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The Rolling Dynamic Deflectometer: A tool for continuous deflection profiling of pavements

Le Rolling Dynamic Deflectometer: Un outil pour caractérisation continue des pavées

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ABSTRACT

The Rolling Dynamic Deflectometer (RDD) is a nondestructive testing device that is used to measure continuous deflection profiles along highway and airport pavements in project-level studies. The RDD has an electro-hydraulic loading system that generates a sinusoidal force on the pavement through two loading rollers. An array of rolling sensors continuously measures the sinusoidal deflections at multiple locations as the RDD moves at about 1.6 km/hr. Continuous deflection profiles contain vast amounts of information about the condition of the pavement. This information provides a detailed picture of existing conditions and allows pavement engineers to select appropriate rehabilitation schemes. Example RDD profiles are shown for rigid, flexible, and overlaid pavements. At one flexible pavement site, the RDD deflection values are compared with deflection values measured by both the Falling Weight and Rolling Wheel Deflectometers.

RÉSUMÉ

Le Rolling Dynamic Deflectometer (RDD) est un appareil non destructif de haut niveau analysant la déformation, qui est utilisé pour mesurer des profils de déformation continue le long des chaussées d'autoroute et des pistes d'aéroport. Le RDD possède un système de charge électro-hydraulique qui génère une charge sinusoïdale sur la chaussée au moyen de deux rouleaux d'appui.. Un jeu de capteurs à rouleaux mesure de manière continue la déformation sinusoïdale de la surface de la chaussée à de multiples endroits tandis que le RDD se déplace à la vitesse d'environ 1,6 km/h. Les profils en long de déformation continue contiennent d'importantes quantités d'information quant à l'état de la chaussée. Cette information fournit une image claire de l'état existant de la chaussée, et permet aux ingénieurs des chaussées de déterminer le plan approprié de réhabilitation. Exemples du RDD profils sont présentes pour des pavées rigides, souple et chaussée en béton avec une couche de surface en asphalte. A l'occasion d'un test de chaussée souple sur les valeurs de déformation obtenues avec le RDD sont comparées avec celles mesurées par le Falling Weight et Rolling Wheel Deflectometers.

1 INTRODUCTION

Nondestructive deflection testing devices are regularly used to evaluate the structural characteristics of pavements in project-level studies. The most commonly used device today is the Falling Weight Deflectometer (FWD). The FWD and other devices like it have the limitation that testing can be performed only when the device is stopped. As a consequence, measurements at discrete locations are made, often tens of meters apart. This procedure generally leads to characterization of less than 10% of the pavement. Characterization of such a limited amount of pavement results in a sparse data set that makes it problematic for the engineer to: (1) evaluate trends in key characteristics such as mid-slab deflections, (2) select representative locations or sections for monitoring purposes, and (3) identify critically weak spots and low load-transfer joints and cracks that might require additional localized repairs.

To overcome some of the limitations of stationary deflection testing, several devices have been developed which perform deflection measurements while moving. The Curviameter, a device that measures vertical pavement deflection and curvature, has been developed in France (Paquet, 1978). The Rolling Dynamic Deflectometer (RDD), a device that measures pavement deflections with rolling sensors, has been developed at the University of Texas at Austin (Bay and Stokoe, 1998). One benefit of these devices is that continuous deflection profiles of pavements are measured. Continuous profiles represent robust data sets that permit well-informed decisions to be made. Furthermore, continuous profiles taken before and at various times after a rehabilitation project allow performance of all locations along the project to be tracked and evaluated.

The objectives of this paper are: (1) to present an overview of the RDD and describe some of its key features, and (2) to illustrate some of the benefits of continuous deflection profiles with examples from project-level studies where RDD testing has been performed. These objectives are addressed below.

2 OVERVIEW OF THE ROLLING DYNAMIC DEFLECTOMETER

The RDD is a truck-mounted, electro-hydraulic system that is used to load the pavement surface and measure resulting deflections while moving. A schematic diagram of the RDD is shown in Fig. 1. The RDD was developed by modifying a Mertz® Vibroseis, which is a truck-mounted vibratory source (with a mass about 22,700 kg) that is commonly used in land-based geophysical exploration. The Vibroseis was modified in two ways. First, the 2.3 by 1.2 m base plate that is used to load the ground during geophysical exploration was removed and replaced with two, stiff, polyurethane loading rollers that are used to load the pavement while moving. Second, rolling sensors were developed (Fig. 2) and placed in a linear array (Fig. 3) beneath the Vibroseis so that pavement deflection basins could be continuously measured "on the fly".

