Development and Preliminary Investigation of Rolling Dynamic Deflectometer

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Nondestructive testing (NDT) is an important part of optimizing any pavement management system. At this time in the United States NDT is performed at discrete points on the pavement to evaluate the properties of the pavement layers. Techniques such as the falling weight deflectometer (FWD), Dynaflect, and spectral-analysis-of-surface-waves are used. A new technique is described. It is called the rolling dynamic deflectometer (RDD) and is a large truck on which a servo-hydraulic vibrator is mounted. The vibrator is used to apply large vertical dynamic loads [up to a total load of 147 kN (33,000 lb)] to rolling wheels that come into contact with the pavement. A receiver wheel located midway between the loading wheels is used to monitor the dynamic deflections. The truck is driven at a slow speed [about 5 km/hr (3 mph)], and continuous profiles of pavement flexibility are measured under heavy traffic conditions. Descriptions of the equipment, calibration results, and test procedures are presented. Several examples involving tests of flexible pavements and comparisons with FWD results are included. The results show that the RDD can be used to (a) determine uniformity along pavement sections, (b) measure differences in average flexibility between different sections, and (c) observe nonlinearities in a given pavement section.

Nondestructive testing (NDT) techniques have been used for several decades in the field to determine the properties of pavement systems. The most common techniques used in the United States are the falling weight deflectometer (FWD), the Dynaflect, and the spectral-analysis-of-surface-waves techniques (*1–5*). Each of the methods requires the equipment to be stationary during testing. Therefore, it is difficult or impossible to obtain continuous or nearly continuous profiles either longitudinally or laterally along the pavement. To overcome this limitation of sampling at discrete points a rolling dynamic deflectometer (RDD) has been developed. With the RDD rapid measurement of continuous profiles of pavement flexibility or stiffness under heavy traffic and overload conditions can be performed. This device can move down the pavement at speeds of 3 to 6 km/hr (2 to 4 mph) and can continuously record pavement deflection under significant static and large dynamic loads. This deflectometer represents a one-of-a-kind piece of equipment. In the following paragraphs a description of the device is given, calibrations of the loading and monitoring systems are presented, and examples of test data are provided. Several field studies with flexible pavements, including comparison with results obtained with the FWD, are also presented.

DESCRIPTION OF RDD

The RDD is shown in Figure 1. This device consists of a large truck with a gross weight of about 195 kN (44,000 lb) on which a servo-hydraulic vibrator is mounted. The vibrator has a 33-kN (7,500-lb) reaction mass that is used to generate vertical dynamic forces as large as 310 kN (70,000 lb) over a frequency range of about 5 to 100 Hz. When the reaction mass is driven by the hydraulic system as illustrated in Figure 2, the resulting vertical dynamic force is applied to two sets of loading wheels that contact the pavement. Simultaneously, the hydraulic system can be used to apply a constant hold-down force to the loading wheels ranging from 65 to 180 kN (15,000 to 40,000 lb) through a system of air springs. This system is under modification so that hold-down forces ranging from 13 to 180 kN (3,000 to 40,000 lb) can be applied.

The static and superimposed dynamic forces are transferred to the pavement through two sets of dual loading wheels as shown in Figure 2. The use of wheels to transfer the load permits continuous loading to be applied while the complete system is moving. The wheels are quite rigid in that they have a solid aluminum rim that is coated with hard urethane. This type of wheel was selected to minimize the resonances that might occur with pneumatic wheels loaded in this manner. Each wheel is 457 mm (18 in.) in diameter and 127 mm (5 in.) wide. A total force (static plus dynamic) of 150 kN (33,000 lb) can be applied to the pavement surface through the loading wheels at this time. However, the wheels could be modified to allow a peak-to-peak force as large as 310 kN (70,000 lb) to be applied if it ever became desirable. The reaction mass and servohydraulic system are already capable of generating this force level. This point is rather important, because it highlights the fact that the gross weight of the truck does not control the force output. Rather, the driving force is coming from the inertial force created by the reaction mass moving at high frequencies.

The servohydraulic vibrator is capable of generating many types of dynamic loading functions. For instance, transient (like the FWD), steady-state (at any frequency from 5 to 100 Hz), swept-frequency, chirps, or random-noise types of loads can be generated. In the initial study steady-state excitation superimposed on a constant static load was used, as illustrated in Figure 3. Dynamic deflections of the pavement surface (due only to the peak-to-peak dynamic loading) are then recorded midway between the two sets of loading wheels. These deflections are recorded with an accelerometer located on a set of two receiver wheels as shown in Figure 2. Two wheels were used to support the receiver (accelerometer) simply for stability during movement. Wheels were again used in this part of the rolling device as an inexpensive way of accomplishing continuous measurements. Wheels similar to the loading wheels, but slightly smaller [30 mm (12 in.) in diameter and 76 mm (3 in.) wide], were used. The twin receiver wheels, hereafter termed *receiver wheel* for convenience, are isolated from the loading mechanism and truck by the support arm shown in Figure 1.

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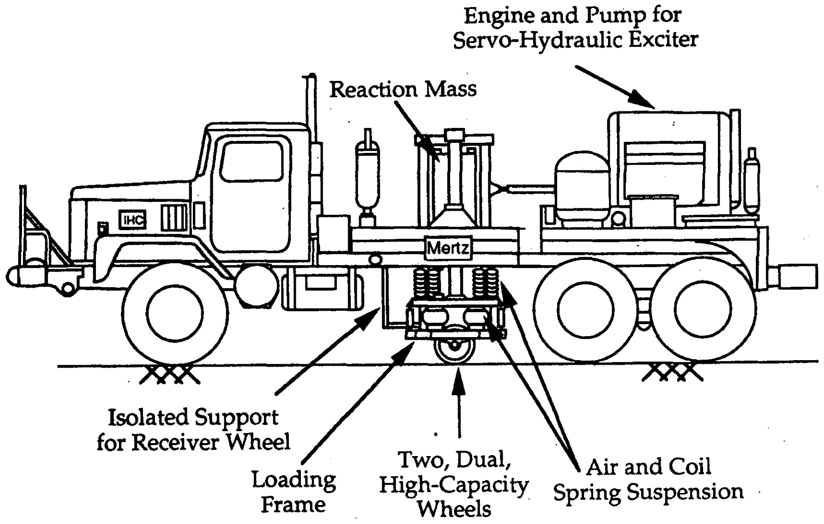


FIGURE 1 Basic components of RDD used to measure continuous pavement flexibility profiles.

The basic idea is to drive the truck at a slow speed along the pavement while applying dynamic loading and simultaneously measuring the resulting dynamic deflections. The accelerometer on the receiver wheel monitors only the dynamic motion; it does not monitor any motion resulting from the static load. In the initial studies measurements have been performed at about 5 km/hr (~3 mph), loading frequencies ranging from 20 to 40 Hz have been used, and only one measurement point (midway between the loading wheels) has been used. There is no reason, however, why multiple measurement points at various distances from the loading wheels could not be monitored.

