TRAFFIC SPEED DEFLECTOMETER — QUEENSLAND TRIAL

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Abstract
Queensland Department of Transport and Main Roads in partnership with the Roads and Traffic Authority of New South Wales (RTA) arranged for the Traffic Speed Deflectometer (TSD) to test 6000km of the state-controlled road network in Queensland and a significant length of road in New South Wales. The Danish Road Directorate agreed to import the TSD specifically to undertake this testing while at the same time familiarise various Australian road authorities with its operation. This device uses highly advanced Doppler laser technology to measure a pavement’s bearing capacity at traffic speeds up to 90km/h to provide a continuous pavement deflection profile with negligible delay to traffic.

The TSD provides crucial information for the road manager as it provides a fast and reliable overview of the structural condition of the road network. Accurate and complete structural data supports the Department’s goals to enhance road preservation strategies, to improve road investment decision-making processes and to minimise whole-of-life maintenance costs.

While TSD measurements were taken on 6000km of Queensland highways, six selected locations were also tested with a Falling Weight Deflectometer (FWD) to cross correlate test results. In addition, one location was tested with the Deflectograph and FWD in parallel with the TSD.

This paper presents details of the trials and provides examples of TSD results for typical road structures in Queensland. It summarises initial outcomes of the network tests and the directions for future analysis, research and development.
Introduction
Road asset management involves whole-of-life-cycle management including the planning, construction, maintenance, operation and finally the disposal of the road asset, with the primary goal being safe and reliable travel. A sound knowledge of the current condition and deterioration rates of road pavements are essential to enable effective road asset management.

Pavement strength is the ability of a pavement to support projected traffic loading and to withstand other environmental conditions throughout its service life. Pavement strength capacity can be measured by either destructive or non-destructive methods. Destructive methods involve coring a sample from a road pavement followed by laboratory testing of the extracted sample to determine pavement strength capacity. Non-destructive methods usually involve measuring pavement deflections produced by a standard load applied on a road pavement surface. Numerous equipment types have been developed for non-destructive pavement strength testing, namely — Benkelman Beam, DynaFlect, LaCroix Deflectograph, Falling Weight Deflectometer (FWD), Heavy FWD, Multi-Depth Deflectometer and now the latest technological innovation, the TSD.

Other techniques such as ground penetrating radar and dynamic cone penetrometer can also be used to gather data about pavements. The dynamic cone penetrometer may be used for detailed testing at project level but it is too slow and costly for conducting road network pavement strength testing. The high speed ground penetrating radar is still in the development phase and its full potential is yet to be realised.

The Department of Transport and Main Roads (TMR) currently conducts network level pavement strength assessment using the FWD at intervals of around 400m. This spacing was identified as appropriate for network level analysis using a probability-based optimisation method (2,3). Between 2005 and 2009, around $350,000 was spent annually by the TMR to collect pavement strength data covering approximately 2,500km per year. This pavement strength data is available via TMR’s ARMIS database.

The extent and frequency of network strength assessment is currently constrained by the slow operating speed of the equipment with consequent high costs for testing and data collection. Because of the slow equipment operating speed, busy roads can only be tested off-peak or at night. The penalties for minimising disruption to road users are high traffic control costs and penalty rates for testing at night and weekends.

The development of the TSD by the Danish Road Directorate has the potential to enable more rapid and economical network testing of pavement strength. In Denmark the TSD has scanned the state road network every year since 2005 with major highways scanned every second year and motorways every third year. Based on the results from these scanning measurements, more detailed Falling Weight Deflectometer (FWD) measurements are conducted on sections in consideration for new overlays and where TSD measurements show bearing capacity problems.

TMR partnered with RTA to bring the TSD machine from Denmark to conduct trials on road networks in New South Wales and Queensland. While 6,000km of road was tested in Queensland, this paper presents some initial findings of the TSD trial performed on select sections of the state-controlled road network.

Origins of deflection measurement
A brief history will be given of three methods for measuring pavement deflection — Benkelman Beam, LaCroix Deflectograph and Falling Weight Deflectometer. There are other methods of measurement; however the three listed are the primary ones that have been used by TMR.

Benkelman Beam — The first significant tool to give a direct reading of pavement strength by non-destructive means was the Benkelman Beam test. The Benkelman Beam was devised by an American engineer Alvin Carlton Benkelman in 1952. The deflection measurement test was first used on bituminous pavements for the American Western Association of State Highway Officials (WASHO) in 1953.

