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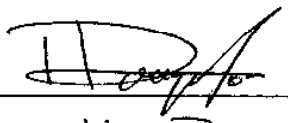
Signature: 

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A NEW APPROACH TO NON-DESTRUCTIVE EVALUATION OF PAVEMENT STRUCTURES USING THE ROLLING DYNAMIC DEFLECTOMETER

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ABSTRACT

This paper describes the use of the Rolling Dynamic Deflectometer (RDD) at two different sites as an example of non-destructive evaluation (NDE) of pavement structures for a qualitative analysis of the continuous deflection profile. A comparison of sections with different deflection profiles allowed engineers to identify relative differences in support conditions for the portland cement concrete slabs, cut and fill sections associated with the initial construction, and other discontinuities in the pavement structure. Additional research recommended for future locations includes tying the continuous deflection profile to discrete measurements taken by coring and performing laboratory tests as well as falling weight deflectometer (FWD) measurements and backcalculation to characterize the materials in the pavement. Other future uses of the RDD are also recommended.

1. INTRODUCTION

The transportation industry is deep in an era of unprecedented demand, despite ever-decreasing resources. Consequently, we can no longer continue to simply build our way out of our transportation problems. As the demand for pavement repair, rehabilitation, and reconstruction dramatically exceeds the public funds available, agencies are expected to maximize their resources, and make the right decisions, more than ever before. To make the right decisions, agencies need practical, reliable methods to evaluate the condition of pavements. Non-destructive methods have become an industry standard in pavement evaluation. The rolling dynamic deflectometer (RDD), introduced in this paper, provides a dramatic advancement over the current state of the practice in non-destructive pavement evaluation.

The RDD is a recent development in the non-destructive evaluation of pavements. The RDD imparts a heavy dynamic load to a pavement surface through loading rollers, and measures the resultant deflections. One of the primary benefits of the RDD is its ability to apply loads and measure deflections in a continuous manner. In other words, the current state of the practice in deflection measurement is to collect measurements or "drops" at specific discrete points along a pavement. The RDD is able to collect continuous measurements along the entire length of pavement. This increased volume of information provides not simply more data, but an entirely more thorough approach to non-destructive evaluation. With the rolling dynamic deflectometer, more information helps state highway agencies better achieve their objectives of making the right decisions, and maximizing their resources. This paper provides examples of applications of the rolling dynamic deflectometer, as well as potential future applications of the technology.

2. THE ROLLING DYNAMIC DEFLECTOMETER

The rolling dynamic deflectometer, originally developed at The University of Texas at Austin, is an improved method for nondestructive testing of highway and airport pavements (1). RDD testing has one major advantage over other nondestructive testing methods: it provides a continuous profile of pavement behavior, while most nondestructive (and destructive) testing techniques provide information only at discrete locations along the pavement. The problem with discrete testing methods is that there is no assurance that critical, or even typical, pavement locations will be tested. With continuous methods, the entire pavement is characterized. Thus, poor, average, and good sections of pavement can be delineated rapidly with the RDD. Additionally, a continuous profile gives a very informative picture of the performance of the pavement system. The behavior of every joint and crack is easily determined. The regions affected by joints and cracks are distinguishable from regions of intact pavement. Continuous deflection profiles of pavements are quickly measured with the RDD, and these measurements can be readily performed in the presence of traffic.

The RDD is a mobile, truck-mounted device, as shown in Figure 1. It generates and measures large dynamic forces, which are applied to the pavement through loading rollers as the truck moves along the pavement. The deflections induced by the dynamic loads are measured with multiple, specially designed rolling sensors. These measured deflections are indicators of the mechanical properties of the pavement system.

