ABSTRACT

Non-destructive deflection testing has been an integral element of the structural evaluation of pavements for several decades. At present, Falling Weight Deflectometers (FWDs) represent the state-of-the-practice, but they are not without shortcomings. FWD deflection testing is a stop-and-go operation that requires lane closures, which in turn cause traffic disruptions and in turn create a safety hazard to personnel involved in the operation. It also implies that production rates are significantly less than a continuous one, which affects operational costs. To overcome these shortcomings, several organizations throughout the world have developed devices that can continuously measure pavement deflections. Recognizing the potential of these devices, the U.S. Federal Highway Administration (FHWA) undertook a study to: (1) assess the current state-of-the-technology, (2) determine whether or not the current devices can be put to good practical use, and (3) determine the best uses of those devices identified as viable. In this study, three moving pavement deflection-testing devices were identified as viable – the Texas Rolling Dynamic Deflectometer (RDD), the ARA Rolling Weight Deflectometer (RWD) and the UK Traffic Speed Deflectometer (TSD). The first of these devices appears better suited for project level structural evaluations, while the remaining two appear to be better suited for network level applications, although some questions remain to be addressed. This paper discusses the major study topics – state-of-the technology, pavement applications and device specifications, and best uses of viable devices – as well as the major findings and conclusions to date.

KEY WORDS: pavement structural evaluation, moving pavement deflection testing, continuous pavement deflection testing, rolling dynamic deflectometer, rolling weight deflectometer, traffic speed deflectometer.
INTRODUCTION

Non-destructive deflection testing (NDT) for the structural evaluation of existing or newly constructed pavements has been around for several decades. In the early days, simpler devices such as the Benkelman beam were used to measure the response of the pavement to a load in terms of a maximum deflection. While much valuable information can be derived from maximum deflections, they have a number of limitations perhaps the greatest of which is that little information can be obtained about the structural capacity of the individual pavement layers and the subgrade soil.

With time and the advances in technology, the pavement community started to measure multiple deflections at various radial distances from the center of the applied load; i.e., deflection basins. Presently there is a large array of equipment that can be used to measure deflection basins, but the most commonly used device by far is the Falling Weight Deflectometer (FWD). There are a number of manufacturers that produce or market FWDs; all of them rely on impact loads to produce a response in the pavement similar to that produced by actual traffic loadings, which is then measured by multiple deflection sensors located at varying distances from the center of the load.

FWDs represent the state-of-the-practice today as far as the structural capacity evaluation of pavements is concerned. Although they represent a quantum leap from the days of the Benkelman Beam, they are not without shortcomings, including the fact that they are a stop-and-go operation, rather than a continuous one. The implication is that lane closures are required, which cause traffic disruptions and in turn create a safety hazard to personnel involved in the operation. It also implies that production rates are significantly less than a continuous one, which affects operational costs.

To overcome the FWD shortcomings, several organizations throughout the world have developed devices that can continuously measure pavement deflections. An excellent history of these devices can be found in Andrén (2006), which documents the evolution of both mechanical and laser-based systems from the 1950s to the present. The more modern versions of these devices include:

- Quest/Dynatest Rolling Weight Deflectometer (Quest/Dynatest RWD).
- Swedish Road Deflection Tester (Swedish RDT).
- Texas Rolling Dynamic Deflectometer (Texas RDD).
- United Kingdom’s Highway Agency Traffic Speed Deflectometer (UK TSD)

The above devices were investigated by the Center for Transportation Infrastructure Systems at the University of Texas at El Paso (UTEP), which conducted a comprehensive study on the technical and institutional requirements for the adoption of such a device by the Texas Department of Transportation (TxDOT) for network-level pavement management purposes. The primary objectives of the study were to summarize the state-of-the-art of moving deflection testing measurement systems and to identify a suitable device or propose a specification for an ideal device if the existing ones did not meet the needs of TxDOT. The results and findings of the UTEP study are included in Jitin, Tandon and Nazarian (2006).

On January 11, 2009, almost three years after completion of the UTEP study, a special workshop on
moving pavement deflection testing was held at the annual Transportation Research Board (TRB) meeting in Washington, D.C.; Workshop 144 – High-Speed Pavement Deflection Measurements. Presentations made by device developers and sponsoring highway agencies highlighted the current state-of-the-technology for various devices as well as the work that remains to be done.