This method provides a very simple way of determining pavement strength in the field. The bearing capacity of roads may be calculated by measuring the deflection pattern caused by a concentrated heavy vehicle wheel load. The measured maximum deflection and the shape with which the pavement deflects have a direct correlation to pavement strength. The shape of the pavement deflection is referred to as a deflection 'bowl'. At the very low speeds at which this test occurs, the deflection bowl is symmetrical; hence only half the bowl shape need be measured.
In this method, a long probe is placed between the rear dual tyres of the rear single axle of a loaded truck (Figures 1 & 2). As the truck moves forward, the stationary Benkelman Beam instrument and operator are located behind the truck and directly measure the shape of the deflection bowl. Care should be exercised so that the levelled position of the reference beam is not unduly influenced by the deflection bowl. The maximum height and width of the bowl provides a valuable insight into the condition of the pavement. For example, a bowl shape with a high deflection and a narrow bowl width would indicate a low strength pavement. Conversely, a bowl with a low overall low deflection and a wide bowl width would indicate a high strength pavement. While this method is still valid it has largely been superseded by other methods.

![Figure 1. Benkelman Beam](image1)

![Figure 2. Benkelman Beam testing circa 1962](image2)
LaCroix Deflectograph — The LaCroix Deflectograph was introduced by the French in the late 1960’s. It is a higher productivity machine based on the Benkelman Beam principle. The primary function of the Deflectograph is to collect network data. The Deflectograph is a special purpose test truck which performs two simultaneous Benkelman Beam tests along the centre of the rear axle wheel path. The Deflectograph takes the simple Benkelman Beam test to the next level by an automated mechanised process.

While the two Benkelman Beams are stationary during the measuring process, the Deflectograph vehicle moves at a constant speed of approximately 3.5km/h (Figures 3a & 3b). All the measuring equipment is contained beneath the vehicle while data storage and processing occurs in a cabin above. This process collects a large amount of data but the vehicle travels slowly on the highway creating a potential safety issue.

Falling Weight Deflectometer (FWD) — The FWD was introduced by the French in the late 1960’s. The FWD also measures the pavement deflection bowl shape but uses a different method. The FWD is built on a small trailer which must be stationary during a test. Prior to a test a number of geophones are lowered to the road surface (Figure 4). The FWD drops a weight onto the pavement causing the pavement to deflect. The geophones measure the road surface deflections at discrete points on the deflection bowl profile.

Figure 3a. Start of a test cycle

Figure 3b. Completion of a test cycle

Figure 4. Falling Weight Deflectometer
Progress in the area of pavement strength measurement has been aimed at reducing the cost of data collection and improving the safety of both the personnel undertaking the data collection and the travelling public.

Technical details of the TSD
The TSD consists of a prime mover and a 10t single axle semi-trailer fitted with dual wheels as shown in Figure 5. The 10t axle load corresponds to the Danish design load. In Denmark the TSD operates at speeds up to 80km/h which is the speed limit for trucks. However on smooth roads, TSD provides reliable results at speeds up to 90km/h and a lower operational speed of 30km/h.

The TSD is the current state-of-the-art technology which measures the small pavement deflections (1mm order of magnitude) in response to the loaded semi-trailer axle. The process of measurement used in the TSD differs greatly from the Benkelman Beam described above. The Benkelman Beam measures the deflections of a static surface while the TSD measures the deflections of a fast moving surface. As the TSD travels forward, the pavement surface immediately in front of the semi-trailer wheel is moving downward to create the deflection bowl. Behind the semi-trailer wheel the pavement is rebounding upward to its previous position.

The innovative aspect of the TSD is that it does not measure the pavement deflection directly: instead, it measures the vertical surface velocity. The measured surface velocity is then integrated with respect to time to yield a deflection value. Four Doppler laser sensors measure the vertical velocity of various points of the deflection bowl in the wheel path between a set of dual tyres and the pavement surface in front of the axle.

The TSD collects continuous data streams of vertical velocity (v) and horizontal velocity (h) for each 20mm travelled. Generally, processed data can be provided for any spacing that a user may specify. The result of the processed TSD measurements is continuous profiles to Danish specification SCI300, centre deflection and curvature (FWD equivalent standard is d0-d300). Reference (1) contains a description of how these parameters are determined.

How the High Speed Deflectograph works:

![Diagram of TSD](Figure 5. Diagrammatic view of the Traffic Speed Deflectometer)
**Aim of the Queensland TSD trial**

The TSD was developed in Europe and has been trialled on European road networks in Denmark and the UK. However, road and environmental conditions in Europe can be very different from conditions in Australia. The Australian TSD project steering committee identified a range of factors that could potentially affect the accuracy of measurements. Some of these factors include — aggregate sizes/texture, aggregate colour, road surface moisture, light conditions, road surface temperature, asphalt surface, roughness, road geometry, pavement types (thin granular of various depths/construction, asphalt), atmospheric impacts on operator, equipment operation, electrical interference, speed, temperature, axle loads and inner and outer wheel path locations.