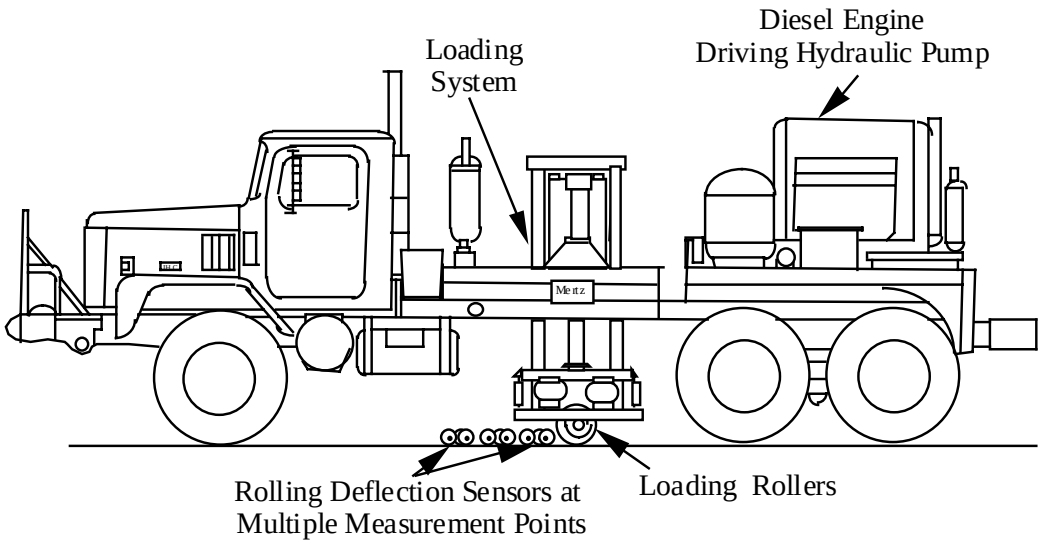

Figure 1. General Configuration of the Rolling Dynamic Deflectometer.

The loading system is shown in Figure 2. Dynamic forces are generated by cycling hydraulic fluid in and out of the top and bottom chambers of the hydraulic actuator inside the reaction mass. The hydraulic pressure in the actuator accelerates the 33.4 kN (7.5 kip) reaction mass up and down. This system is capable of generating dynamic forces up to 154 kN (34.7 kip) peak at frequencies from 5 to 100 Hz. The dynamic forces are transferred down the stilt structure, to the loading frame, and then through the loading rollers to the pavement. The force applied to the pavement is measured with load cells located between the loading frame and the bearings of the loading rollers.

The RDD was developed to overcome weaknesses inherent in discrete pavement testing techniques. The variability inherent in pavements, which nearly always traverse various geological formations, cuts, and fills, ranks among the highest degrees of variability encountered in engineering design. Statistical analysis provides a useful tool for estimating pavement properties from discrete measurements, but the ideal approach is to measure continuous properties of the entire pavement. The RDD rapidly measures continuous deflection profiles of a pavement.