Recognizing the potential of moving deflection testing devices for assessing the structural integrity of in-service pavements, the U.S. Federal Highway Administration (FHWA) undertook a study to assess the current state-of-the-technology, to determine whether or not the current devices can be put to good practical use, and to determine the best uses of those devices identified as viable. The following sections of this paper address these three topics, with a separate section for each – state-of-the technology, pavement applications and device specifications, and best uses of viable devices. The final section of the paper provides a summary of the major findings and conclusions.

STATE-OF-THE-TECHNOLOGY

In assessing the state-of-the-technology, the findings of a study conducted at the University of Texas at El Paso (Jitin, Tandon and Nazarian (2006)) and the information shared at the January 11, 2009 Transportation Research Board Workshop 144 “High-Speed Pavement Deflection Measurements” provided the starting foundation. Other activities included the pursuit of recent literature, completion of a survey questionnaire by the device manufacturers, exchange of information with those manufacturers, and interviews of actual and potential device users. From these activities, the three devices identified as having the greatest potential for good practical use at present or within the next five years were the Texas RDD, ARA RWD and UK TSD. The other two devices – the Quest/Dynatest RWD and Swedish RDT – were not considered viable because development funding has been cancelled; commercialization activities have not been carried out over the past few years; and/or the prototype is no longer available.

Texas Rolling Dynamic Deflectometer (Texas RDD)

The Texas RDD was developed by The University of Texas at Austin. As shown in Figures 1, it is a truck-mounted device consisting of a servo-hydraulic loading system and force and deflection measurement systems. The device collects deflection data at an operational speed of 1 mph (1.6 km/h) for the first-generation rolling sensors, but second-generation rolling sensors can achieve an operational speed of 3 mph (4.8 km/h). Typically, the device applies 8 kips (36 kN) of static load ± 3 kips (13 kN) of dynamic load for highway projects, and 12 kips (53 kN) static ± 5 kips (22 kN) dynamic load for airport projects.

A hydraulic actuator drives a mass up and down to generate both static and dynamic forces. These forces are transferred down to the loading frame and to two loading rollers. The rollers apply the static and dynamic forces to the pavement, which are measured by four load cells located between the loading frame and the loading rollers. Four rolling sensors measure the vertical pavement deflections induced by the static and dynamic loads. Each of these sensors consists of a lightweight, rigid, three-wheeled cart supporting a vertically sensitive velocity transducer (geophone) with a 2-Hz resonant frequency. The sensors are pulled along with the truck by cables attached to an isolated frame, and the position of the sensors can be configured in different ways.
A sinusoidal dynamic force is continuously applied to the pavement while the device drives along
the road. As it moves over the pavement, the rolling sensors measure the deflections induced by the
dynamic force. The overall stiffness of the pavement can be determined with the data collected by
the in-line sensors. Also, the shape of the induced deflection basin can be determined with the
output of all of the sensors. The shape of the basin is a function of the stiffness of the various layers
of the pavement’s structure. To evaluate the load transfer efficiency of joints in rigid pavements, the
outputs of the first and second leading sensors are normally utilized.

While the operational speed for the Texas RDD is not suitable for testing at highway speeds, this
device is being used extensively for project level and forensic studies by the Texas Department of
Transportation (TxDOT) for delineating weak spots in pavements and for assessing the load transfer
efficiency of joints. In addition, since the device provides up to four deflection values, it is currently
the most versatile of the existing devices in terms of measuring deflection basins.

The initial field evaluation of the Texas RDD was conducted in 2000 at the Seattle-Tacoma
International Airport in Seattle, Washington. Subsequently, numerous forensic investigations and
pavement rehabilitation projects have been performed. In a recent study, for example, Chen, Nam
and Stokoe (2008) evaluated three projects and concluded that the “RDD data not only are able to
provide 100% coverage but also offer quantifiable and objective information for forensic and
rehabilitation studies in terms of relative movements at crack and joints.” In another recent study,
Chen (2008) evaluated seven projects to characterize the ability of the asphalt concrete (AC)
overlay to resist reflective cracking. This study concluded that the Texas RDD in tandem with the
Overlay Tester “…provide an objective evaluation that correlates to field performance data. It is
strongly recommended that both tools be used for the rehabilitation of concrete pavement with AC
overlays to evaluate the potential for reflective cracking.”