Excessive pavement roughness can have a potential effect on the accuracy of the TSD device in measuring pavement deflection. TRL reported that poor longitudinal profiles affected TSD’s measurement of pavement deflection in two ways:

- instantaneous loading on the pavement affected by dynamic wheel loading
- poor data rate resulting from excessive vehicle dynamics.

The impact of pavement roughness on the TSD’s pavement deflection measurement will be investigated as part of the trial, however this information is unavailable at this time.

The trial was arranged to verify the TSD under Australian conditions and to obtain first-hand experience, hence obtain greater confidence in the TSD technology.

Specifically, the TSD trial objectives were:

- investigate the correlation of TSD data to that obtained from other deflection measuring devices such as FWD and Deflectograph
- identify any factors that affect repeatability and reliability of correlation
- identify factors that may affect TSD performance under local conditions
- assessment of the suitability of the TSD as a network screening tool.

A research project involving TMR, Queensland University of Technology and the Cooperative Research Centre for Integrated Engineering Asset Management was established to quantify the above objectives. A number of other research projects have been initiated in parallel with the TSD trial in order to determine the consistency and suitability of the technology in collecting pavement strength data.

These research projects include short term and long term studies. The short term study aims to confirm the reliability of the TSD technology for Queensland conditions by comparing TSD pavement strength data with historical FWD data for the trial road networks. The long term studies aim to assess the complex relationships among pavement strength, pavement condition, material property, traffic and environmental variables for predicting pavement deterioration. The second aim of the long-term study is to develop pavement performance prediction models to improve evaluation and investment of road maintenance and rehabilitation.

**Setting up of trial**

Repeatability of results from the TSD may be affected by ambient and road surface temperature, vehicle testing speeds and test axle load. Danish Road Directorate and the Transport Research Laboratory of the United Kingdom have conducted TSD repeatability tests assessing the impact of the above mentioned parameters. The Transport Research Laboratory reported variation in ambient temperature could affect reliability of TSD data collection. Due to time limitations, the Transport Research Laboratory adjusted the TSD equipment to suit United Kingdom conditions only.

The TSD trial was conducted on the national highways in Queensland covering approximately 6,000km. The majority of the tests covered the Bruce Highway, Landsborough Highway, Flinders Highway, Barkly Highway, Cunningham Highway and Warrego Highway. Figures 6 & 7 indicate the locations across Queensland where specific tests were performed to confirm the repeatability of the TSD. Selection of these test sites was based on:

- pavement types that were typical for Queensland
- previous long-term monitoring sites
- sites where historical FWD data was available
- a range of climate and soil types.
<table>
<thead>
<tr>
<th>Sites</th>
<th>Highway</th>
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<th>Traffic (AADT)</th>
<th>Types of pavement</th>
<th>Zone</th>
<th>Testing</th>
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<tr>
<td>10A*</td>
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<td>46000</td>
<td>Deep Asphalt</td>
<td>WNR</td>
<td>TSD &amp; FWD</td>
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<td>5800</td>
<td>Granular</td>
<td>WNR</td>
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<td>Bruce</td>
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<td>Flinders</td>
<td>200km – 201km</td>
<td>500</td>
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<td>DNR</td>
<td>TSD &amp; FWD</td>
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<td>49km – 50km</td>
<td>560</td>
<td>Granular</td>
<td>DR</td>
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<td>Warrego</td>
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<td>DNR</td>
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<td>28A</td>
<td>Gore</td>
<td>58.5km – 59.5km</td>
<td>2250</td>
<td>Granular</td>
<td>DR</td>
<td>TSD, FWD and Deflectograph</td>
</tr>
</tbody>
</table>

**Note:** WNR = Wet-Non Reactive Soil, DNR = Dry-Non Reactive Soil, DR = Dry Reactive Soil. These test sites are a minimum of 1000m in length. * See Figure 7 for locations

During testing, the TSD speed must be between 30km/h and 90km/h. For the tests conducted in Queensland, the aim was to test at a constant speed of approximately 80km/h. In circumstances when the TSD travel speed fell below 30 km/h, testing were temporarily halted and only resumed when traffic conditions permitted travel within the correct speed range.

FWD and TSD tests were conducted at all test sites to check the correlation between devices. Only Site 28A was tested with the TSD, FWD and Deflectograph, for comparative assessment of the consistency among the three devices. Most repeatability tests involved leaving a short period between test runs. At Site 10A on the Bruce Highway near Brisbane, some long term repeatability tests were conducted approximately one month after the initial short term tests.
Figure 7. Six TSD & FWD test sites
Initial trial results

Survey speed dependency
Speed dependency tests were not conducted by TMR, however RTA conducted these tests in NSW at speeds of 40km/h, 60km/h and 80km/h (Figure 8). It may be seen that there was excellent correlation between results at the various speeds.