EQUIPMENT CALIBRATION

To conduct stiffness or flexibility measurements while rolling, it is critical to perform dynamic calibrations of the equipment used to measure both forces and displacements. Any equipment resonances that fall within the range of excited frequencies will affect the dynamic response of the measurement systems and must be accounted for in the analysis of the recorded data. A set of weigh-in-motion (WIM) load cells were used to calibrate the static and dynamic loads applied in RDD testing (*6*). A velocity transducer (geophone) was

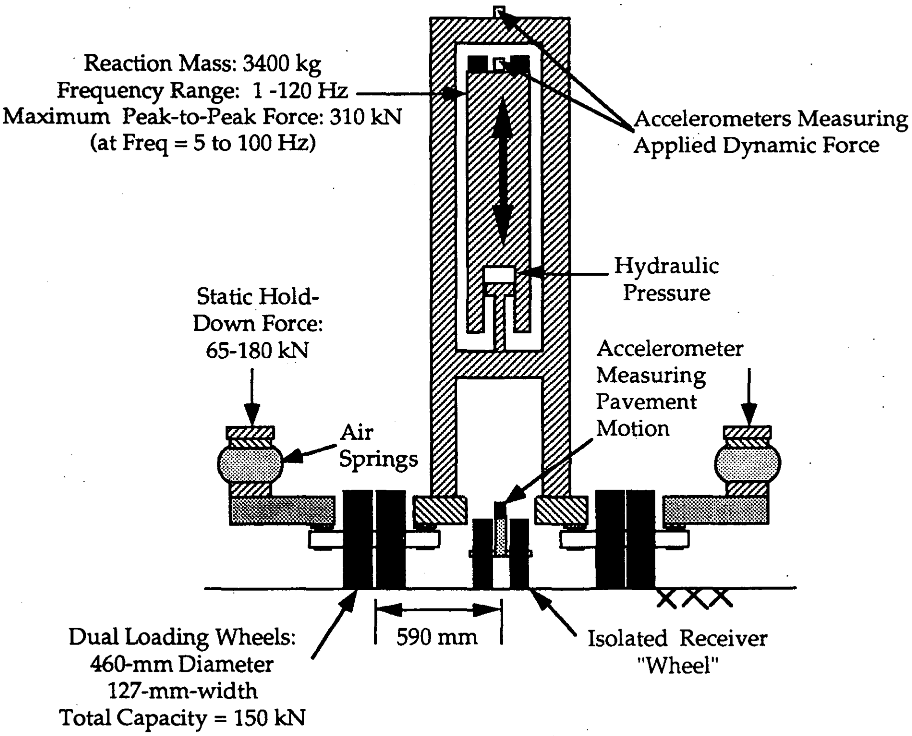


FIGURE 2 Front cross-sectional view of dynamic loading and monitoring systems of RDD.

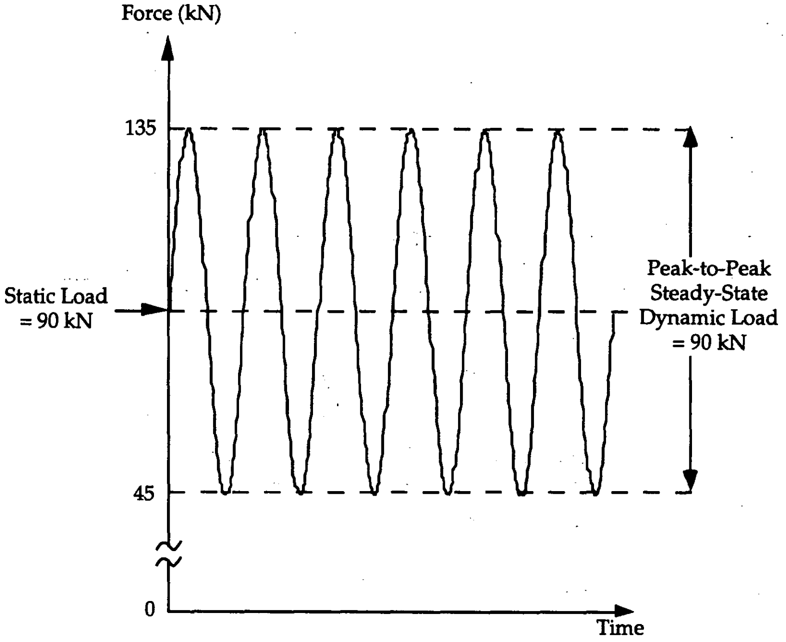


FIGURE 3 **Example of combined static and steady-state dynamic loads applied continuously by RDD.**

used to calibrate the receiver wheel, and an accelerometer was used to measure the dynamic displacements.

Static Force Calibration

The simplest calibration was the calibration of static load applied to the loading wheels. The static load is a combination of the dead weight of the reaction-mass-load-frame system and the force applied through the hydraulic cylinders. The static force was calibrated by comparing the pressure in the hydraulic cylinders with the force measured with the WIM load cells. This calibration curve is shown in Figure 4(*a*). With no hydraulic pressure in the cylinders a force of 55 kN (12,300 lb) was measured. This represents the dead weight of the reaction-mass-load-frame system. The pressure control valve used on the RDD system applies a minimum of 1380 kPa (200 lb/in.^{2}), and a lifting force cannot be applied with the hydraulic system while driving the reaction mass. Therefore, the lowest static force that can be applied at present is about 67 kN (15,000 lb). Future modifications will make it possible to apply much lower static loads.

Dynamic Force Calibration

The dynamic force applied by exciting the reaction mass is measured by two accelerometers, one on the reaction mass and a second on the loading frame, as shown in Figure 2. From Newton's second law it can be determined that the dynamic force applied to the pavement through the loading wheels, F_d, is equal to the sum of the accelerations of these two parts times their masses as

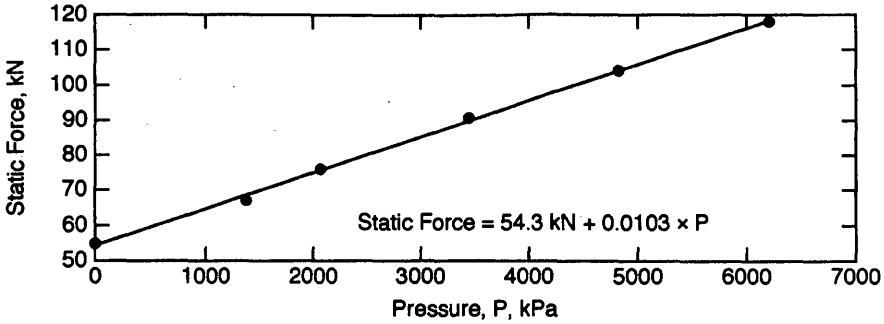
$$F_d = A_1 \times M_1 + A_2 \times M_2 \tag{1}$$

where A_1 and M_1 are the acceleration and mass of the reaction mass, respectively, and A_2 and M_2 are the acceleration and mass of the combination of the loading frame and the wheels, respectively. To measure the dynamic force the signals from each accelerometer were amplified with a gain proportional to the mass of the respective system, one signal was inverted, and the two signals were summed with a differential amplifier. To generate a calibration curve the combined outputs of the two accelerometers were divided by the dynamic force measured with the load cells, because the RDD was driven at various frequencies. This calibration curve is shown in Figure 4(*b*). The calibration curve is quite uniform up to 47 Hz. Above 47 Hz the performance of the system could not be evaluated because of resonances in the load cells. Further work is required to calibrate the RDD at higher frequencies. However, the frequency range shown in Figure 4(*b*) was satisfactory to perform the initial studies described here.