During testing, two types of vertical forces are applied to the pavement through the loading rollers. They are: (1) a static, hold-down force that keeps the loading rollers in contact with the pavement (typically about 44.5 kN), and (2) a single-frequency sinusoidal force that dynamically loads the pavement (typically about 44.5 kN peak-to-peak). The combined vertical loading is shown in Fig. 4. A testing frequency between 20 and

40 Hz is used, with the frequency selected at the site based on the pavement conditions. The sinusoidal force is generated by the electro-hydraulic loading system which drives a 3400-kg mass. Surface displacements induced by the dynamic force (not the static force) are continuously measured at multiple locations by the array of rolling sensors shown in Fig. 3.

An example deflection profile is shown in Fig. 5. The profile is 243 m long and was taken from a 3-km profile along a pavement runway. The pavement is a jointed reinforced concrete pavement, JRCP. For clarity, only an expanded portion of the 3-km profile is shown. Further, only measurements from sensor #1 are shown so that the trends are easily observed. The resulting deflections are presented in terms of peak deflections for a load level of 89 kN. The major peaks in the profile represent the deflections at each transverse joint. These peaks are 23 m apart which corresponds to the construction joints; hence, there is no major mid-slab cracking. The lower deflections represent the mid-slab areas between transverse joints. The minor variations in the mid-slab areas are due to minor cracking in the slabs. A more detailed discussion of this and other deflection profiles is provided in Section 3.1.

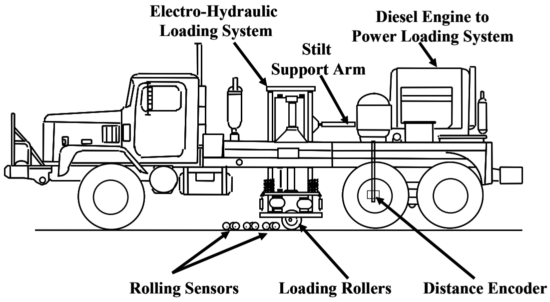

Figure 1. Diagram of the Rolling Dynamic Deflectometer (RDD).

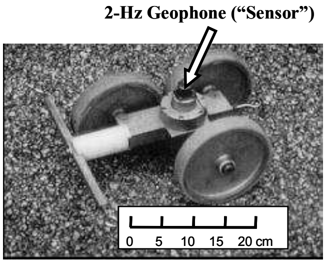

Figure 2. Photograph of a RDD rolling sensor.

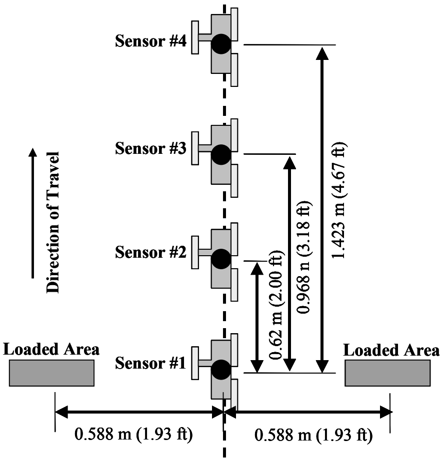

Figure 3. Typical arrangement of the RDD rolling sensor array (plan view).

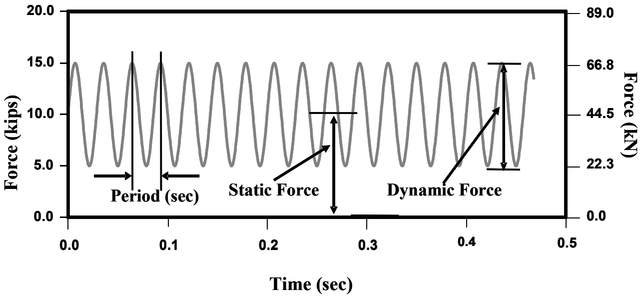

Figure 4. Typical vertical loading applied by the RDD.

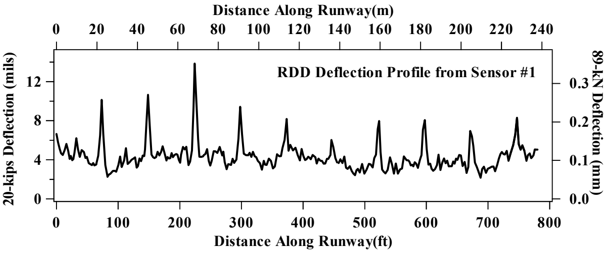

Figure 5. An example of an RDD deflection profile collected on a JRCP section along runway 8R/26L at Hartsfield Atlanta International Airport.