Repeatability
Due to time restraints, only the test results for sites 10N, 14B and 13E are presented here together with a comparison of TSD, FWD and Deflectograph from Site 28A.

Figures 9, 10 and 11 shows repetitive test results of SCI300 values (FWD measurements as d0-d300) on Site 10N, 14B and 13E respectfully.

Site 10N is located in wet-non reactive soil conditions. This is a flexible pavement of around 300mm thickness with AADT of around 4300 vehicles per day (vpd). Figure 9 shows good consistency between the three repetitive tests for this site.

Site 14B is located in dry-non reactive soil type. This is a flexible pavement of around 150mm thickness with AADT of around 500 vpd. Figure 10 shows small discrepancies in the SCI 300 values however the figure shows the patterns in the level of pavement deflection characteristics are generally repeated in the three test runs.
Site 13E is located in dry reactive soil conditions. This is a flexible pavement of around 100mm thickness with AADT of around 560 vpd. Figure 11 shows good consistency between the three repetitive tests for this site with relatively small discrepancies in the SCI 300 values.

To assess the effectiveness of the TSD device in measuring maximum deflection values, a plot of three repetitive maximum deflection values for three repetitive runs of the Site 10N is presented in Figure 12.

Figure 11. SCI 300 values of three repetitive tests for Site 13E

Figure 12 shows good consistency in the maximum deflection characteristics of the three repetitive test runs.

It can be concluded that for these three sites with flexible pavements of different thicknesses, different climatic zones and soil conditions, the TSD device provides practical repeatability in measuring pavement strength.
Correlation with other devices
The aim of comparing the characteristics of TSD deflection data with the deflection data obtained from other pavement strength testing devices is to assess the compatibility of the TSD device against other devices that have been used for pavement strength testing in Queensland.

FWD tests were conducted at six sites as given in Figure 6 for comparison with the TSD testing. Initially a comparison was made for deflection results for three repetitive TSD test results and one FWD test for Site 10N (Figure 13). Both devices show an increase in maximum deflections at similar chainage location of around 124.15km, and overall patterns of maximum deflections of both devices show similarity. Further comparison studies between TSD and FWD devices will be conducted for the remaining test sites when both TSD and FWD data become available.

Additionally, three devices including TSD, FWD and Deflectograph were employed in testing pavement strength at Site 28A. This section of the road is a flexible pavement of around 500mm thickness, carrying AADT of around 2250 vpd, located in dry reactive soil. It can be seen from Figure 14 that maximum deflections of Run 1, Run 2 and Run 3 obtained from TSD device has a good repeatability. A simplified comparison of the maximum deflection values as shown in Figure 14 of three different devices show reasonable patterns among the three devices. It can be observed that there were some discrepancies in the maximum deflection patterns between TSD and FWD devices for this site. It is worth noting that the FWD device used in conducting testing for Site 28A was a different device used for testing on the 10N site. From previous experiences it has been found that different FWD devices may deliver different values of pavement deflection data due to calibration differences. Further analysis is being undertaken to assess the effect of different FWD devices on the comparative testing at Site 28A.

At this point in time, it can be summarised that the TSD device provides reasonably comparable results to the pavement strength characteristics as measured by FWD. An in depth analysis will be conducted in a further research project to assess the correlation between TSD, FWD and Deflectograph.
Conclusions
The following operational performances of the TSD were observed:

- The TSD can operate at traffic speeds in the range 30km/h to 90km/h without traffic disturbance.
- Variations of vehicle speed within the testing range did not affect the quality of output data.
- The TSD provides repeatable test results (also demonstrated in trials by RTA).
- Continuous measurements can be reported at various intervals (0.1m, 1m, 5m or 10m).

The following constraints in operating TSD device were also identified, namely:

- TSD device cannot be operated in wet rainy condition.
- Operating TSD in Queensland requires a special permit since the TSD device has a 10t rear axle load. The maximum single axle load limit in Queensland is 9t.
- The Danish Road Directorate indicated difficulties in processing data collected on rough and bumpy roads. Further analysis is required to determine the maximum acceptable pavement roughness for effective operation of the TSD.
- It is not possible to collect data at speeds less than 30km/h.

In conclusion, it was found that the TSD device provided good repeatability in measuring pavement deflections and a comparison of the maximum deflection measurements obtained from TSD, FWD and Deflectograph shows good correlation patterns of deflection characteristics. More in-depth analyses will be conducted from the results of this trial and from other research projects to further quantify these initial test results.

References

