Implementation of Road Rater Deflection Testing for Pavement Evaluation and Overlay Design

Gary W. Sharpe
University of Kentucky

Herbert F. Southgate
University of Kentucky

Robert C. Deen
University of Kentucky

This paper is posted at UKnowledge.
https://uknowledge.uky.edu/ktc_researchreports/773
IMPLEMENTATION OF ROAD RATER DEFLECTION TESTING
FOR PAVEMENT EVALUATION AND OVERLAY DESIGN

by

Gary W. Sharpe
Principal Research Engineer

Herbert F. Southgate
Chief Research Engineer

and

Robert C. Deen
Director

Transportation Research Program
University of Kentucky

prepared for the
International Symposium on
Bearing Capacity of Roads and Airfields
Trondheim, Norway
June 23-25, 1982

The contents of this report reflect the views of the authors
who are responsible for the facts and accuracy of the data
presented herein. The contents do not necessarily reflect
the official views or policies of the Kentucky Department of
Transportation, of the University of Kentucky, nor of the
Federal Highway Administration. This report does not
constitute a standard, specification, or regulation.

January 1982
IMPLEMENTATION OF ROAD RATER DEFLECTION TESTING
FOR PAVEMENT EVALUATION AND OVERLAY DESIGN

Gary W. Sharpe, Principal Research Engineer
Herbert F. Southgate, Chief Research Engineer
Robert C. Dean, Director

Transportation Research Program
University of Kentucky
Lexington, Kentucky
United States

0. Abstract
Road Rater deflection data were used to estimate the in-place subgrade strength and the in-place structural capacity of existing pavements. Pavement behavior can be expressed in terms of a reduced thickness of "reference" quality paving materials or as a reduced modulus of elasticity for the constructed thickness of asphaltic concrete. Mathematical relationships were developed making it possible to "program" the evaluation procedure (in modular form) for use with small hand calculators or minicomputers.

The pavement evaluation method has been successfully implemented in making recommendations for overlay designs for several pavement sections. Road Rater deflection data were used to estimate the in-place subgrade strength and the structural capacity of the existing pavement. Pavement rutting and roughness were also considered in determining final overlay thickness recommendations.

1. Collection and Analysis of Data
1.1 Road Rater Testing and Data Analyses [3]
Random number tables were used to select five sites per mile. Road Rater and rutting measurements were obtained in both wheel tracks in the outside (shoulder) lane. Pavement roughness data were also obtained.

Subgrade moduli were estimated by a method that uses the No. 1 sensor reading and the No. 1 projected deflection [4,5]. The No. 1 projected deflection, an empirical evaluation of Road Rater deflection data, involves extrapolating a straight line through the magnitudes of the deflections of the No. 2 and No. 3 sensors when log deflection is plotted versus distance from the load head. Extrapolation of the line to the position corresponding to that of the No. 1 sensor results in the No. 1 projected deflection. The slope of the semilog line (a secant line), the difference in magnitude between the No. 1 projected deflection and the No. 1 deflection, and the magnitudes of all deflections are indicative of the shape of the deflection bowl.

For a given pavement structure, asphaltic concrete modulus, and subgrade modulus, there is a difference between the No. 1 projected deflection and the No. 1 deflection for theoretical deflections. There will also be a difference between these values for field-measured deflections. Normally, the differences between the No. 1 projected deflection and the No. 1 deflection for both theoretical and field measurements are similar. Slab deterioration, however, may be suggested when field measurements indicated a No. 1 deflection greater than the No. 1 projected deflection, and the difference is greater than the difference for theoretical deflections. A foundation problem, or lack of supporting capability, may be indicated by increased magnitudes of all field deflections and the difference between the No. 1 projection and the No. 1 deflection.
is greater than normally expected for the magnitudes of the measured deflections.

A plot of No. 1 projected deflections versus No. 1 deflections in log-log form may be used to identify variations in the pavement structure. The solid lines (left side of Figure 1) show the theoretical relationships of No. 1 projected deflections and No. 1 deflections for a constant structure and asphaltic concrete modulus. Subgrade modulus varies along the line. The variation in position of the theoretical line due to changes in the deflections by ± one unit (2.54 x 10⁻⁴ mm or 1.0 x 10⁻⁵ inches) on the Road Rater meters and the associated change in calculated No. 1 projected deflection is indicated by two dashed lines. The zone inside these lines represents a normal variation due to reading the meters of the Road Rater.