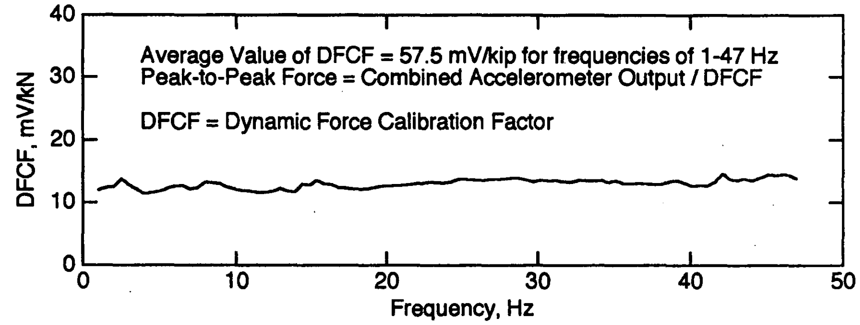
Receiver Wheel Calibration

Dynamic displacements created by the RDD are measured on the pavement surface with an accelerometer mounted on the axle of the two rigid receiver wheels shown in Figure 2. This system acts like a single-degree-of-freedom damped spring-mass system, with the urethane coating on the wheels acting as the damped spring. Therefore, it is expected that the response of this system will vary with frequency and will have a single resonant peak. To measure this response a velocity transducer with a known calibration was secured to the pavement surface between the receiver wheels, and the pavement was driven at a series of frequencies with the RDD while it was stationary. The outputs of the geophone and accelerometer were both measured. In the frequency domain, the output of the geophone was converted from velocity to acceleration in g's by the following equation:

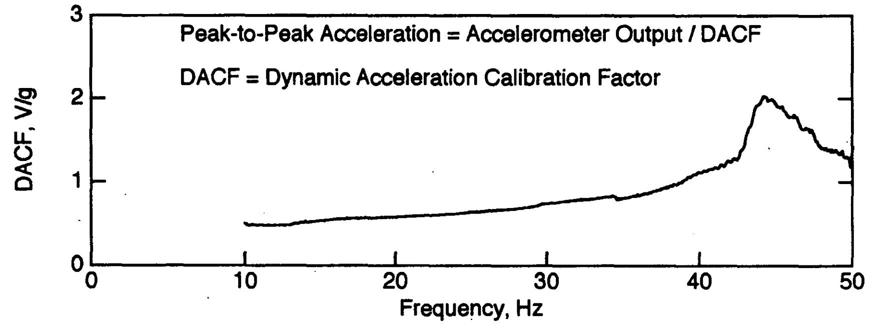
$$\text{acceleration} = \frac{\text{geophone output} \times \text{calibration factor} \times i2\pi f}{9.81\ \text{m/sec}^2/\text{g}} \tag{2}$$



a) Calibration of Applied Static Force



b) Variation of Dynamic Force Calibration Factor, DFCF with Loading Frequency for the Applied Dynamic Load



c) Variation of Dynamic Acceleration Calibration Factor, DACF with Loading Frequency for the Receiver Wheels

FIGURE 4 **Calibration factors associated with load and displacement measurements using RDD.**

This result was divided by the output of the accelerometer to determine the calibration curve. This resulting curve is shown in Figure 4(*c*). Below 10 Hz the accelerometer output becomes unstable. However, over the range of frequencies of interest in most pavement testing, the receiver wheel is quite well behaved and acts as a single-degree-of-freedom system with a resonance around 44 Hz. The calibration curve shown in Figure 4(*c*) was applied to all displacement measurements in the frequency domain.

TESTING AND ANALYSIS PROCEDURES

Testing Procedure

The RDD is designed to move along a pavement at velocities of 3 to 6 km/hr (2 to 4 mph) while generating large dynamic loads with the servohydraulic system and applying them to the pavement through the loading wheels. The pavement motions are measured at the isolated receiver wheel, which rolls along the pavement at the midpoint between the loading wheels. Currently, the position of the RDD along the testing axis is determined by knowing the velocity of the truck and the elapsed time. This is only suitable for continuous profiling over short sections of pavement (less than about 30 m). Very long sections of pavement could be profiled continuously by incorporating a distance measuring device, which is contemplated for future adaptations.

In the present configuration the operator must control four parameters when profiling with the RDD. The first parameter is the velocity of the truck. Currently, this is very important because it is used to determine the testing location with time. However, the vehicle velocity also controls the magnitude of the noise generated by the loading and receiver wheels rolling on the rough pavement surface. Initial experience indicates that velocities of 5 km/hr (3 mph) or less provide adequate signal-to-noise ratios for the reasonably heavy loads and the close measurement point used. The second parameter is the static force, F_s, applied to the loading wheels. As discussed previously the static force cannot be set at less than 65 kN (15 kips) until further modifications to the hydraulic system are completed. With the modifications the static force can be varied from 13 to 180 kN (3,000 to 40,000 lb). Considerations in selecting a static force involve the third parameter, the dynamic force, F_d. This force is controlled by regulating the flow of hydraulic fluid through the servovalve. The possible range of dynamic force is 9 to 310 kN (2,000 to 70,000 lb) peak to peak.

Three criteria must be met in selecting the static and dynamic forces. First, one must satisfy

$$F_s - \frac{F_d}{2} > 4.5\ \text{kN} \tag{3}$$

This criterion ensures that the loading wheels will be in constant contact with the pavement. The second criterion is

$$F_s + \frac{F_d}{2} \leq 150\ \text{kN} \tag{4}$$

which ensures that the capacity of the loading wheels will not be exceeded. The third criterion is

$$F_s + \frac{F_d}{2} < \text{pavement capacity} \tag{5}$$

This criterion ensures that the pavement will not fail under testing. Unfortunately, the authors have not always been successful with this criterion in their initial tests. One reason is that higher dynamic forces provide larger pavement motions that result in higher signal-to-noise ratios. The desire to create very large signals resulted in overloading one flexible pavement.

The last parameter that the operator must select is the operating frequency of the RDD. The RDD is capable of operating at frequencies of from 5 to 100 Hz. The choice of an operating frequency is not a simple one. Considerations in selecting an operating frequency include site resonances due to shallow bedrock, frequency dependencies in the pavement materials, desired depth of sampling, and the frequency content of rolling and vehicle noises. Site resonances and frequency dependencies can be identified by exciting the RDD with broadband excitation (transients, swept-sines, or chirps) while it is stationary and measuring the response spectra. Up to this point frequencies around the predominant frequency of 30 Hz often found in FWD measurements have been used.

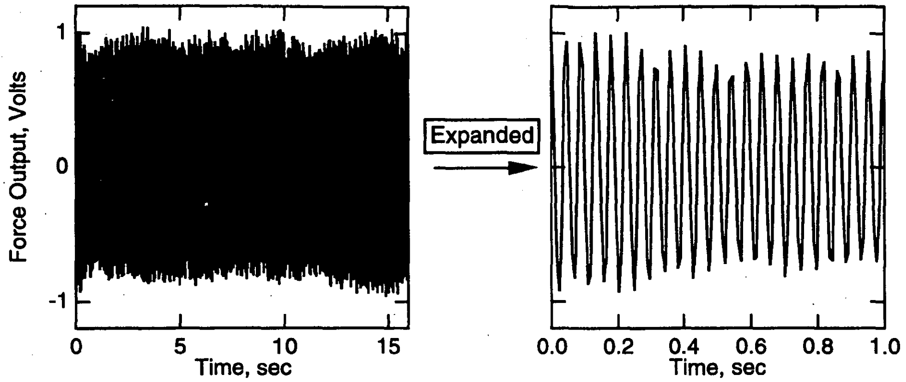
Analysis Procedure

The procedure used to analyze RDD data is illustrated by stepping through the procedure for a typical measurement. The example measurement is from tests at the Texas Transportation Institute (TTI) testing facility at Texas A&M University. The pavement used in this example is designated Section 10. Details about this flexible pavement and the other ones tested at TTI are provided in Table 1 and in a report by Scrivner and Michalak (*7*).