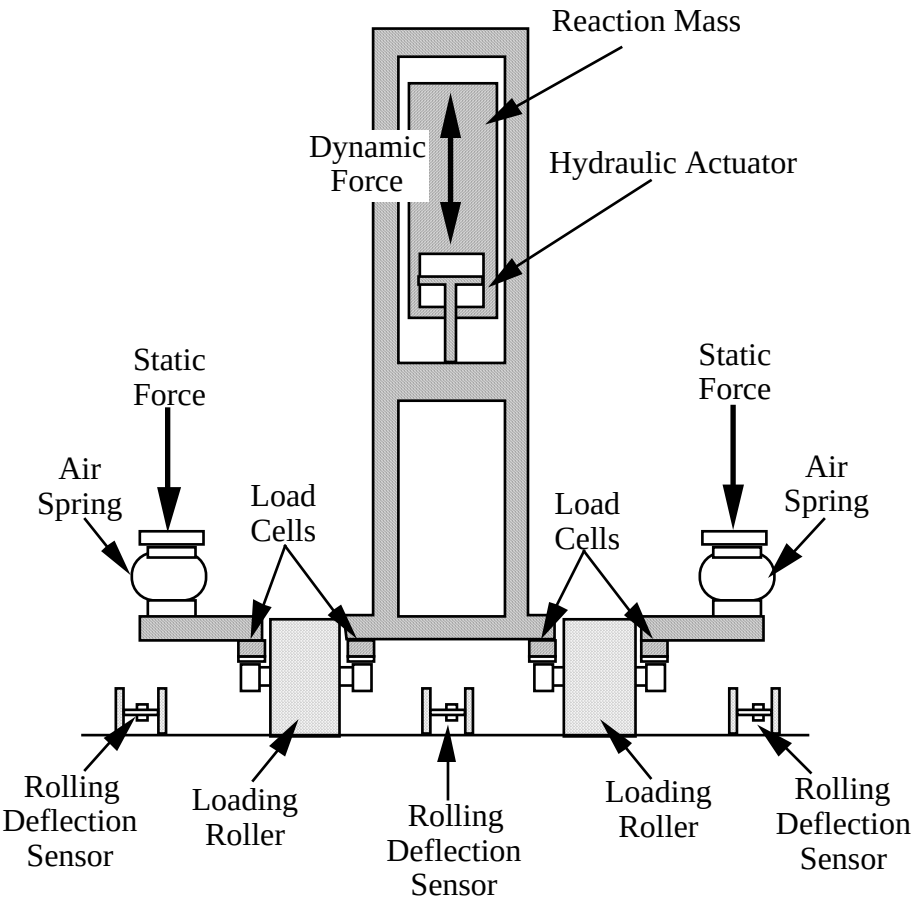

Figure 2. Front Cross-Sectional View of the RDD Loading and Measurement Systems. (1)

3. OBJECTIVES

The primary objective of this report is to provide information to the pavement engineering community on a proven alternative state-of-the-art technology for the non-destructive evaluation of pavements. This objective can be divided into two sub-objectives, including:

- To provide information on proven current applications of the Rolling Dynamic Deflectometer technology, and
- To provide information on planned applications of the Rolling Dynamic Deflectometer technology.

4. CURRENT APPLICATIONS

Throughout its use by the University of Texas at Austin, the Rolling Dynamic Deflectometer has provided valuable non-destructive evaluations of pavements throughout the United States. Several of the most useful applications of RDD data are presented in this section.

Load Transfer Across Joints

In the evaluation of in-place jointed concrete pavements, the performance of transverse joints can have a dramatic impact on the total performance and service life of the pavement. When a transverse joint between two slabs performs well, there is minimal increased vertical movement at the joint as compared to the midslab, and traffic loads are supported well over both the approach and leave slab. If a joint includes dowels and is constructed properly, the dowels will serve to help distribute the impact of the traffic loads between the two slabs. The concept of sharing, or transferring, load between two slabs that have dowels is commonly termed Load Transfer Efficiency.

Load Transfer Efficiency (LTE) can be estimated at each joint with the leading sensor of the RDD, which is often positioned 0.5 to 1.5 m (1.5 to 3.0 ft) ahead of the dynamic force. As the leading sensor rolls over a joint, there is a characteristic drop in deflection response. This relationship can be represented with the use of Equation 1.

$$Load\ Transfer\ Efficiency = \frac{D_2}{D_1} \times 100\% \quad (1)$$

where:

D_2 = the deflection measured immediately after the leading sensor has crossed the joint, and

D_1 = the deflection measured immediately before the leading sensor has crossed the joint.

Relative Comparisons Between Pavements

The RDD can provide comprehensive information about the deflection response behavior of a continuous segment of pavement for the purpose of relative comparisons. Figure 3, for example, reveals valuable information about the difference in performance of two adjacent sections of pavement with different typical cross-sections. The RDD provides information that would otherwise not be attainable in an expeditious, non-destructive manner. In Figure 3, the RDD was employed to collect data over a pavement where one section had been

rehabilitated with a concrete overlay, and the second section had been fully reconstructed. As shown in the figure, the relative difference between the two sections is significant.

With the use of the RDD in this application, the state highway agency is able to accurately locate the limits of a section with markedly higher deflection responses. The agency is also able to identify significant changes in the relative stiffness characteristics of the subgrade layers beneath the surface pavement. This enables the agency to prioritize maintenance and rehabilitation activities, as well as to understand better the behavior of the pavement sections.

