TECHBRIEF

# Advanced Methods for Using FWD Deflection-Time Data to Predict Pavement Performance

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## Introduction

An important property of materials that defines the viscoelastic and inelastic characteristics of materials is the dissipated work or dissipated energy of the material. Dissipated energy is simply defined as the area included in the loaded and unloaded portion of the stress-strain curve (referred to as the hysteresis loop). Dissipated energy has been used in the asphalt concrete fatigue area for many years by some agencies. Similarly, the falling-weight deflectometer (FWD) load deflection-time data can be used to measure the dissipated work during the loading and unloading of the pavement structure from the FWD impact load. This dissipated work should be related to the occurrence of selected surface distresses, especially for asphalt concrete-surfaced pavements.

The deflection-time history data collected within the Long-Term Pavement Performance (LTPP) program represent an invaluable data source and critical data element that has yet to be thoroughly investigated and used to its full potential in pavement diagnostic studies. As such, a limited study was undertaken under contract number DTFH61-95-C-00029 to determine if there is any relationship between the dissipated work as measured with the FWD and levels of pavement distress. This study also shows some of the different parameters that can be used from the deflection-time data and the benefit of using these data for pavement diagnostic studies and pavement classifications.

## Background

Wave propagation nondestructive testing (NDT) methods were largely initiated by the U.S. Air Force for nondestructive pavement evaluations in the late 1960's. However, a procedure was not formally adopted by the Air Force for routine pavement evaluations until 1978.[1] During the late 1970's, transient wave propagation behavior became better understood, and more reliable instrumentation for measuring the pavement response was available. For these types of tests, deflection-time histories of motion from an applied dynamic load are recorded by several receivers or sensors placed on the pavement surface. By computing the surface-wave travel time between adjacent receivers, as produced by different frequencies, a dispersion curve is obtained relating phase velocities to frequencies (or wavelengths). This type of testing includes the FWD, which has the most widespread use because of its ability to impose high-amplitude dynamic loads.

The Long-Term Pavement Performance (LTPP) program is a 20-year study of inservice pavements across North America. Its goal is to extend the life of highway pavements through various designs of new and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices. LTPP was established under the Strategic Highway Research Program, and is now managed by the Federal Highway Administration.

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## Load-Deflection Response Data

The load pulse produced during deflection testing with an FWD generally occurs over a time of about 15 to 35 ms. Both the loading time and load-pulse shape can have an effect on the measured peak deflection basins, especially for viscoelastic materials. This is graphically illustrated in figures 1 and 2, and clearly shows differing creep effects from the applied load.

Another parameter received from these data is the recovery time for the induced deflections (i.e., the time required to recover all of the deflection). The time to recover all of the peak deflection generally varies from about 25 ms to more than 60 ms. In fact, for some of the sites, all of the deflection still had not been recovered at 60 ms.

Using the deflection-time plots, the pavement can be categorized into two basic types of response: elastic and viscoelastic. The elastic and viscoelastic properties of the pavement structure can be illustrated by reviewing the deflection-time data measured with the FWD. Figures 2 and 3 show these different types of pavement response characteristics. Figure 2 shows the response for a pavement section that is basically elastic, while figure 3 shows pavements that are considered viscoelastic.

A pavement that behaves elastically will recover most or all of the induced deflection immediately after the load pulse reaches zero, as shown in figure 2. General Pavement Study (GPS) test section 481056 (figure 2) is a thin asphalt concrete-surfaced pavement (less than 51 mm (2 in) in

FIGURE 1

Double-peak FWD load pulse and deflections measured by each sensor at GPS site 011001.

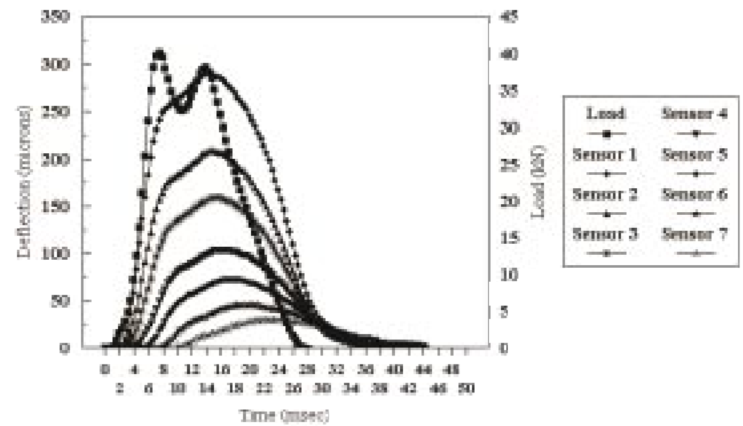



FIGURE 2

Typical FWD deflection-time data from testing performed on an asphalt concrete pavement with elastic behavior, GPS site 481056.