The solid line on the right side of Figure 1 represents the theoretical relationship between Road Rater No. 1 deflections and subgrade moduli. The "x" points represent those that would be suspected of having problems in the bound layers (from the No. 1 projected deflection versus No. 1 deflection relationship). The "o" points represent points suspected of having foundation or supporting layer problems.

The "x" points have a No. 1 deflection higher than would be theoretically expected for the given values of deflections for the No. 2 and No. 3 sensors and the corresponding No. 1 projected deflections. It is necessary to adjust the No. 1 deflection to a theoretical value that matches the measured No. 2 and No. 3 deflections. The adjusted No. 1 deflection is then used to predict subgrade modulus. The predicted subgrade modulus is plotted versus the measured No. 1 deflection and compared to the theoretical relationship of Road Rater No. 1 sensor deflection versus subgrade moduli. The point will plot above the theoretical line, indicating behavior weaker than the reference conditions. The behavior may be expressed in terms of reduced asphaltic concrete modulus or a reduced thickness of asphaltic concrete at reference conditions. In terms of overlay design, effective behavior expressed as a reduced thickness is more meaningful and easier to use.

The "o" points have a No. 1 deflection lower than would be theoretically expected. The deflection bowl is very "broad" and "flat" and representative of a problem in the foundation or supporting layers. The adjusted No. 1 deflection will have a greater magnitude than the measured No. 1 deflection and will be compatible with the measured No. 2 and No. 3 deflections and associated No. 1 projected deflection. When the predicted subgrade strength (E₃) (from the No. 1 sensor deflection) is plotted versus the adjusted No. 1 deflection, the expression of pavement behavior is in terms of a predicted subgrade strength and a reduced thickness of reference quality materials.

The effective behavior of a pavement may be expressed in terms of a predicted subgrade modulus and an effective thickness (any combination of asphaltic concrete and dense-graded aggregate) that match the measured deflection behavior. For this analysis, the effective thickness is determined by assuming the thickness of dense-graded aggregate equal to the "design" or constructed thickness; and the thickness of "reference" asphaltic concrete is determined having a theoretical deflection bowl that matches the measured Road Rater responses [4].

1.2 Analysis of Rutting Data

Rut measurements were obtained by stretching a stringline across the pavement. The maximum rut in each wheel track was measured. Rut measurements were plotted on a strip chart and used in developing overlay design; such a chart is a good indicator for estimating leveling course requirements.

1.3 Seasonal Effects on Predicted Subgrade Modulus

In-place CBR or subgrade moduli are directly related to moisture in the subgrade. When new pavements have been tested with the Road Rater, spring tests have tended to indicate abnormal behavior while fall tests have indicated results more consistent with behavior normally expected from new pavements and that match elastic theory. For these reasons, most Road Rater tests have been conducted in the summer and fall months.

While summer and fall Road Rater tests have been best for pavement evaluation, design parameters should be
based on a "weaker" or "weakest" condition. Therefore, it was necessary to make adjustments from a "fall" condition to a "spring" condition (expected to be the "weaker" or "weakest" condition).

Historical deflection data were available for two three-layed pavement sections used to investigate seasonal effects. Those sections consisted of 165 mm (6.5 inches) of asphaltic concrete on 305 mm (12 inches) of dense-graded aggregate and 173 mm (6.8 inches) of asphaltic concrete on 483 mm (19 inches) dense-graded aggregate. Subgrade moduli were predicted for each season. Data were available for April, May, June, and September.

The September prediction was selected as the reference condition. Ratios of predicted subgrade moduli for other times to the September moduli were computed and plotted in Figure 2. The April estimates of subgrade moduli were 67 percent of the September estimates (Figure 2). The relationship was extrapolated to cover a period of one year. The limited data of Figure 2 indicated a factor of 0.6 to adjust from the strongest to the weakest condition. In Pennsylvania [1], an adjustment factor of 0.5 has been suggested. Additional research is needed to clearly define the relationships, even though they appear consistent with other research.