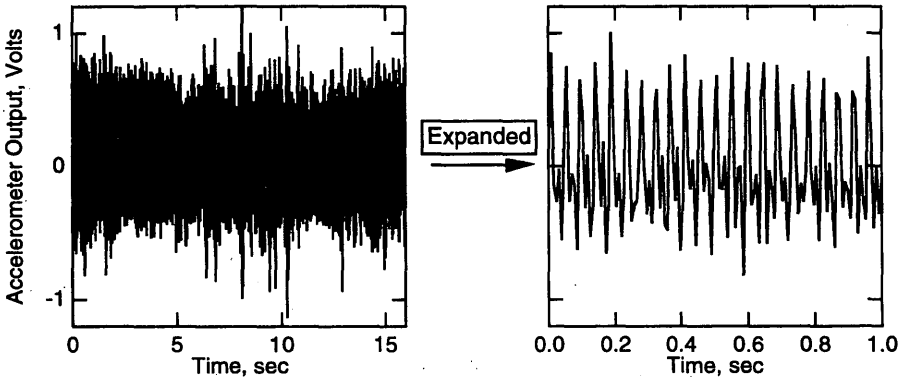
Figure 5 contains time records of force and acceleration that were measured while rolling across Section 10 and operating the RDD at

TABLE 1 Layer Thicknesses and Materials of the Flexible Pavements at TTI Facility Tested with RDD

Section Number	Layer Thickness			Material Type		
	Surface	Base	Subbase	Base	Subbase	Subgrade
9	127 mm (5 in.)	102 mm (4 in.)	102 mm (4 in.)	Crushed Limestone	Crushed Limestone	Sandy Gravel
10	25 mm (1 in.)	305 mm (12 in.)	102 mm (4 in.)	Crushed Limestone	Crushed Limestone	Sandy Gravel
11	25 mm (1 in.)	102 mm (4 in.)	305 mm (12 in.)	Crushed Limestone	Crushed Limestone	Sandy Gravel
12	127 mm (5 in.)	305 mm (12 in.)	305 mm (12 in.)	Crushed Limestone	Crushed Limestone	Sandy Gravel
14	25 mm (1 in.)	305 mm (12 in.)	102 mm (4 in.)	Crushed Limestone with 4% Cement	Crushed Limestone with 4% Cement	Sandy Gravel
15	25 mm (1 in.)	102 mm (4 in.)	305 mm (12 in.)	Crushed Limestone with 4% Cement	Crushed Limestone with 4% Cement	Sandy Gravel
16	127 mm (5 in.)	305 mm (12 in.)	305 mm (12 in.)	Crushed Limestone with 4% Cement	Crushed Limestone with 4% Cement	Sandy Gravel
29	76 mm (3 in.)	203 mm (8 in.)	203 mm (8 in.)	Crushed Limestone with 2% Lime	Crushed Limestone with 2% Lime	Sandy Gravel



a) Dynamic Force Applied to Pavement Surface



b) Motion of Pavement Surface Measured with Receiver Wheels

FIGURE 5 Typical time records from RDD operating at 22 Hz and traveling 7 m along flexible pavement Section 10 at TTI test facility.

22 Hz. The complete time record for a 7-m-long, continuous profile is shown along with one for an expanded portion. The force output is quite monochromatic, with little harmonic distortion or rolling noise. The accelerometer output exhibits significant amounts of harmonic distortion and rolling noise. However, the effects of this distortion and noise are greatly reduced in the process of converting the acceleration measurement to a displacement measurement, as will be discussed.

To analyze the data it is necessary to isolate the components of force and displacement at the operating frequency (22 Hz). This can be done in several ways. One method would have been to filter the signals through a notch-pass analog filter. Another method would be to use digital filters. Each of these methods has limitations. The method that was finally used was spectral analysis with the Fast Fourier Transform (FFT). By using the FFT the data were separated into the frequency components, and measurements were made not only at the operating frequency but also at frequencies around the operating frequency. Measurements at these additional frequencies permitted quantification of the noise level and allowed evaluation of measurement quality.

The spectral analysis procedure applied to the excitation force is illustrated in Figure 6. The force output shown in Figure 6(*a*) is that for the same record given in Figure 5. The time record is divided into a number of sections. Each section is determined by multiplying the time record by the weighting function shown in Figure 6(*b*). This function is a Hanning window, which is commonly used in spectral analysis. The effect of using the Hanning window (weighting function) is to average the measurement over a region in which more weight is applied to the center of that region. By using the window shown and the velocity at which the RDD was moving, the data were effectively averaged over about a 0.6-m (2-ft) interval. Successive measurements are analyzed by using overlapping weighting functions so that all data are used equally. The weighted force output for one section is shown in Figure 6(*c*). An FFT is performed on this time record, transforming it into the frequency domain. The magnitude of the resulting frequency function is shown in Figure 6(*d*). At this point the dynamic force calibration factor (DFCF) shown in Figure 4(*b*) is applied to the data to convert from units of voltage to units of peak-to-peak force. This conversion is shown in Figure 6(*e*), and a peak-to-peak loading force of 69.0 kN (15,500 lb) is measured at 22 Hz. Only noise at frequencies close to the measurement frequency could adversely affect the force-level measurements. To analyze this noise level the same spectrum shown in Figure 6(*e*) is plotted in Figure 6(*f*) by using a vertical logarithmic scale. The average noise level measured at frequencies of ±5 Hz from the operating frequency were considered. The average noise level in this frequency range (17 to 27 Hz) was found to be 0.36 kN (80 lb). Therefore, the actual driven force would be 69.0 ± 0.36 kN (15,500 ± 80 lb).

The same procedure is shown in Figure 7 for the displacement measurement. The procedure is identical except when converting from units of volts in the frequency domain to units of displacement