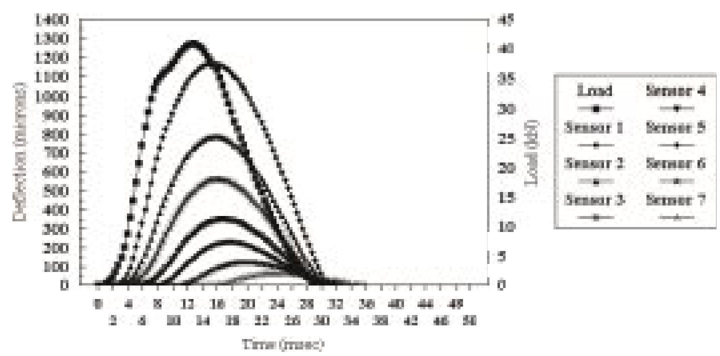
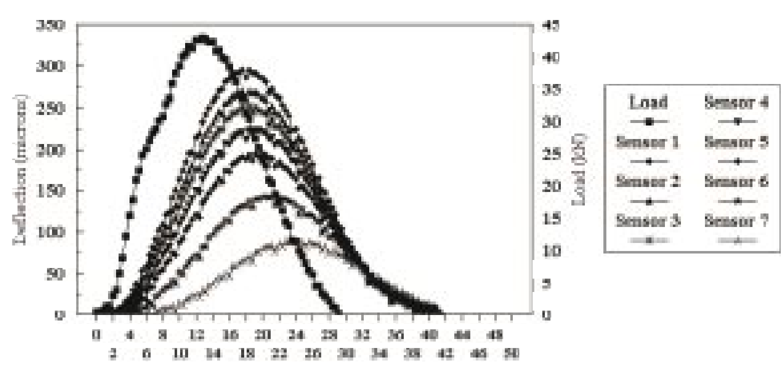



FIGURE 3

Typical FWD deflection-time data from testing performed during the month of January on an asphalt concrete pavement with some viscoelastic behavior, GPS site 481060.



thickness). Asphalt concrete mixtures are viscoelastic materials, but the surface of this test section is so thin that the viscoelastic properties are insignificant in relationship to the total measured deflection.

A highly viscoelastic pavement will take time to recover the induced deflection after the load pulse reaches zero, as shown in figures 1 and 3. As shown, the maximum load and peak deflections are not coincident, and it takes nearly 20 ms past the end of the load pulse for the pavement to recover the deflection. GPS test section 481060 (figure 3) is a relatively thick asphalt concrete-surfaced pavement (193 mm (7.6 in)). The time difference between peak load and peak deflection is very pronounced.

## Dissipated Work

Dissipated work, as measured by the FWD, was calculated for several LTPP-GPS sites during similar time periods (summer months). Figures 4 and 5 show examples of the hysteresis loop used to calculate dissipated work for different types of pavements that vary from very thin to very thick, and from soft to stiff. Based on a review of selected sites, the hysteresis loop and dissipated work do vary extensively by structure and pavement type.

Dissipated work was also evaluated on a seasonal basis using some of the LTPP Seasonal Monitoring Program (SMP) sites. For the most part, dissipated work was found to be independent of season or month for those sites where the properties are more uniform throughout the year (i.e., no frost penetration into the subgrade and no spring thaw occurring in the base and underlying subgrade). It is expected that the dissipated work will be significantly different between seasons for those sites where frost penetration and spring thaw occur.

## Pavement Performance Comparisons

Dissipated work should be related to the rate of pavement deterioration and/or damage. This becomes an extremely important parameter in evaluating pavement structures to determine remaining life and rehabilitation requirements. It is hypothesized that the dissipated work calculated from the FWD load deflection-time data is proportional to, if not directly related to, pavement damage in terms of fatigue cracking and other types of distress, excluding permanent deformation (rutting) that is confined to the asphalt concrete surface layer.

Various sites were selected with varying International Roughness Index (IRI) values, distress magnitudes, and traffic levels to deter-

FIGURE 4

Hysteresis loop as measured by the FWD during the month of July on an asphalt concrete pavement, GPS site 481122.