2. Comparison of CBR Data

Laboratory CBR data were obtained from soils laboratory reports and from soil profile sheets of the construction plans. Soil samples were taken from the completed subgrade prior to paving. The stationing associated with the CBR data was converted to equivalent milepoints, making it possible to relate these values to those predicted by the Road Rater.

Road Rater estimates of subgrade strength were expressed in terms of moduli of elasticity, which may be converted to an approximate CBR by dividing the modulus (in psi) by 1500. This estimate is reasonably adequate for CBR values up to 20 [2]. Plots of CBR predicted from Road Rater data versus laboratory CBR were developed.

Laboratory CBR values represent the worst expected condition because the sample is soaked to saturation before testing. Since subgrade strengths from Road Rater data represent an "in-place" condition, it would be expected that the CBR values from the Road Rater deflections would be greater than the corresponding laboratory CBR values. A plot of CBR predicted from fall Road Rater deflections versus laboratory CBR was developed to verify this expectation. Approximately 60 percent of the Road Rater estimates were greater than their laboratory counterparts. Inspection of the remaining data indicated that practically all the outlying points could be explained by geological and drainage conditions.

3. Selection of Design Parameters

Strip charts were developed by plotting estimated subgrade modulus and effective pavement thickness versus milepoint (Figure 3) to locate natural breaks in the behavior of the pavement. Those natural breaks were merged with breaks associated with changes in traffic volumes. This resulted in several "design" sections. Statistical analyses were used to evaluate the data within a given design section.

Within a given design section, a design CBR, a design effective thickness, a maximum rut depth, and a minimum present serviceability index (PSI) based on pavement roughness were selected. The design CBR was selected by calculating the mean CBR and then subtracting 1.5 times the standard deviation from the mean. This value was then multiplied by 0.6 to convert to a soaked or "spring" condition. The effective thickness was calculated by determining the mean effective thickness and subtracting 1.5 times the standard deviation. The maximum rut depth was estimated by adding 1.5 times the standard deviation of rut depth to the mean rut depth in each section. The minimum PSI was estimated by subtracting 1.5 times the standard deviation of PSI values in the section from the mean PSI of the section. The addition or subtraction of 1.5 times the standard deviation corresponded to the selection of an 92nd percentile value [4]. The multiplier 1.5 was based on engineering judgment and may be varied according to desired design level. Design EAL values were estimated from projections of the traffic stream over the design period.
4. Overlay Design Procedure

In Figure 4, Curve "A" was created using the constructed thickness of the dense-graded aggregate (unbound crushed-stone) based. The total thickness for various percentages of thickness of asphaltic concrete to the total thickness was determined from the following equation:

\[ \text{Total thickness} = \frac{(100 \times \text{DGA})}{100 - \left(\frac{\text{AC} \times \text{Total}}{100}\right)} \]

in which AC is the design thickness of asphaltic concrete and DGA is the constructed thickness of dense-graded aggregate base.

Road Rater data were used to determine the CBR value (weakest in-place subgrade modulus) for each design section. Statistical procedures discussed above were used to estimate the expected weakest condition.

With the selected design EAL and design CBR, design charts for new pavements were used to determine design thicknesses. Those thicknesses were plotted versus percentage of asphaltic concrete thickness in the total thickness, as illustrated by Curve "B" of Figure 4.

The total pavement thickness for the design year was determined by the intersection of Curves A and B in Figure 4. The overlay thickness was the difference between the total design thickness (existing pavement and overlay) and the effective thickness of the existing pavement and was determined from the following relationship:

\[ \text{Overlay thickness} = \text{Total Thickness (intersection of Curves A and B)} - \text{Total Equivalent (Existing) Thickness} \]

The total equivalent thickness can be determined from deflection data (Road Rater, Dynaflect, Falling Weight Deflectometer, etc.) or by other means of estimating the effective supporting capacity of a partially deteriorated pavement.

Additional thicknesses for leveling were added when rutting was greater than the statistically expected maximum for that section. Thicknesses added were equal to the difference between the measured rut depth and the statistically expected maximum rut depth for that section.