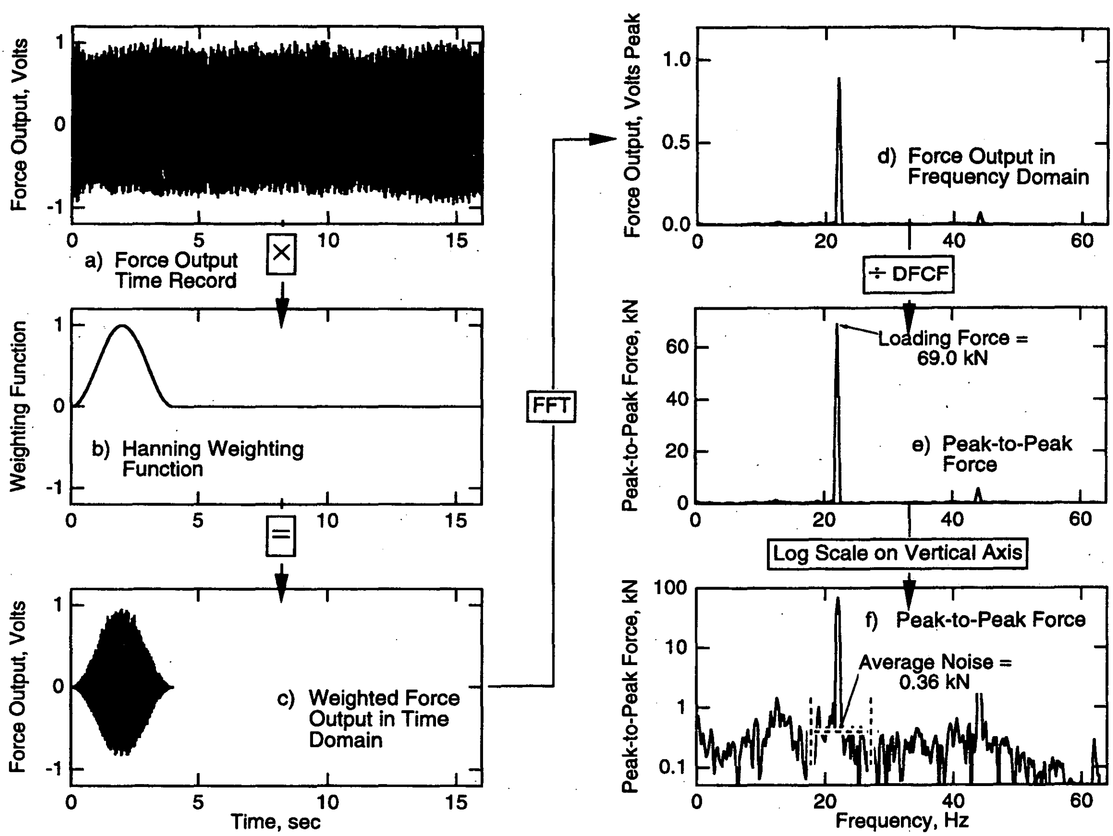


FIGURE 6 Sample calculation of dynamic force applied when RDD was operating at 22 Hz.

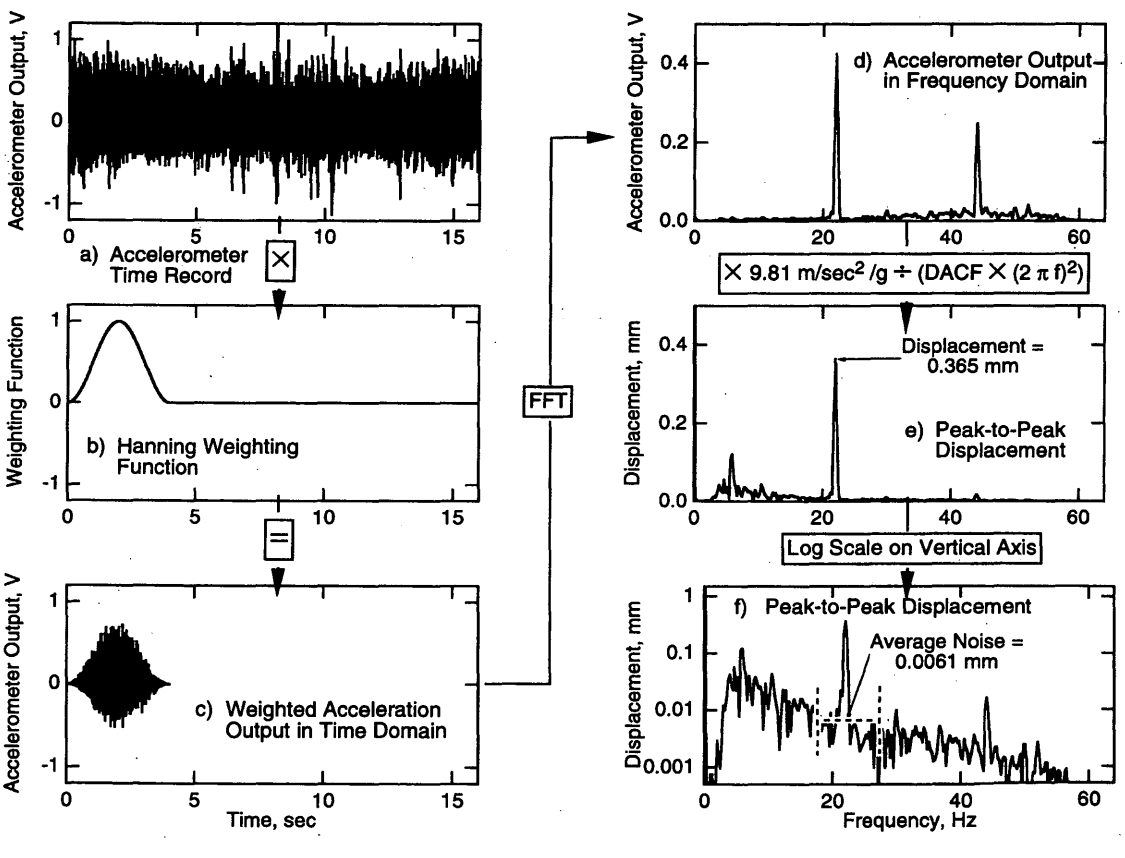


FIGURE 7 Sample calculation of dynamic displacement measured with receiver wheel when RDD was operating at 22 Hz.

in meters. In this case the displacement was found to be 0.365 mm (0.0144 in.), with an average noise level of 0.0061 mm (0.00024 in.) The rolling noise has much more of an effect on the displacement measurement than on the force measurement. However, both measurements are high-quality measurements, as shown by signal-to-noise ratios in excess of 50.

To quantify a property of the pavement system, the flexibility is calculated next. Flexibility is the inverse of stiffness. Therefore, higher flexibility indicates a softer pavement system and lower flexibility indicates a stiffer system. Flexibility is defined as follows:

$$\text{flexibility} = \frac{\text{dynamic displacement}}{\text{dynamic force}} \qquad (6)$$

By using 25 successive Hanning weighting functions with the records in Figure 5, successive values of force, displacement, flexibility, and average noise levels were calculated for the time records measured at Section 10. These values are plotted in Figure 8. The flexibility profile shown at the bottom of Figure 8 reveals that the section is quite uniform longitudinally.

RDD RESULTS AT TTI FLEXIBLE TEST SECTIONS

A series of tests was performed with the RDD at the TTI pavement test facility. At that facility a number of flexible pavement sections have been constructed with different materials and thicknesses of pavement, base, and subgrade. RDD profiling was performed at eight of these test sections. Table 1 contains the materials and layer thicknesses of the sections where the tests were performed. The objectives of the testing were (a) to determine uniformity along the longitudinal centerline of each section, (b) to observe differences in average flexibility between the different sections, and (c) to observe nonlinearities in the pavement sections. FWD tests were also performed concurrently at some of the pavement sections to compare those results with the results of the RDD test. Most RDD tests were performed at an operating frequency of 22 Hz. However, a few tests were performed at 40 Hz to observe the effect of frequency. All testing was performed with a static force of 67 kN (15,000 lb).

