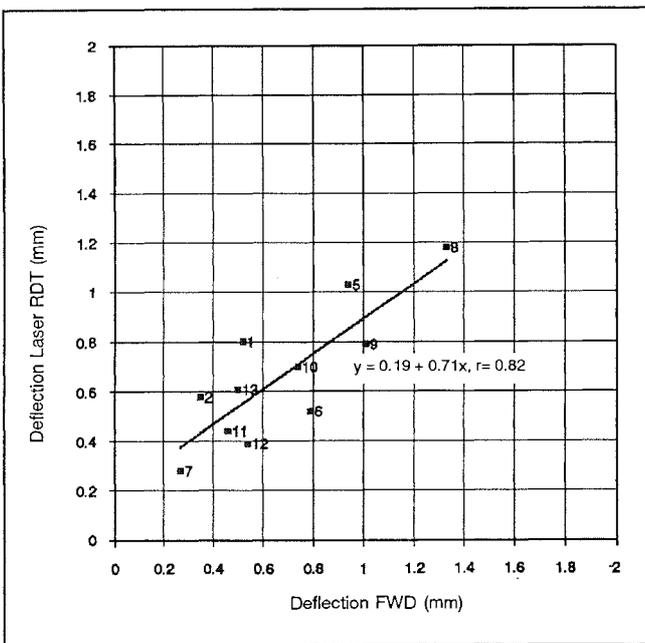


Figure 8 Comparisons of maximum deflections as measured by the Laser RDT and the FWD. Corrected for outliers as described in the text

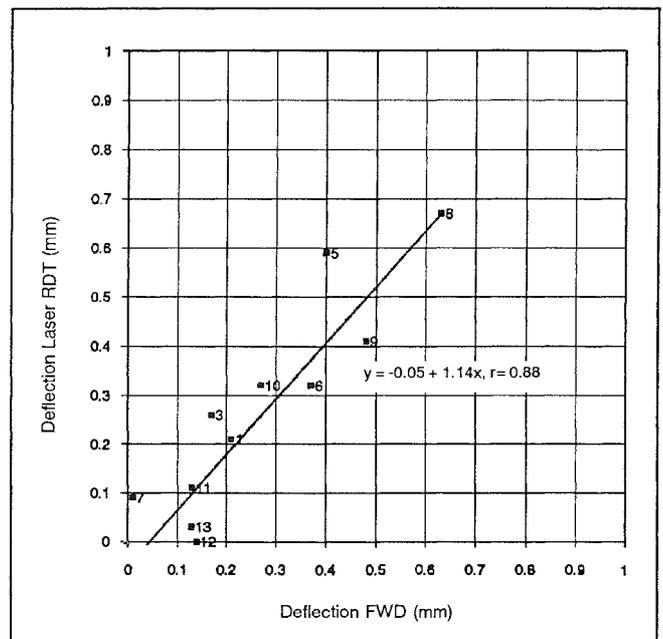


Figure 10 Comparison of deflections within a 300-mm radius around the center of the load as measured by the Laser RDT and the FWD. Corrected for outliers as described in the text

These measurement data will then be used to describe not only the surface condition as is done now by the Laser RST but also how the bearing capacity varies along the road.

A prognosis for the evaluation of the road condition can be made by combining Laser RDT results, like the difference in the deflection under the right and left wheels, with results like rut depth in the right and left tracks and how the rut depth and unevenness varies along the road. Other measured parameters such as crossfall, texture, and RMS values for different wavelength ranges could also be used as indicators of possible pavement problems.

Road surface temperature influences the magnitude of the deflection caused by a certain Load. Some initial measurements have been carried out with the Laser RDT, but there have been no systematic studies of this to date.

Four different potential uses of measurement data from the Laser RDT have been identified:

1. to give an overall evaluation about the bearing capacity of the roadnet;
2. to direct more precise measurements to identified critical areas;
3. to collect information about the real road deflection caused by heavy vehicles at different speeds and in different seasons, providing a better basis for decisions regarding regional and seasonal regulations about speed and payload; and
4. to study actual road deflections caused by different types of vehicle suspensions and tires

The Laser RDT is still in its infancy, but the results of the testing to date indicate its strong potential.

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