ARA Rolling Wheel Deflectometer (ARA RWD)

Applied Research Associates, Inc. (ARA) developed the Rolling Wheel Deflectometer (RWD) in
cooperation with the FHWA. A picture of the ARA RWD is shown in Figure 2. The device is
intended for network-level evaluation of primarily AC pavements and it is meant to complement project-level deflection devices such as the FWD. The theory of operation for this device is reported by (Hall and Steele, 2004); it is based on the spatially coincident methodology for measuring pavement deflections. The device uses four triangulation lasers to collect continuous deflection profiles at normal highway speeds. Three lasers measure the unloaded pavement surface profile surface (i.e., forward of and outside the deflection basin), while a fourth laser located between the dual tires behind the rear axle of the truck (see Figure 2) measures the deflected surface produced by a 9 kip (40 kN) load through two wheels spaced 13 in. (330 mm) apart.

Deflections are calculated by subtracting the profile of the deflected shape (measured by the laser between the dual tires) from that of the un-deflected shape profile (measured by the first three lasers) measured at the same location. The deflections are measured in mils (1 mil = 0.001 in) and they are collected in real-time at a frequency of 2 kHz and averaged every 0.1-mile (160-m) to produce a single deflection measurement. The device utilizes proprietary hardware and software for data acquisition.

The four distance-measuring lasers are attached to an aluminum beam of 26 ft (7.8 m) length retrofitted into a custom built trailer of 53 ft (16 m) length. The beam uses a curved extension to pass under and between the dual tires, placing the rear most laser around 6 in. (150 mm) behind the axle centerline and 7 in. (175 mm) above the roadway surface. The other three lasers are positioned 12 in. (305 mm) above the road surface.

The device was evaluated in 2004 at six test locations and at a nominal speed of 55 mph (90 km/hr) (Jitin, Tandon and Nazarian (2006)). In general, the repeatability of the device deflection measurements was found to be good. The comparison with the FWD also indicated that a relationship exists between the deflections measured by both devices, but the readings can be a magnitude different. Subsequently, several highway agencies performed evaluations and/or demonstration projects to familiarize themselves and others with the device; each evaluation had unique objectives because of different pavement application plans (Focus, March 2006). Many of these evaluations are documented at: http://www.fhwa.dot.gov/pavement/management/rwd/
More recently, a study was completed by the Virginia Transportation Research Council to evaluate the suitability of the device as a network-level pre-screening tool to identify areas where more detailed investigations (i.e., FWD testing) are needed (Diefenderfer 2010). Three of the more significant findings from the study include: (1) repeat measurements were statistically the same on 53% (8 of 15) of the cases, (2) the average standard deviation of the 0.1-mile (160-m) deflections (i.e., variability within 0.1-mile (160-m) segments) is very high; and (3) the range of ARA RWD and FWD deflection values was similar, but they were not well correlated. Based on these findings, and in particular the third one, use of the device by the Virginia DOT on pavements with low deflection values and uniform in structural cross-section (e.g., interstate facilities) is not recommended by the study author.

The ARA RWD can collect deflectometer data over approximately 150-250 lane-miles (240-400 lane-km) per day and cost of data collection is estimated to be approximately $50 per mile. Its application to date has been network-level evaluations of AC pavements. Its biggest challenges at present are the roughness and texture of the roadway surface and measuring very small readings while moving. The method of accounting for errors generated by the vibration of the beam on which the sensors are mounted and the impact of truck speed on the measured deflections is also of concern (Jitin, Tandon, and Nazarian (2006)). In addition, the device provides only a single deflection value and not a deflection basin.

**United Kingdom’s Traffic Speed Deflectometer (UK TSD)**

Greenwood Engineering A/S originally developed the High Speed Deflectograph (HSD) in Denmark. At the time of the University of Texas at El Paso study, the Danish Government funded development of this device and hence it was known as the Danish HSD. Subsequent to the UTEP study, the Danish Government stopped devoting development and research funding towards the device.

Despite the funding setback, Greenwood continued working on development of the device but now with technical support from the UK’s TRL, who shares their experiences and problems with Greenwood and, in turn, Greenwood implements the necessary modifications and then adopts them for their production. As a result, the device originally known as the Danish HSD started to be called the UK Highway Agency Traffic Speed Deflectometer (UK TSD) and is shown in Figure 3. The change in name to “Traffic Speed Deflectometer” or “TSD” came about as a result of liability concerns associated with the term “High Speed.”