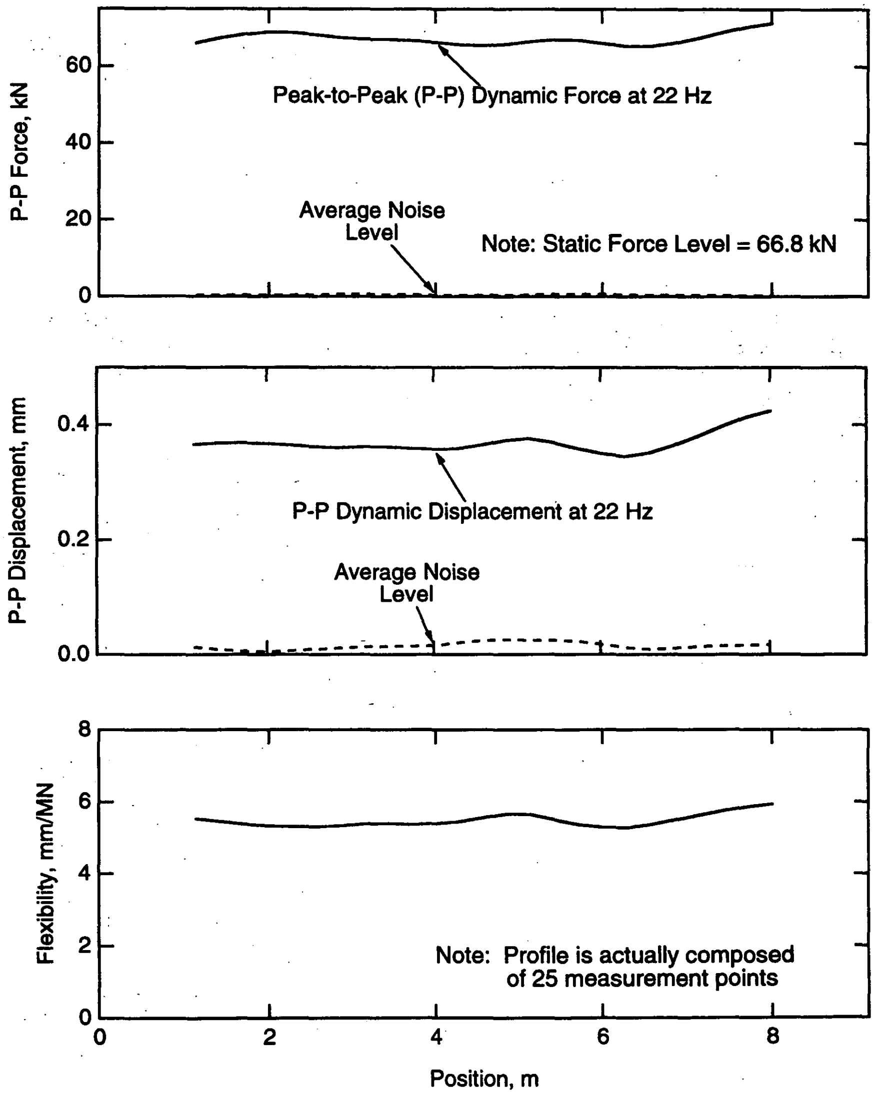


FIGURE 8 Continuous profiles of flexible pavement Section 10 at TTI test facility determined with RDD operating at 22 Hz with high dynamic force level.

Variability Within Pavement Sections

One of the major benefits of the RDD is that continuous measurements of pavement flexibility can be performed. This makes the RDD especially well suited for studying the variability (longitudinally or laterally) of pavement systems. This benefit is demonstrated by the continuous profile of Section 10 shown in Figure 8. Another approach that can be used to observe longitudinal variability is to normalize the flexibility measured continuously by dividing by the average flexibility determined over the entire section at one load. This was done for Sections 9, 10, and 16 at the TTI test facility. These normalized profiles are shown in Figure 9. Sections 9 and 10 are quite uniform, with less than 5 percent variation along the longitudinal axis. On the other hand, Section 16 exhibits a high degree of variation in the longitudinal direction, with more than a 60 percent variation in the 6-m-long section.

FWD measurements were also performed on Sections 9, 10, and 16 at the locations noted in Figure 9. These test locations were selected before the RDD profiles were determined. The FWD results from Sections 9 and 10 should properly characterize the whole section as shown by the continuous profiles. However, the average stiffness of Section 16 would be grossly overestimated by using only the FWD results at the location tested, because that location is not representative of the entire section. This result demonstrates the powerful tool that RDD testing represents in determining bounds in pavement characterization and the limitations of using discrete tests. Comparisons of RDD and FWD results are presented in a later section.

Comparison Between Flexibility Profiles of Different Pavement Sections

RDD profiling was performed at two different dynamic force levels on eight different pavement sections. Testing was nominally performed at peak-to-peak force levels of 33.5 and 67 kN (7,500 and 15,000 lb). However, in practice higher and lower force levels were generated at some pavements because of the lack of experience with the equipment. To compare the flexibilities of the pavements at one force level, interpolation was used to determine a flexibility representative of a dynamic force level of 67 kN (15,000 lb). These results, along with a graphical representation of the pavement layers, are shown in Figure 10. These results are very consistent, with thicker and stiffer pavement materials yielding lower flexibilities

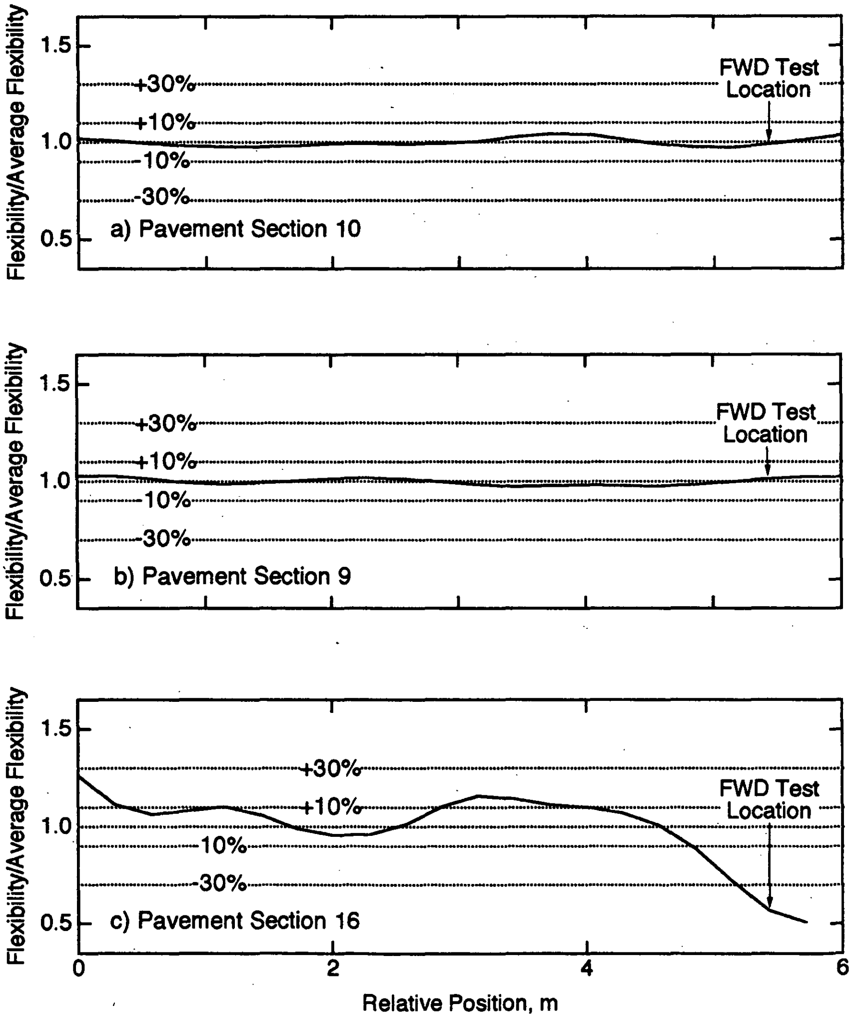


FIGURE 9 Continuous profiles of normalized flexibility for three flexible pavement sections at TTI test facility measured with high dynamic force level with RDD operating at 22 Hz.