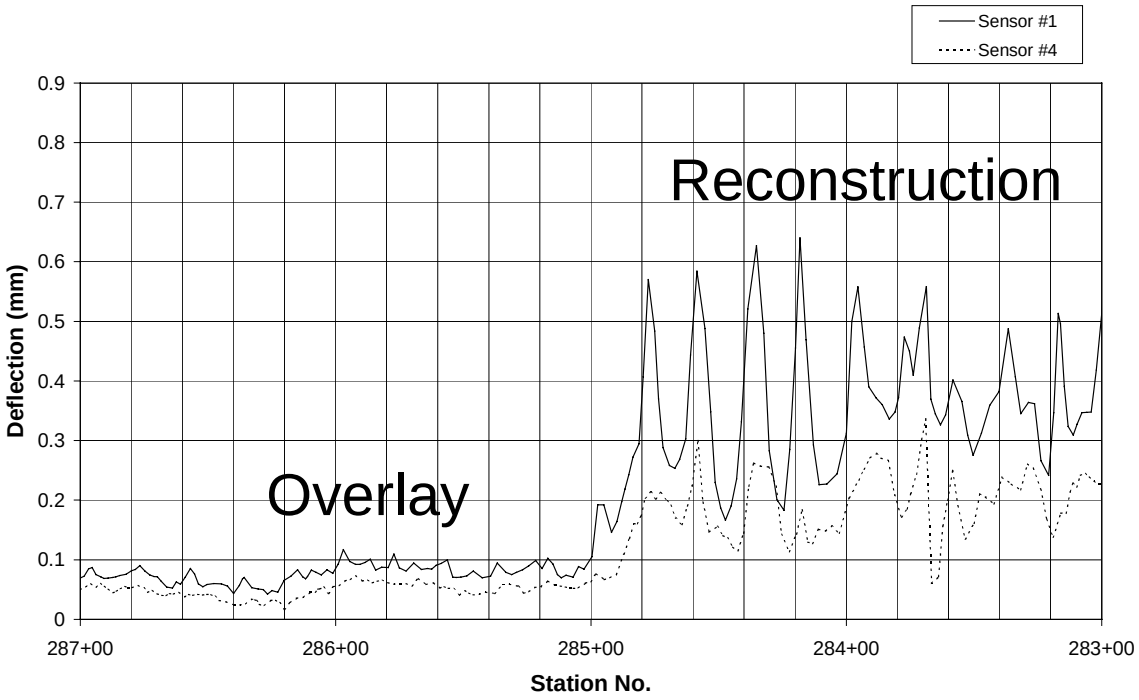

Figure 3. Identification of Change in Typical Section.

Identify Hidden Features

Similar to the application of RDD technology for the purpose of identifying and characterizing known transitions in pavement types, so too can the RDD help to identify transitions in pavement that are not known. Many state highway agencies have conducted extensive invasive investigations to isolate the cause of apparent distresses in a section of pavement. With the RDD, much of this information can now be obtained accurately and non-destructively.

Figure 4 illustrates a sample of RDD data collected on a jointed concrete pavement on an interstate highway. At the time of data collection, there was no expectation of a change in deflection characteristics of the pavement section. The RDD is able to identify the length, location and magnitude of this unexpected increase in deflection characteristics. This application of RDD technology is of significant value to state highway agencies in its ability to identify explicit sections of pavement that could currently display pavement distresses such as faulting, spalling or others. Similarly, if pavement distresses are not apparent at the time of data collection, this change in deflection characteristics can alert the agency to the increased possibility of the development of adverse pavement performance over time.