3 EXAMPLE APPLICATIONS

Over the past decade, the RDD has been used to collect continuous profiles along numerous highways in several states and along taxiways and runways at several airports around the United States. A wide range of pavement types have been evaluated which include: (1) rigid pavements (e.g. jointed and continuously reinforced concrete pavements), (2) rehabilitated pavements, such as a rigid pavement with an asphalt concrete (AC) overlay, and (3) flexible pavements. Examples of some of these measurements are presented below.

3.1 *Rigid pavements*

As is well understood, cracks and joints are weak points in a rigid pavement. Therefore, to investigate the pavement condition in a project-level study, it is important to measure movements at cracks and joints as well as mid-slab areas. Deflection basins at mid-slab areas are used to back-calculate layer moduli (Lytton, 1989) . Significant deflections at joints and cracks impact the need for additional remedial work since high-deflection joints or cracks are likely to be the first problem areas in the future. Therefore, the reliability of a pavement condition assessment depends on the number of deflection tests performed. For instance, an 8-km long highway section of jointed concrete pavement (JCP) with a typical joint spacing, (i.e. 4.6 to 6 m) would have over 1300 transverse joints. It is apparent that using stationary deflection testing methods to evaluate every joint in a project-level investigation is time consuming, if not cost prohibitive. On the other hand, the RDD can be used to evaluate the deflection at every transverse joint, transverse crack, and mid-slab area in less time than it takes to evaluate 10% of the pavement by stationary methods. Evaluation of the entire pavement is illustrated in the case study below.

The main runway at Hartsfield Atlanta International Airport was evaluated in Fall 2001 using the RDD (Turner et al., 2003). For simplicity, only a representative portion of one RDD profile collected with sensor #1 is shown. This profile is shown in Fig. 5. The runway was constructed in 1969 using a 406-mm thick jointed reinforced concrete pavement (JRCP) over 152 mm of crushed stone base, 152 mm of a soil-cement mixture and a prepared soil subgrade. The dimensions of the slabs are 23 m long by 7.7 m wide. RDD profiling was performed in the longitudinal direction in the center of the slabs parallel to the longitudinal centerline of the runway. As noted in discussing Fig. 5, the peaks in the profile coincide with the transverse joints in the pavement. Each 23-m long slab can be clearly identified from the profile (i.e. each slab has a mid-slab area and is bounded by two transverse joints). Since the RDD profile is continuous, the transition from a joint to mid-slab area is readily identified. It is well understood that the mid-slab area is represented by the area where the deflection remains fairly constant. Also, deflections increase rapidly when approaching a transverse joint. To clearly distinguish between the joints and mid-slab areas, the RDD deflection profile is marked with “J” and “M” for joint and mid-slab area in Figs. 6a and 6b, respectively. The deflection value around each joint is highlighted in Fig. 6a. High variability in the measured joint deflections is readily seen in Fig. 6a. Therefore, it is crucial to measure the deflection at each joint to account for the variability in pavement response. The deflection values at the mid-slab areas are highlighted in Fig. 6b. Even though there are some minor peaks located within the mid-slab areas, which represent cracks within each concrete slab, the deflections measured in the mid-slab areas are more consistent than the deflections measured at the joints. The mid-slab deflections range between 0.7 and 0.13 mm per 89-kN load. From this continuous profile, poor performing joints can be readily identified as well as candidate locations for further discrete testing.

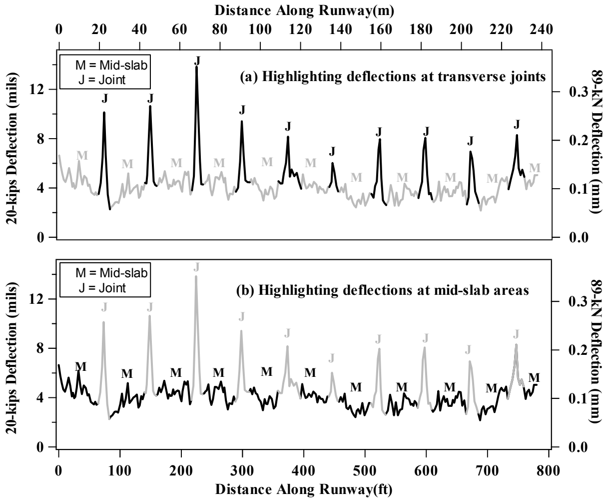

Figure 6. RDD deflection profile collected along runway 8R/26L at Hartsfield Atlanta International Airport, Georgia, USA.