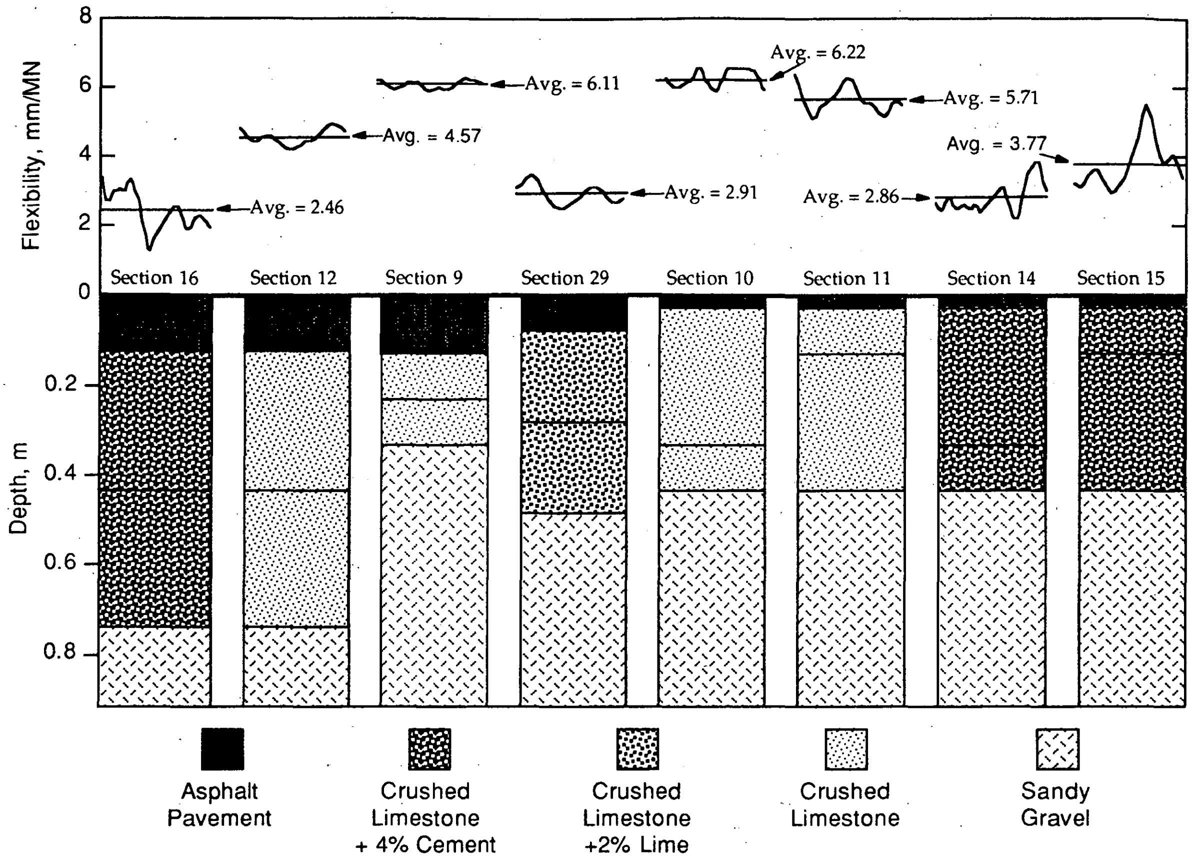


FIGURE 10 Flexibility and pavement profiles of eight flexible pavement sections at TTI test facility determined with RDD operating at 22 Hz and 67 kN (15,000 lb).

and with the flexibilities of similarly constructed sections being similar. Plotting at the horizontal scale shown accentuates the longitudinal variations in these sections.

Effect of Dynamic Force Level

Another benefit of the RDD is that testing can be performed with heavy loads. Profiles of dynamic force level and flexibility are shown in Figure 11 for three pavement sections at TTI. Tests were performed at two different dynamic force levels at each pavement section, with the upper level being near or above nominal allowable loads. These profiles show some nonlinear effect, with higher force levels yielding higher flexibilities. This effect is especially pronounced in Section 9. However, the high force level at this section was inadvertently applied at a much higher dynamic force level than was applied at the other sections. This level probably caused the excessive nonlinearity. The results demonstrate the capability of investigating nonlinear pavement response with the RDD.

Comparison Between RDD and FWD Results

FWD tests were performed at three load levels at several of the TTI test sections within 1 hr of RDD testing. The distance from the center of the receiver wheel to the center of the loading wheels is nearly 0.6 m (2 ft) in the RDD. Therefore, comparisons were made between deflections measured with the RDD and deflections measured with the FWD at Measurement Station 3 at a distance of 0.6 m (2 ft) from the center of the loaded area. Comparisons of FWD and RDD flexibilities for a range of dynamic loads are shown in Figure 12. In addition to the RDD tests discussed previously, stationary tests using broadband excitation with very low loads [about 1.3 kN (300 lb) of dynamic force] were also performed. These results are plotted along with the RDD results in Figure 12. The flexibility measured with the FWD is consistently lower than the flexibility measured with the RDD operating at 22 Hz. However, both tests show the same basic nonlinearity with dynamic load level. A few RDD tests were performed at an operating frequency of 40 Hz. These results are also plotted in Figure 12. A substantial difference between the results of the 22- and 40-Hz tests was found, indicating a significant effect of frequency on the measurements. The FWD applies a broadband, transient loading function, with the frequency content depending on the mass being dropped and the properties of the pavement. With the RDD a single monochromatic frequency is being applied. In view of the effect of frequency observed in 22- and 40-Hz tests, it should not be expected that the RDD and FWD would give the same results.

Further work needs to be done to understand the relationship between the results of FWD and those of RDD. The frequency content of the FWD must be characterized for the pavement being tested, and the effects of steady-state RDD loading on the pavement response must be determined. However, the consistency between FWD and RDD results in this preliminary study suggests that this research is very promising.