The device utilizes two sets of lasers based on the Doppler technique to measure the deflection velocity of the road surface. The first laser sensor measures the un-deflected profile of the pavement while a second set of three-laser sensors measure the deflected profile, as illustrated in Figure 3. The difference between these two measurements is the total deflection of the pavement. The motion of the sensors is monitored by inertial systems. The operational speed is 50 mph (80 km/h), and a total load of 11,000 lb (50 kN) is applied through a load wheel monitored by a servo system.

Laser rays mounted on a rigid beam in front of the right wheel of the device strike the surface of the road and the sensors measure the velocity in the direction of the rays. In this way, the velocity of the
Deflection due to the load wheel can be measured. The velocity of the sensors with respect to the road and their angle is measured with three accelerometers and three gyro sensors. The velocity of the sensors and their angle of incidence are adjusted and accounted for when computing the velocity of the laser. The movement of the sensors is limited and controlled by the servo system. At the same time, two distance-measuring lasers control the servo system.

Figure 3. UK TSD and Laser Footprints in Front of Rear Tires

Current expectations are that the UK TSD will eventually replace the existing UK Highway Agency’s 15 deflectographs (Ferne (2009)). Implementation of the device on a routine network basis for AC pavements is expected to begin in 2010, traveling at speeds of 6 to 50 mph (10 to 80 km/h) to collect deflection data over approximately 300 miles (483 km) per day, with testing gradually shifting from the TRL to consultants over the next few years, initially using the research TSD but later with a separate new TSD. In terms of portland cement concrete (PCC) pavements, it appears that the device is promising but there are still several hardware and software issues to resolve; highway speeds will not be feasible in the near future but it will eventually be possible to attain speeds of 6 to 13 mph (10 to 20 km/hr).

The UK TSD (then the Danish HSD) was initially evaluated in Denmark in the early 2000s; Hildebrand, et. al., (2002). The repeatability of deflection velocities was determined to be good, but some shifts in the trend were noticed possibly caused by differences in driving speed. The results were also compared to FWD measurements and it was determined that a good correlation can be established between the two devices. Subsequent evaluations by the UK TRL showed that the UK device was less repeatable than the Danish one based on side-by-side testing, but that issue was resolved by making the UK trailer more rigid (Ferne (2009)). Those evaluations also raised a couple of concerns over the impact of temperature on the deflection profiles. The significant issue of the temperature gradient in the beam that holds the lasers was resolved by adding an air conditioning unit to the trailer to maintain the temperature of the beam constant. However, the pavement temperature issue has yet to be resolved through development of a “robust temperature correction” methodology (experience used at present). The more recent UK TRL evaluations have focused on comparing the UK TSD data to the low-speed deflectographs, and the results have shown that the trends between deflectograph peak deflections and the TSD deflection slope are similar; a
significant relationship has been obtained between them. The limited comparisons of the device with the FWD have shown that they produce very similar deflection profiles.

PAVEMENT APPLICATIONS AND DEVICE SPECIFICATIONS

On completion of state-of-the-technology review, rather than performing a direct assessment of the individual devices identified as potentially viable, the approach taken in the FHWA study was to:

- Develop a comprehensive list of potential pavement applications for moving deflection testing devices,
- Select a subset of pavement applications from the comprehensive list that can realistically be accomplished at present or within the next five years,
- Develop general device specifications required for accomplishment of the subset of pavement application considered realistic at present or within the next five years, and
- Assess the devices identified during state-of-the-technology review against the general specifications developed as a function of pavement application.

Factors considered in developing the subset of potential pavement applications included the possible need for FWDs to supplement the moving deflection results and the readiness of the moving deflection devices for use in the pavement applications. The resulting subset of pavement applications and associated specifications are detailed over the remainder of this section.