3.2 *Rehabilitated concrete pavements*

Over the life of a concrete pavement, there will be a point in time when some kind of rehabilitation work is needed. Common rehabilitation schemes include: (1) placing an AC overlay, (2) using the break-and-seat technique (i.e. break the existing concrete pavement into small pieces and use the material as the base course), and (3) performing full-depth repairs at selected locations in the existing concrete pavement. Before deciding which rehabilitation scheme or combination of schemes to use, a thorough evaluation of the existing pavement condition is crucial. This point is illustrated in a rehabilitation project that was performed along Interstate Highway (IH) 20 near Marshall, Texas. Before rehabilitation, the pavement was a 10-cm AC overlay on an 18-cm continuously reinforced concrete pavement (CRCP). The rehabilitation project involved milling the existing AC overlay and replacing it with a new 10-cm AC overlay. RDD deflection profiles were collected at different stages during the project. The entire project was roughly 5.6 km long. The deflection profile from sensor #1 for a 100-m section in the wheel-path of the outside lane is shown in Fig. 7. Figures 7a through 7d show the same 100-m long section: (1) after milling the old overlay, (2) shortly after placing the new overlay, (3) 10 months after placing the new overlay, and (4) 23 months after placing the new overlay, respectively.

The after-milling profile (Fig. 7a) is considered here to illustrate identification of a poorly performing area. This area is located near station 1250+90 and exhibited a particularly high measured deflection after milling. Based on the RDD deflection profile, a decision was made to perform a full-depth repair at this location to prevent premature failure. As a result, the deflection at this location was significantly reduced after repairing and placing the new overlay (Fig. 7b). Further, the deflection at this location remain relatively low after 10 and 23 months after placing the new overlay, as shown in Figs. 7c and 7d, respectively. This example illustrates how RDD deflection profiles can assist pavement engineers in choosing the appropriate rehabilitation scheme.

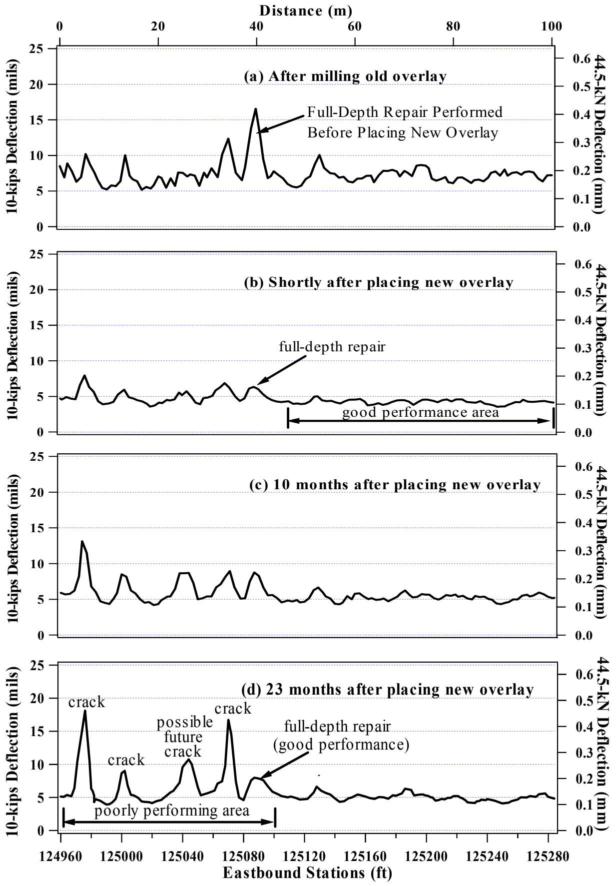

Figure 7. RDD deflection profile measured along Interstate Highway 20 near Marshall, Texas, USA.

3.3 *Monitoring rehabilitated pavements with time*

After rehabilitation work is performed, it is beneficial and educational to monitor the effectiveness of the rehabilitation work. Typically, two methods are used to monitor a pavement with time. These methods are: (1) perform regular visual condition surveys (i.e. visually identify types of pavement distress and classify them according to their severity), and (2) perform nondestructive deflection testing at selected locations and selected times. While most discrete deflection testing is performed at locations where there are no adjacent discontinuities (i.e. testing at an area that is a reasonable distance from any cracks or joints). The writers suggest that these are not the weak locations in a pavement, and if the pavement is to fail years after the rehabilitation, the cracks, joints, and other higher-deflection areas are the most probable places to fail. The continuous nature of the RDD profile allows every transverse crack and joint and all weak zones to be evaluated. Therefore, when used periodically at a rehabilitation project, the rate of deterioration at these weak points (i.e. cracks and joints) is automatically monitored.