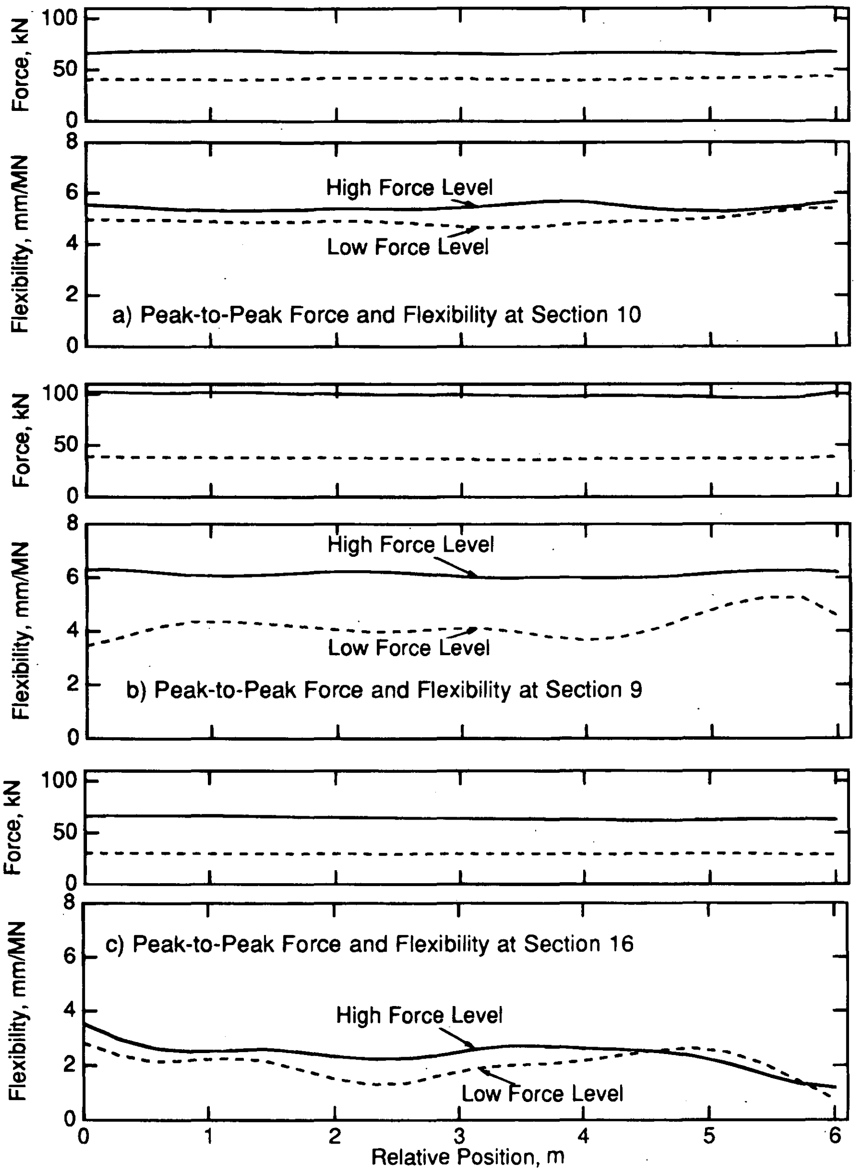


FIGURE 11 Continuous profiles of force level and flexibility for three flexible pavement sections at TTI test facility measured at two dynamic force levels with RDD operating at 22 Hz.

SUMMARY

An RDD has been developed. With the RDD continuous profiles of pavement flexibility or stiffness can be measured under heavy loads. The RDD uses a servohydraulic vibrator to apply static hold-down and vertical dynamic forces to two sets of dual loading wheels. A total force (static plus dynamic) of 147 kN (33,000 lb) can be applied to the pavement surface while the RDD is moving at velocities of 3 to 6 km/hr (2 to 4 mph). Dynamic deflections of the surface are continuously recorded with an accelerometer located on a set of receiver wheels positioned midway between the loading wheels.

The loading and monitoring systems of the RDD have been calibrated, and initial testing has been performed at the TTI pavement test facility. Eight flexible pavement sections covering a range of flexibilities have been successfully tested. Loading frequencies of 22 and 40 Hz have been used with a wide range in dynamic loads. With the RDD measurements were made of longitudinal variability within each section, differences in flexibility between sections, and nonlinearities in flexibility at several sections. Finally, a comparison of the measurements obtained by the RDD and FWD show that the flexibilities measured by both methods are consistent and closely related.

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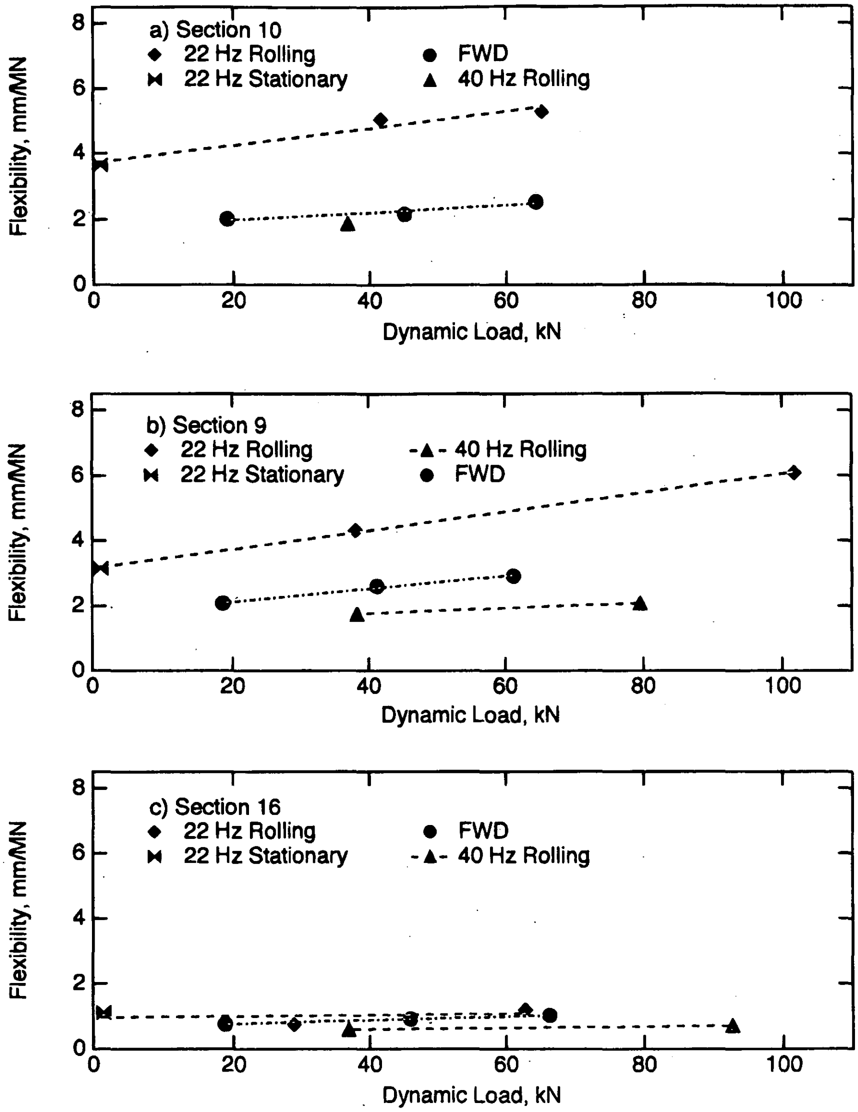

FIGURE 12 Comparison of flexibilities determined at several dynamic force levels using FWD and RDD operating at two different frequencies on three flexible pavement sections at TTI test facility.

calibrate the RDD. The authors thank the U.S. Air Force Office of Scientific Research for support in purchasing the large truck and servohydraulic vibrator. John Bedenbender and Heavy Quip Corp. provided valuable advice on the design of the RDD. The authors appreciate the efforts of those who helped to construct the RDD, James Stewart, Larry Larson, and Bernard Tippie. Homer Ward and Laurence Stienbach of the University of Texas Department of Utilities and Energy Management made construction of the RDD possible on the limited budget by providing the authors with the services of their skilled employees. Their assistance is sincerely appreciated.

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