1. Identification of Pavement Changes/Anomalies at Network and Project Level

This application is considered important at both the network and project level because it can serve to: (1) assess the variability and/or uniformity of pavements, (2) delineate homogeneous pavement sections and/or subsections, and (3) identify potential problem spots/areas or anomalous locations. Moving pavement deflection testing devices could potentially replace FWDs entirely in carrying out these activities, but they must meet the following specifications:

- **Precision (Repeatability) of Deflection Measurements.** For this application, the most important factor is the relative differences in deflections between different points. As such, the precision of the measurements is important. The precision of measurements is defined as obtaining similar results on a given section with multiple surveys within a short period of time. The more precise the reported deflections are, the more certain the conclusions drawn with respect to the assessment of the uniformity of the pavement and the identification of problem spots and anomalous locations will be. The desirable level of precision has to be determined based on the pavement structure and relevant application. For project-level studies a higher precision is required than for the network-level studies.

- **Monitoring Applied Load.** The magnitude of the load applied by the tire to the pavement as well as the area of the instantaneous contact between the tire and pavement impact the measured deflections. The magnitude of load may change due to change in parameters such as the roughness of the road, and the contact area may change due to change in tire pressure (e.g., with temperature). It is recommended that the applied load be monitored during surveys. In the short-term, the tire pressure can be monitored during the operation, and in the long-term appropriate instrumentation can be added to the devices for this purpose.
**Operating Speed.** One of the benefits of the moving deflection devices, especially for network level operations, is that traffic control is not necessary. The device should preferably operate at the posted speed limit on a given road. The recommended minimum speed is at least 25 mph for most project level surveys, and at least 45 mph for the network level surveys.

**Distance between Deflection Measurements.** One of the big advantages of the moving deflection devices is the denseness of the data collected. The recommended point-to-point density of the measurements for this pavement applications is 1 ft or less.

**Reporting Measured Deflections.** Based on the denseness of the data collection suggested, the use of statistical methods to report a representative deflection over a representative distance is desirable (especially for network level surveys). The reported representative deflections should also include the standard deviation for each representative distance in addition to the mean value. The representative distance should be adjustable based on the length of the survey and variability in the representative deflections reported. It is recommended that the point-by-point deflection measurements also be optionally available to the analysts for further segmentation (especially for project level projects).

**Collecting Ancillary Data.** In addition to the deflection and possibly applied load, the device should be equipped with sensors to measure the air and pavement surface temperatures for possible adjustments of the measured deflections. A Global Positioning System (GPS) and/or accurate Distance Measuring Instrument (DMI) are also necessary to tie all measurements to the test locations for the convenience of the users.

### 2. Overall Pavement Structural Capacity Indicators at Program and Network Levels

This application is considered important at both the program and network level because it can serve to: (1) assess overall pavement structural capacity in terms of index values or structural remaining life and (2) support development of maintenance and rehabilitation (M&R) decisions and cost estimates on the basis of a structural indicator. It is envisioned that moving pavement deflection testing devices could potentially reduce the need for or entirely replace FWDs in carrying out these activities. To accomplish this, however, the devices must meet the specifications outlined earlier for the “Identification of Pavement Changes/Anomalies at Network and Project Level” application. In addition, because of the value-added use of the deflections, the device should also comply with the following specifications:

**Accuracy of Deflection Measurements.** For this application, the absolute values of deflections are also important. As such, the devices should be able to make accurate deflection measurements. The accuracy is defined as the closeness of measured deflections to their actual values. Once again, the level of accuracy required needs to be established based on the pavement structure and relevant application. Alternatively, FWD testing can be carried out in conjunction with the moving deflection survey at a number of points along the length of the project for “calibration purposes.” This “calibration” process is analogous to the use of pavement cores to calibrate the Ground Penetrating Radar (GPR) thickness measurements. The FWD and moving deflection device deflections can be correlated to remove the bias in the measurements with the moving deflection device.

**Collecting Additional Information.** For this application, additional information about pavement structure from other rapid field-testing data is desirable; e.g., device retrofitted
with a GPR to estimate the pavement layer thicknesses, and changes in the pavement structure along the survey. A high-speed video camera is also valuable for visual inspection of the condition of the pavement sections with anomalous deflection readings.