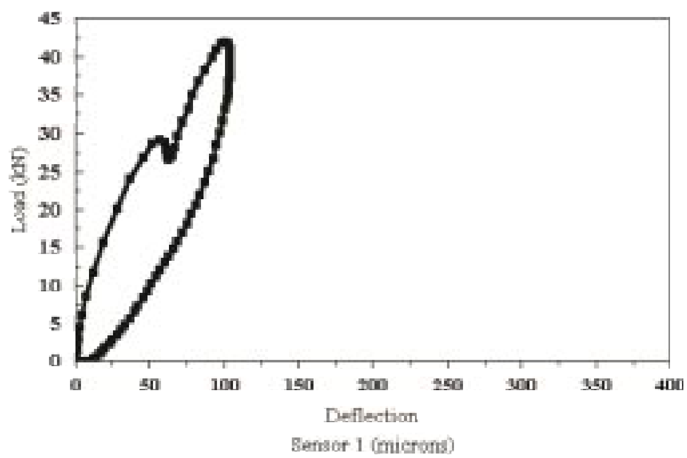
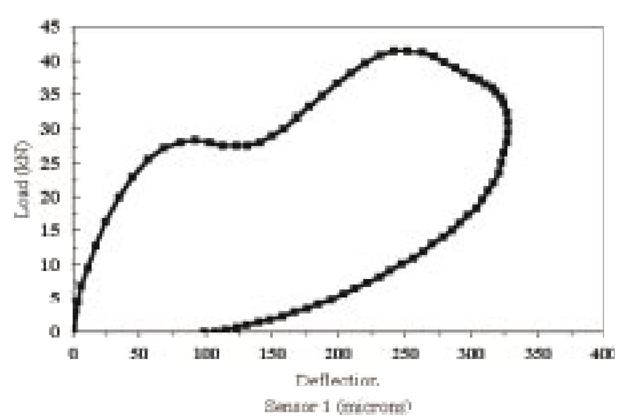



FIGURE 5

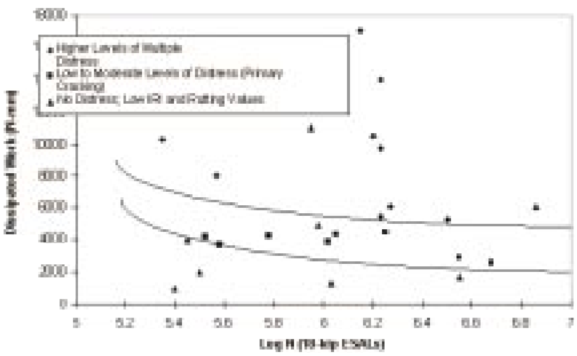
Hysteresis loop as measured by the FWD during the month of July on an asphalt concrete pavement, GPS site 481060.



mine whether there is a relationship between dissipated work and pavement performance or the rate of pavement deterioration. These data are shown in figure 6 and indicate that the greater the dissipated work, the more pavement distress (both in magnitude and severity) and the greater the number of different types of distresses that were observed at these sites. Thus, dissipated work appears to be a material or pavement response parameter (or property) that can be used to evaluate the performance behavior of pavement structures. More importantly, dissipated work can be measured directly with the FWD.

FIGURE 6

Comparison of dissipated work to pavement condition for different traffic levels for selected GPS sites in the LTPP southern region.




## Summary

In conclusion, the differences between the elastic and viscoelastic responses of a pavement structure, as measured by the FWD, may begin to explain some of the differences normally observed and reported between the laboratory and backcalculated moduli of a pavement material and/or subgrade soil. These observed differences should be studied in depth in future data analysis studies regarding the LTPP data base, especially when developing mechanistic-empirical pavement performance models.

The authors strongly recommend that agencies begin to use these deflection data sets to their full potential, especially with the nationally increased awareness of using mechanistic-empirical design procedures. These data should represent a key parameter in the development of these new design procedures that are being planned by the American Association of State Highway and Transportation Officials by the year 2002.

References


1. Nielsen, J.P. and G.T. Baird, *Evaluation of an Impulse Testing Technique for Nondestructive Testing of Pavements*, Report No. CEEDO-TR-77-46, Civil and Environmental Engineering Development Office, Tyndall Air Force Base, Florida, September 1977.



Researcher: This study was performed by Brent Rauhut Engineering, Inc., Contract No. DTFH61-95-C-00029.

Distribution: This TechBrief is being distributed according to a standard distribution.

Availability: The publication related to this TechBrief is *Analyses Relating to Pavement Material Characterizations and Their Effects on Pavement Performance* (FHWA-RD-97-085). It will be available in late 1997. Copies will be available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. A limited number of copies will be available from the R&T Report Center, HRD-11, FHWA, 9701 Philadelphia Court, Unit Q, Lanham, MD 20706, telephone: (301) 577-0818, fax: (301) 577-1421.

Key Words: Falling-weight deflectometer, FWD, deflection, time history, dissipated work.