Patch thicknesses were also designed for those areas where the predicted subgrade strength was weaker than the selected "design" value. Design curves were used to determine the thicknesses of the patches using the same procedures used in designing the overlay thicknesses [6,7]. Patch thicknesses were equal to the difference between the total thickness required for the "weaker" areas and the total thickness required for the selected design CBR.

5. Summary

The criteria and logic used to determine overlay thicknesses for asphaltic concrete pavements take into account Road Rater data, roughness data, and rutting data. Road Rater deflections were used to predict subgrade strength and the current load-carrying capability of the existing pavements. Predictions of subgrade strength were compared to laboratory CBR values. When the predicted CBR values (from Road Rater deflections) were adjusted for seasonal effects, the predicted CBR's were (in most cases) within the range of laboratory CBR's.

6. References


of Michigan, August 1962.

3. SHARPE, G. W.; and SOUTHGATE, H. F.; Overlay Recommendations for I 64: Rowan, Carter, and Boyd Count­
Ties, Kentucky, Research Report 551, Division of Research, Kentucky Department of Transportation, August 1980.

4. SHARPE, G. W.; SOUTHGATE, H. F.; and DEEN, R. C.; "Dynamic Pavement Deflections," Transportation Engineer­


---

Figure 1. Illustration of Procedures to Estimate Subgrade Strength and the Effective Pavement Structure.
Figure 2. Seasonal Variation in Predicted Subgrade Modulus from Road Rater Deflections.
Figure 3. Example of Strip Charts Illustrating Effective Subgrade Strengths and Effective Thicknesses.
Figure 4. Illustration of the Procedures to Determine Overlay Thickness Designs.
CORRELATION OF ROAD RATER AND BENKELMAN BEAM DEFLECTIONS

Robert C. Deen, Director
Gary W. Sharpe, Principal Research Engineer
Herbert F. Southgate, Chief Research Engineer
Transportation Research Program
University of Kentucky
Lexington, Kentucky
United States

Abstract

The Benkelman beam is commonly used to measure surface deflections of highway and airfield pavements. The Benkelman beam is based on a simple lever-arm principal and uses dial gauges to measure surface deflections under an applied axleload. The Road Rater is an electro-hydraulic testing device that applies a sinusoidal force to the pavement at a fixed amplitude and frequency; surface wave velocities are measured and electronically integrated to obtain surface deflections. Road Rater and Benkelman beam deflections have been successfully simulated using elastic theory and the Chevron N-layer computer program. The analyses presented in this paper illustrate relationships between Road Rater deflections and the more commonly used Benkelman beam deflections.

I. Introduction

The Road Rater and Benkelman beam are comparable in the sense that both measure surface deflections of pavements. The Road Rater loading was dynamic and consisted of a vibrating load that impulsed the pavement. Frequency and amplitude of vibration were pre-selected variables that controlled the dynamic load induced by the Road Rater. The forced motion of the pavement due to the vibratory load was measured by velocity pickup sensors located at various distances from the center of the test head. Deflection measurements for each sensor were displayed on meter scales and were read directly by the operator.

The Benkelman beam operated on a simple level-arm principal and used dial mechanisms to measure surface deflections. Benkelman beam tests were conducted at a creep speed of the test vehicle (0.5 Hz to 1.0 Hz). The test vehicle consisted of a two-axle, six-tire dump truck with a load of 80 kN (18 kips) on the rear axle. Two Benkelman beams were used, with the tips of the beams placed between the two dual tires at each end of the axle. The maximum surface deflection was read as the vehicle tires rolled past the tips (points) of the Benkelman beams. The movement of the pavement was measured by dial mechanisms attached to the beams.

2. Simulation of Benkelman Beam Test Results

Benkelman beam deflections have been simulated by elastic theory using the Chevron N-layer computer program. Assuming equal load distribution, each rear tire of the test truck applied a 20-kN (4.5-kip) load to the pavement. Superpositioning principles were used to compute the deflections between the two tires of the rear duals. Superpositioning is applicable provided the deformations are small and do not substantially affect the action of external forces. For the principles of superpositioning to apply, a linear relationship between displacement and external force must exist or be assumed to exist [5]. Thus, the deflection sensed by the Benkelman beam is the sum of deflections caused by each of
the four tires on the rear axle at their respective distances from the point of measurement. This approach was used to calculate deflections at any location on the pavement and for any axle configuration and loading.