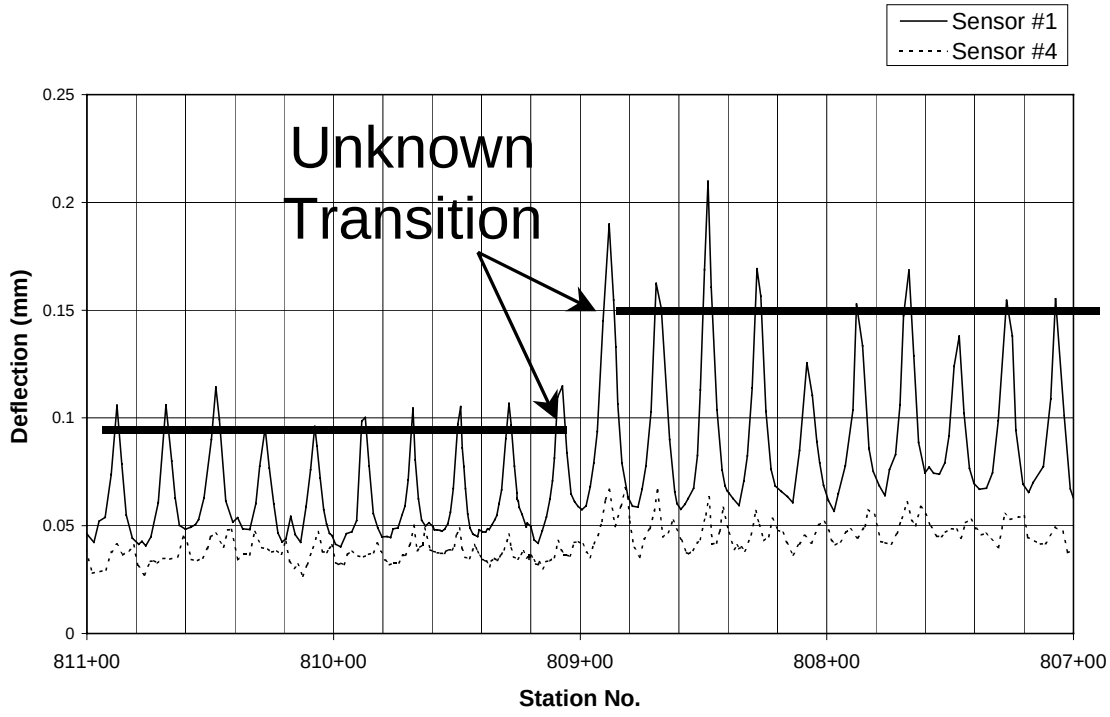

Figure 4. Identification of an Unknown Change in Pavement Deflections.

Identify Full-Depth and Partial-Depth Cracks

Many state highway agencies perform visual or video condition surveys of pavements These surveys are able to locate visible cracks in pavements, but are typically unable to identify hairline or very narrow cracks. Since RDD technology measures deflection response in a continuous profile manner, changes in deflections are able to help identify even hairline cracks and those that would otherwise not be visible in a typical condition survey. Moreover,

the RDD technology is able to identify cracks that are not full-depth. This level of information is not readily available with other non-destructive evaluation technologies.

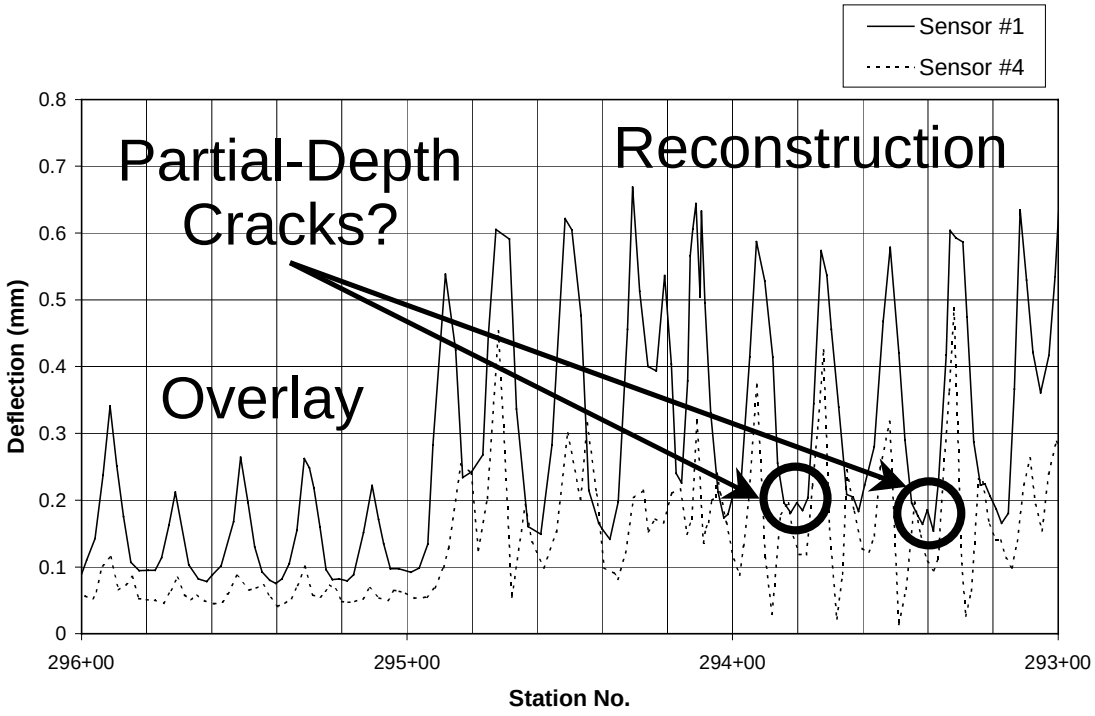

Figure 5. Identification of Discontinuity at Midslabs.