Figures 7a through 7d show the deflection profile, collected using sensor #1, at various times after the rehabilitation of IH-20. Increases in the magnitude of the deflections with time indicate the extend of pavement deterioration. Figure 7b shows the deflection profile collected shortly after the new overlay was placed. Within the first 40 m of the test section, there are five peaks found in Fig 7b. The deflections at these locations are less than 0.2 mm. Moreover, there were no transverse cracks visible on the surface shortly after placing the new overlay. With time, as shown in Figs. 7c and 7d, four of these locations have significantly increasing deflections. In contrast, the deflection at the location where the full-depth repair was performed remained relatively low. This point is interesting because it shows the value of the full-depth repair. It is believed that if this location had not been chosen for repair at the beginning, a transverse crack would be found at this location. However, no transverse crack was found. Obviously it would have been beneficial to perform repairs at several of the cracks between Stations 1249+60 and 1250+80.

3.4 *Flexible pavements*

A pilot study was carried out at College Station, Texas, on a Rolling Wheel Deflectometer (RWD) during July 2003 (Steele and Hall, 2003). The RWD is a continuous deflection measuring device which is fundamentally different from the RDD. Some of the differences are: (1) the RWD is a network-level device while the RDD is a project-level device (i.e. RDD measurements have better spatial resolution while the RWD moves at highway speeds), (2) the RWD uses measurements from multiple laser sensors to calculate a single deflection point while each RDD rolling sensor measures deflections at the sensor location, and (3) the RWD measures the deflection induced by the dead-load of the RWD trailer while the RDD measures deflections induced by the single-frequency sinusoidal force. By measuring the deflections at a single, known frequency, RDD measurements are very robust in a noisy environment.

The primary goal of the pilot study was to compare deflection measurements between different deflection-based nondestructive testing devices. Therefore, the FWD and RDD were included. A total of 33 flexible test sections was tested. The deflections measured at one, 152-m section are presented in Fig. 8. The section has 7.6 cm of AC over 15.2 cm of granular base. The RDD profile collected with sensor #1 is shown in Fig. 8. For simplicity, the deflections from only FWD sensor #0 (i.e. located at the center of the load plate) are shown in the figure. In this pilot study, FWD tests were performed every 15 m, an unusually close spacing even in project-level studies. On the other hand, the RWD (moving at 88 km/hr) gives only one average point every 30 m. The average RWD deflection over the 152-m section is shown in Fig. 8. As shown in Fig. 8, deflections measured by the RDD and FWD are very similar. On the other hand, the RWD overestimated the deflection for some unknown reason at this particular test section.

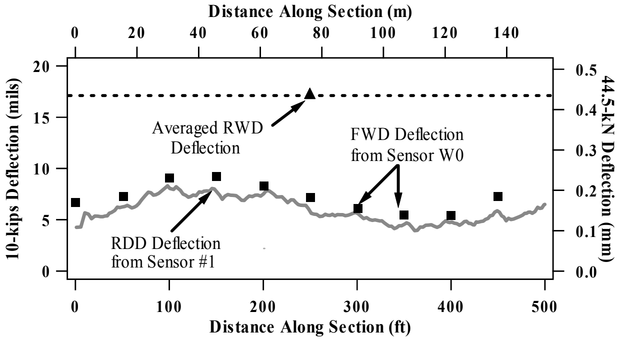

Figure 8. RDD, FWD and RWD deflection profile measured at a flexible pavement near College Station, Texas.

4 SUMMARY AND CONCLUSIONS

The RDD is a project-level nondestructive deflection testing device that is capable of measuring continuous deflection profiles along both highway and airport pavements. The device moves at approximately 1.6 km/hr and measures a robust deflection profile. Over the past decade, the RDD has been used on many different types of pavements. Example deflection profiles measured on different pavements are illustrated using case studies.

RDD continuous profiles are shown to be a very powerful tool for identifying changes in pavement stiffness. Application of this technique to evaluate the deflection at all transverse cracks and joints along a rigid pavement is useful to a pavement engineer for purposes of identifying locations for repairs prior to rehabilitation, monitoring rates of deterioration…etc. The vast amount of information collected by the RDD cannot be matched by other conventional discrete-type NDT devices, because of the time and costs to perform so many tests.

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