3. Structural Capacity of Individual Pavement Layers at Project Level
This application is considered important at the project level because it can serve to: (1) assess structural capacity of individual pavement layers (i.e., layer moduli) as well as overall structural capacity of pavement, (2) identify problem/weak pavement layers within the project limits that must be corrected, and (3) Support the development of detailed M&R strategies and cost estimates using a multitude of empirical or mechanistic empirical procedures. For these activities, moving pavement deflection testing devices could potentially replace FWDs entirely, however, they should meet the specifications for the “Overall Pavement Structural Capacity Indicators at Program and Network Levels” application, but with some modifications as detailed below:

- **Measuring Deflection Basins.** For this application, more than one deflection point is necessary. A minimum of four deflections at each test point location is recommended. The spacing among the deflection measurements should be adjustable to best suit the pavement structure being tested.

- **Accuracy of Deflection Measurements.** The accuracy of deflection measurements should be ascertained using an appropriate calibration facility through a well-defined calibration process. Due to associated costs of operation, it is desirable that the moving device be used without the mobilization of a FWD.

- **Precision (Repeatability) of Deflection Measurements.** The device should be in principle more precise than the level required for the previous two applications.

- **Operating Speed.** For this application, the speed of operation does not seem to be as critical as the network and program level surveys. A minimum speed of 3 mph (4.8 km/h) is recommended, and a production level of at least four times greater than the effective operational speed of the FWD.

- **Reporting Measured Deflections.** It is recommended that the point-by-point deflection measurements be available to the analysts for appropriate processing so that the segmentation of the data and the determination of the representative deflection basins can be carried out by the analysts.

- **Layer Moduli Analysis Capabilities.** All of the above specifications relate to the collection of deflection and supporting data. However, in order for moving pavement deflection testing devices to be viable for this application, analysis capabilities (i.e., software) for determining layer moduli from the collected deflection data must also be available. Much effort has been devoted over the past couple of decades to the development of software for the backcalculation of layer moduli from FWD deflections, but it is our contention that such software cannot readily be used with data generated from moving pavement deflection testing devices without significant modification. Accordingly, significant software development effort will be required to make this application truly viable.

4. Joint/Transverse Crack Counts and Joint Load Transfer Efficiency
This application is considered important at both the program and network level because it can serve to: (1) estimate number of joints and working transverse cracks along the length of a PCC pavement...
project, at both network and project level and (2) assess the load transverse efficiency at joints and working transverse cracks at both network or project level PCC pavements. As with previous applications, moving pavement deflection testing devices could potentially replace FWDs entirely for this application.

The specifications for the moving pavement deflection testing device capable of successfully carrying out the listed activities is quite similar to the specification for the device recommended for “Structural Capacity of Individual Pavement Layers at Project Level” application, but with some relaxed requirements. More specifically, for this application:

- **Measuring Deflection Basins.** The deflection basin measurements are not necessary.
- **Distance between Deflection Measurements.** A denser measurement of the deflections is desirable in order to better identify the location of the joints.
- **Monitoring Applied Load.** The documentation of the load applied is not necessary.
- **Collecting Additional Information.** The use of GPR is optional.

### BEST USES OF VIABLE DEVICES

Having established potential pavement applications and generic device specifications, the final phase of the FHWA study entailed the assessment of the viable devices against the generic specifications developed as a function of pavement application. To accomplish this, raw deflection data were pursued from the device manufacturers or through their clients, the state departments of transportation. To date, some data have been received for the Texas RDD and the ARA RWD, but additional data are being pursued for these two devices as well as for the UK TSD.

Figures 4 and 5 illustrate field data collected with the Texas RDD and the ARA RWD, respectively. The Texas RDD data shown in Figure 4 were collected in December 2009 on the northbound frontage road of Interstate 35 in Georgetown, Texas using a static force of 10 kips and a dynamic force of 10 kips with a frequency of 30 Hz; measurements were averaged every 0.6 to 0.9 m (2 to 3 ft). Around 2,300-feet (700-m) of precast pre-stressed concrete pavement with a nominal thickness of 8-inches (200-mm) were tested with the Texas RDD in two separate repeat runs. FWD testing was also performed on the pavement in question. As shown in Figure 4, the Texas RDD measurements appear repeatable and deflections follow the same trend as the FWD measurements.