5. POTENTIAL FUTURE APPLICATIONS

The previous section discussed applications of the RDD that have been implemented successfully in the past. This section presents applications that have been envisioned by the developers and users of the RDD, but have not yet been used on an actual project with tangible results. Many of these applications build on the experience and knowledge gained by implementing the applications in the previous section. These potential future applications include the following:

- Prediction of future performance,
- Coupling RDD results with other technologies,
- Identification of features in pavement structures,
- Super-accelerated pavement testing, and
- Pavement management.

The remainder of this section will describe these applications and potential methods that could be used to implement them into standard RDD data analysis. Each subsection, representing the future applications enumerated previously, will also describe the application's interaction with current RDD use. They will also discuss how the various current and future applications can work interactively to enhance the information that can be obtained from a pavement structure.

Predict Future Performance

The RDD enables an analysis of future pavement performance when an agency measures the continuous deflection multiple times over the course of a pavement's life. Given a time history of a pavement's deflection profile, future cracking and loss of support conditions may be identified early in the development of such failures. For a given pavement structure at a specific location, current cracking patterns can be used to identify the deflection signature under which cracking develops. This information can then be applied to the next measure of the pavement's continuous deflection profile to identify locations which fit the deflection signature for cracking development.

Coordination with other Technologies

The RDD can be used together with several other non-destructive technologies, such as ground penetrating radar, laser profilometer, and falling weight deflectometer. Each of these applications provide valuable information about pavement performance and characteristics, both on network and project levels. Individually, these technologies each describe one aspect of pavement conditions. Together with the RDD, and organized within a geographical information system, these technologies can describe more completely the pavement performance and conditions of the structure as well as the component materials and layers. Further studies must be performed to determine the best combination and uses for each of these technologies in a comprehensive pavement materials and structural analysis.

Identification of Features in Pavement Structures

In the analysis of the RDD measurements given here, several additional features were identified, as described in Section 4. Some of these features were known to the state highway agency, but their location were not necessarily known. For example, the large difference in deflections obvious in Figure 3 identified the exact location of a change in pavement typical section, from an overlay to new construction. Figure 4 shows a section of pavement where the deflection profile changed without any apparent reason. Further investigation of this location should reveal the reason for the increase in deflections.

Another feature not readily ascribed to a probable cause is shown in the deflection profile plot in Figure 5. This plot indicates both a change in typical section as well as discontinuities in several slabs at the midslab location. Again, further investigation will likely identify the reason for the discontinuity, but a preliminary hypothesis is that it is caused by a partial depth crack that has not fully formed. The visual condition survey conducted in association with the RDD measurements did not identify a crack at that location.

Figure 6 shows a transition in subgrade conditions from a cut section to a fill section. Several features can be identified in this plot. In the cut section, the 6.1-meter (20-foot) slabs are intact, while every slab in the fill section that is included in the scope of this plot has cracked. Also, the maximum deflections have decreased slightly, but the minimum deflections in Sensor #1 have increased dramatically. This indicates that the midslabs (of the cracked slabs, thus 3.0-meter (10-foot) intervals) deflect approximately 0.38 mm (15 mils) in the fill section, while the midslabs of the 6.1-meter (20-foot) slabs deflect about 0.13 mm (5 mils). This is only a portion of what can be detected in the continuous deflection profile, indicating the wealth of untapped information stored in the data produced by the RDD.