An array of conditions (thicknesses of asphaltic concrete, dense-graded aggregate thicknesses, and moduli of elasticity for asphaltic concrete, dense-graded aggregate, and subgrade) was used in the Benkelman beam simulation. Estimation of the modulus of the crushed stone layer was obtained from the relationship \( E_2 = F \times E_3 \), in which there is an inverse linear relationship between \( \log F \) and \( \log E_3 \). The ratio of the modulus of the base (\( E_2 \)) to the modulus of the subgrade (\( E_3 \)) is equal to 2.8 at a California Bearing Ratio (CBR) of 7 and is equal to one when the modulus of the asphaltic concrete (\( E_1 \)) and the subgrade modulus (\( E_3 \)) are equal: \( E_1 = E_2 = E_3 \). Subgrade moduli (\( E_3 \)) in psi may be approximated by the product of the CBR and 1500. This appears adequate for normal design considerations up to a CBR of 18 to 20. Other inputs used in the simulation [1] included the following:

Poisson's ratio:
- Asphaltic Concrete: \( \mu = 0.40 \)
- Granular Base: \( \mu = 0.40 \)
- Subgrade: \( \mu = 0.45 \)

Load per tire: 20 kN (4.5 kips)

Tire (contact) pressure: 0.55 MPa (80 psi)

Analyses [3] have shown that changes in Poisson’s ratio and tire pressure have relatively insignificant effects upon the calculated deflections. An example of results of the simulation of Benkelman beam deflections is illustrated in Figure 1.

3. Simulation of Road Rater Tests Results

The testing head on the Kentucky Road Rater, mounted on the front bumper of a 1971 International Travelall, consisted of a vibrating mass weighing 72.6 kg (160 pounds), which impinges the pavement; the forced motion of the pavement is measured by velocity sensors normally located at 0 mm (0 feet), 305 mm (1 foot), 610 mm (2 feet), and 914 mm (3 feet) from the center of the test head. The vibrating mass was suspended by a system of rubber bellows. A second set of bellows housed in the test head distributes the dynamic load equally to two "feet". Frequency of the vibratory loading may be chosen from pre-selected frequencies of 10, 20, 25, 30, and 40 Hz. The vibrating mass was lowered to the pavement by a hydraulic system. Optimum and resonant frequencies were a function of the location of the test head, the dynamic force, the location of the load-bearing "feet", and the pavement structure. The dynamic force was a function of frequency and amplitude of vibration and the pressure in the hydraulic system. At a hydraulic pressure of 4.82 MPa (700 psi), the static load for the Kentucky unit was 7.43 kN (1,670 pounds).

A frequency of 25 Hz and an amplitude of vibration of 1.524 mm (0.06 inch) resulted in a peak to peak dynamic force of 2.67 kN (600 pounds). Once the dynamic force was set for a given frequency and amplitude, the other preset frequencies will vary the amplitude of the vibrating mass such that the dynamic force remains constant for all pre-selected frequencies. The composite loading consisted of a static load of 7.43 kN (1,670 pounds) with a dynamic force of 2.67 kN (600 pounds), peak to peak, oscillating about the static load. The loading was transmitted to the pavement by two "feet" symmetrically located on either side of a beam extending ahead and supporting the sensors.

Superposition principles are applicable in computing the deflection at each sensor location. Applying superposition principles to the Road Rater, the deflection resulting from the load applied to one "foot" must be added to the deflection due to the load applied by the other "foot". For the symmetrical conditions of the Road Rater, deflection calculations only need to be made for one "foot" and radii corresponding to each sensor location.

The dynamic loading (sine wave) of the Road Rater can be approximated by a square wave. For short time periods, this is representative of a steady-state condition that approximates a static load. The peak-to-peak loadings of the Road Rater are 8.37 kN (1,882 pounds) and 6.49 kN (1,458 pounds). From symmetry, the loads on each "foot" of the test head are equal to 4.19 kN (941 pounds) and 3.24 kN (729 pounds). The dynamic deflection is the difference between the
calculated deflections caused by the 8.32-kN (1,882-pound) and 6.49-kN (1,458-pound) loads.