The ARA RWD data shown in Figure 5 were collected in October 2005 on the westbound side of Interstate 64 in Virginia; measurements (approximately 60,000 of them) were averaged every 0.1-miles (160-m). Approximately 20-miles (32-km) of pavement composed of a hot-mix asphalt (HMA) overlay placed over an existing continuously reinforced concrete pavement (CRCP) was tested; other pavement sections were also tested as part of the project. The data in question came from the earlier referenced Virginia Transportation Research Council study whose major findings included repeat measurements being statistically the same on only ~50% of the cases, variability within the 0.1-mile (160-m) averaging segments is very high, and range of ARA RWD and FWD deflection values is similar, but they are not well correlated.
Although UK TSD field data are still being pursued, some relevant data were found in the literature such as that illustrated in Figure 6, which shows data collected on a large test loop in November 2005. While the actual data that went into preparation of the plots has not been reviewed, this figure appears to show that the device is repeatable and that the measurements match well with those from the FWD.

The specific issues being considered as part of the review and assessment of the raw data include:

- Consistency of raw data over short distances,
- Averaging of the raw data (i.e., moving averages)

Figure 4. Texas RDD and FWD Data
(Note: Initial run is shown at top of figure and repeat run at bottom of figure)
Use of various signal analysis techniques, including frequency-domain, in an attempt to
delineate sensor information due to deflection of the pavement from undesirable mechanical
and electrical "noise" of the device, and

(Note: in this figure, slope is the ratio of the measured deflection velocity to the horizontal
component of the deflection velocity as measured by the reference sensor)
Effect of temperature on measured data for both flexible and rigid pavements.

Although preliminary at best, Table 1 summarizes the initial assessment of the viable devices on the basis of the available data to date and the established pavement application specifications. Major observations relating to this table are provided below:

- The Texas RDD appears to be the only device ready for the “joint/transverse crack counts and joint load transfer efficiency” application. Because it is the only device that measures deflection basins, it also appears to be the only one ready for the “structural capacity of individual layers at project level” application; however, it is shown as “potential” because layer moduli analyses capabilities do not presently exist and development of those capabilities will require significant time and effort. In terms of the remaining two applications, this device is not considered viable due to its operational speed.

- The ARA RWD could potentially be used at present for the “pavement changes/anomalies at network and project levels” and “overall pavement structural capacity indicators at program and network levels” applications; however, issues relating to its repeatability and averaging technique need to be addressed. The device is not considered viable for the remaining two applications because it does not collect deflection basins and because of the referenced repeatability and averaging technique issues.

- The UK TSD could potentially be used at present for the “pavement changes/anomalies at network and project levels” and “overall pavement structural capacity indicators at program and network levels” applications; however, this needs to be confirmed through the review of recent raw data. The device is not considered viable for the remaining two applications because it does not collect deflection basins and because of the density of the measurements.

A more conclusive assessment of the three devices identified as viable under the FHWA study will be completed by October 2010 and the results – a technical report and two technology briefs, one on the state-of-the-technology and the other on the best uses of the devices – will be available.
SUMMARY AND CONCLUSIONS

To overcome shortcomings associated with FWDs, the state-of-the-practice in terms of pavement structural evaluation, several organizations have developed devices that can continuously measure pavement deflections. Recognizing their potential, the FHWA undertook a study to assess the current state-of-the-technology, to determine whether or not the current devices can be put to good practical use, and to determine the best uses of those devices identified as viable.

Three devices were identified as having the greatest potential for good practical use from the state-of-the-technology – the Texas RDD, ARA RWD and UK TSD. Rather than directly performing an assessment, however, a comprehensive list of potential pavement applications was developed. A subset of pavement applications that can realistically be accomplished was then selected from the comprehensive list and general device specifications required to accomplish each application were developed. Finally, relying on data gathered for each, the viable devices were compared against the general device specifications to determine their best uses. Although still preliminary, the Texas RDD appears better suited for project level structural evaluations, while the remaining two appear to be better suited for network level applications.

Despite their potential, however, a number of issues concerning these devices remain to be addressed. They include equipment-related issues (e.g., establishing precision and accuracy of measurements as well as defining the load applied to pavement), measurement-related issues (e.g., understanding sources of differences in deflections between moving devices and FWDs, exploring systematic differences in deflections between FWDs and moving devices, and developing a methodology for calibration of moving devices) and application-related issues (e.g., establishing sensitivity of measured deflections to potential distresses in different pavement structures, identifying minimum number of deflection points necessary for specific applications, establishing other pavement parameters aside from deflection that can improve the reliability of a specific application, and defining an index that relates the pavement capacity/condition to deflection).

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