Traffic Speed Deflectometer (TSD) Measurements for Pavement Evaluation

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Abstract
This paper presents the Traffic Speed Deflectometer (TSD) device that has been operating in Poland since 2012. As of 2014, it is one of eight such devices used worldwide. This paper starts with a general information on the TSD, including its mechanical features, concept of operation, and data interpretation approaches. Since it is still a relatively new device, there is no globally accepted approach in analyzing the TSD measurements. In order to demonstrate the capabilities of the TSD measurements, a second part of this paper presents example data and associated analysis for the network and project levels. Different data processing and interpretation procedures pertinent to both levels are outlined and discussed.

Keywords: Traffic Speed Deflectometer (TSD), bearing capacity, pavement, structural evaluation

1. Introduction
Severe climate changes and overloaded vehicles are the primary causes of premature failures of roadway pavements in many regions. The damage occurs not only onto pavement surface but also within the pavement structure. For that reason there is a need to employ a quick and reliable method capable of acquiring information on pavement bearing capacity especially on a network level. Traditionally, pavement bearing capacity is assessed using surface deflections due to static, dynamic or moving load. Deflections or their derivative parameters can be then implemented into pavement management systems (PMS) in order to directly capture the structural aspect of the pavement condition and more effectively manage maintenance and rehabilitation activities under common budget constraints [1]-[4].

2. TSD Background
The first prototype of the Traffic Speed Deflectometer (TSD) was developed in Denmark in the late 1990’s [5]. Currently, there are eight working TSD devices in the following countries: UK, Denmark, Italy, Poland, USA, South Africa, Australia and China. The following section presents a brief development of deflection devices and the next section explains the TSD operational concept and main components of the TSD system.

2.1 Pavement Structural Evaluation
Historically, pavement structural evaluation techniques have been using pavement surface deflections and curvature to assess structural condition of pavement multi-layer structures. One of the first devices used was Benkelman Beam proposed in 1952. Over the years, techniques have developed due to the following considerations:
1. Measurement efficiency (speed of testing).
3. Realistic loading.
4. Simplicity and safety of operation.
5. Data interpretation.

Deflection devices can be categorized by loading characteristics into following groups (example devices listed in parentheses):
1. Static (Plate Load Test)
2. Impulse (Falling Weight Deflectometer, FWD)
3. Steady-state vibratory (Road Rater, Dynaflect)
4. In-motion (moving):
   a. Deflectographs (Benkelman Beam, LaCroix, Curviameter)
   b. Deflectometers (Road Deflection Tester, RDT; Rolling Wheel Deflectometer, RWD; TSD)

It should be noted that deflectographs use deflection acquisition systems that are in-contact with a pavement. On the other hand, deflectometers employ loading and deflection acquisition systems that are moving as one system and deflections are measured via non-contact techniques.

2.2 TSD Overview

TSD is an example of a moving deflectometer device and while it has been constantly evolving with new features, its concept remains the same, i.e. a long and rigid beam is placed inside a semi-truck and it is instrumented with high-rate sensors, including Doppler sensors, accelerometers and laser distance sensors. These sensors are used to keep the beam as parallel to pavement surface as possible during the measurements and to measure pavement response due to TSD weight. In order to cause realistic conditions, TSD semi-truck is equipped with a dedicated dead weight of 100 kN (22 kips) located in the proximity of the rear-axle. While truck is moving, vertical pavement deflection velocities are recorded at a very high rate. In the next step, deflection velocities are divided by the instantaneous vehicle speed and this produces the deflection slopes at discrete points along the TSD route [6][7]. The absolute deflections can be obtained by integrating the deflection slopes either numerically [8] or using a closed-form solution of a mechanical model [7][9]. Having deflection bowls, one can calculate different condition indicators, e.g. Structural Condition Index (SCI).

2.3 Factors Influencing TSD Results

Accuracy and precision of TSD measurements can be influenced by a number of internal and external aspects, e.g. calibration and QA procedures, wind and temperature during the measurement, pavement roughness and tire-pavement interaction [10]. Figure 1 and 2 present respectively example effects of wind velocity and pavement roughness on dynamic TSD load [10].

![Figure 1. Simulated wind velocity effect at 90° angle and 22 m/s TSD speed.](image)
3. TSD Example Results

TSD collects high-rate data that can be post-processed using various approaches depending on the analysis scope (project vs. network level) and objective as well as other factors, such as number of Doppler sensors and available analytical tools. The following two sections present example approaches in interpreting TSD data.

3.1 Standard Results

Figure 3 shows typical deflection basins from two different sections obtained from a standard data processing algorithm [7]. It be noted that both sections differ significantly in their bearing capacities. This type of analysis is suitable more for a project level. As for the network level, Figure 4 presents TSD post-processing results in terms of $d_0$ and SCI300 along 1220 m sections. Section #1 is fairly uniform in terms of both parameters but Section #2 could be split into two sub-sections. One can clearly observe that sub-section after approx. 600 m is weaker and produces more variability.

Figure 3. Typical results (deflection basins) from two sections at particular TSD location.
3.2 Example of Alternative Approaches

Previous section demonstrated typical approach in interpreting the TSD measurements associated with TSD position (Lagrangian description). However, it is also possible to process the TSD measurements using Eulerian description that focuses on a specific location along a road and observes the deflections that occur with time at that specific location [11]. Eulerian description is demonstrated in Figure 5 and Figure 6. This type of analysis is more suitable at the project level and it is complementary to Lagrangian approach.
4. Summary

Any National Road Administration (NRA) needs a tool to assess structural capacity of its pavement network in an efficient and safe manner. TSD is one of very few existing devices that seems to fulfill this objective. However, there are still several issues that need to be resolved and further work is needed to establish the precision and accuracy limits of the TSD measurements. When fully verified and validated, TSD has a good chance to become a great tool for both project and network level analysis.

References