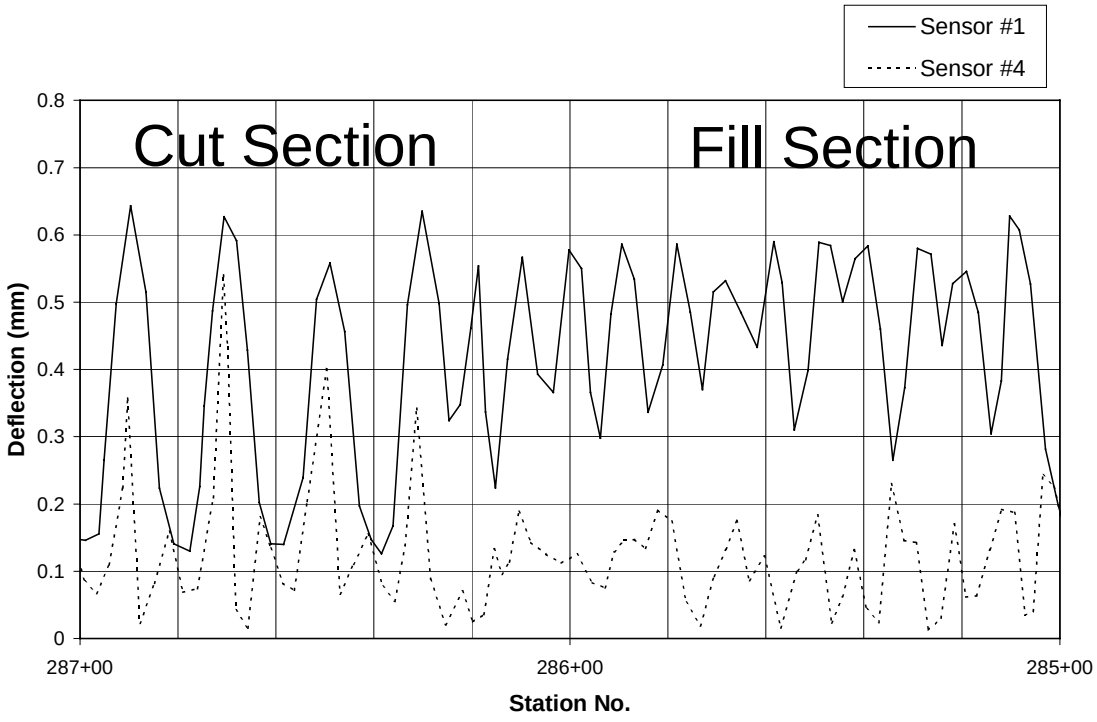

Figure 6. Transition from Cut Section to Fill Section.

The examples given in this section are representative of the type of features that can be identified using RDD data. The analysis and interpretation such features can only be improved by further experience and work in this field.

Super-Accelerated Pavement Testing

Several applications are under development in the area of accelerated pavement testing (APT) with the RDD. When compared to conventional APT, similar testing with the RDD has been termed *super*-accelerated pavement testing. In comparisons to the Texas Mobile Load Simulator (MLS), Dr. Ken Stokoe has replicated performance and load applications in two to three days that required up to three months for the MLS.

One method of super-APT, as mentioned above, is to test the remaining life of a pavement structure by testing loading the pavement with the RDD in place. Normally the RDD moves forward at 0.45 to 0.89 m/s (1 to 2 miles per hour). In-place testing, however can load the same section of pavement to failure in a short amount of time. The RDD can be used to simulate various loads and tire pressures, thereby closely simulating actual loading conditions.

Other applications of super-accelerated testing include determining the effects of early-age loading on concrete pavement. The RDD can be used to load test slabs at various ages (time since placement) and at various loading levels and number of applications. Once the slabs have set and cured properly, they are then loaded to failure. For a given pavement design, then, the effect of early-age loading can be evaluated. This method can similarly be used to test long-term performance in a short period of time using different materials.

Pavement Management

Using the RDD as a component of a pavement management system is similar to using data collected by falling weight deflectometer or profilometer devices, as described in a previous section. The RDD collects a continuous deflection profile which can be used in pavement management systems to track the performance of the pavement, joint load transfer, and distresses such as cracking and loss of support.

Just as pavement profiles on a network level must be reduced to a manageable amount of data, so must RDD data. The data must be analyzed and compiled in order to capture and use the information contained in it. Such analysis remains to be developed for the RDD to be come more useful to the pavement management field.

6. CONCLUSIONS

The Rolling Dynamic Deflectometer is a relatively new technology that provides a continuous deflection profile of a pavement structure. Its use as a non-destructive testing tool has greatly enhanced the ability of pavement engineers to identify features in the pavements in their jurisdiction. The examples presented in this paper from test sections in two districts of a state highway agency show the RDD's ability to provide highly detailed information regarding the pavement's overall structural stiffness, joints, cracks (full- and partial-depth), subsurface, and typical section.

The important experience gathered from agencies who have used the RDD is encouraging as more applications of the RDD and its wealth of data are realized and put into practice. Further research is recommended to determine the most effective methods of coupling the data with that of other technologies to provide an even better representation of the subsurface and structural conditions. As these methods are perfected, it is expected that even more applications of the RDD will be manifested.

7. REFERENCES

1. Bay, J. A. and K. H. Stokoe, Center for Transportation Research, Research Report 1422-3F, The University of Texas at Austin, 1998.