Simulated deflections for Road Rater loadings were obtained using the Chevron N-layered computer program, which are based on elastic theory [1]. The contact pressure of the low and high loads were inputed to maintain the correct area for each "foot". The following constants were used in simulating the Road Rater deflections [1]:

- Poisson's ratio:
  - Asphaltic Concrete $\mu = 0.40$
  - Granular Base $\mu = 0.40$
  - Subgrade $\mu = 0.45$

Load = 4.186 kN (941 pounds): Contact pressure = 0.231 MPa (33.5 psi)
Load = 3.243 kN (729 pounds): Contact Pressure = 0.183 MPa (26.5 psi)

An array of asphaltic concrete and crushed stone thicknesses and moduli for the asphalt, crushed stone, and subgrade layers was used in the simulation [1].

4. Comparison of Road Rater and Benkelman Beam Deflections

A log-log plot of Benkelman beam versus Road Rater No. 1 Sensor deflections (both computed (simulated) by elastic theory) for equivalent conditions is illustrated in Figure 2 and shows the effects of total thickness and thickness of asphaltic concrete to be a family of curves. Road Rater and Benkelman beam deflections were obtained from the results of the simulation previously described. A similar relationship exists for field measured deflections (Figure 3). The dashed lines in Figure 3 represent theoretical lines (from Figure 2) for specific pavement structures. Deflections were plotted to an arithmetic scale in Figure 3 while log scales were used in Figure 2. The points on Figure 3 represent pairs of field measured Road Rater No. 1 Sensor deflections and Benkelman beam deflections. Both Road Rater and Benkelman beam deflections were adjusted to the moduli of the asphaltic concrete corresponding to the mean pavement temperature and their respective test frequencies [1].

The Figures 4-8 compare field measured pairs of Road Rater and Benkelman beam deflections with their corresponding theoretical values. These values have been adjusted to a 21.1°C (70°F) reference [4]. Initial comparisons indicated unreasonable amounts of scatter. However, when the limits of operator error in reading the dials of the Benkelman beam and the meters of the Road Rater were considered, much of the scatter was explained.

Road Rater deflections were displayed on meter scales ranging from 0 to 100 with divisions for every two units. Normal reading error is ±1 unit on the meter. The true deflection is determined by multiplying the meter reading by the scale factor. In most instances, the scale factor is $2.54 \times 10^{-4}$ mm (1 x 10^-5 inches).

Benkelman beam deflections were recorded by dial gauges. The number of divisions on the dial face was a major contributor to operator error. Also, since the Benkelman beam functions on lever-arm principles, the location of the fulcrum must also be considered. For the Kentucky Benkelman beam, the dial was located 1.22 m (4 feet) from the fulcrum, and the tip of the beam was 2.43 m (8 feet) from the fulcrum. Therefore, a dial reading for the Kentucky Benkelman beam was multiplied by 2 to obtain the true deflection. One division on the dial was 2.54 x 10^{-2} mm (1 x 10^{-3} inches). For an error of ±1 division, the error in deflection is ±5.08 x 10^{-2} mm (2 x 10^{-3} inches). The solid lines in Figures 4-8 illustrate theoretical relationships between Road Rater No. 1 Sensor deflections and Benkelman Beam deflections as determined by simulations using elastic theory.

The dashed lines on Figures 4-8 illustrate different levels of error in Benkelman beam deflections with corresponding levels of error for the Road Rater. The figures indicate that an operator error of ±1 division in dial reading of the Benkelman beam is more significant than an error of ±1 unit on the Road Rater meter scale for a scale factor of 2.54 x 10^{-4} mm (1 x 10^{-5} inches). All Road Rater deflections were determined using a scale factor of 2.54 x 10^{-4} mm (1 x 10^{-5} inches). When plots of Benkelman beam deflection versus Road Rater deflections were compared with the theoretical relationships and the reading tolerance (dashed lines) superimposed on each plot, the following results were obtained: 45
percent of the points were within ± 2.54 x 10^-2 mm (1 x 10^-3 inches) of the theoretical Benkelman beam deflection; 71 percent were within ±(5.08 x 10^-2 mm (2 x 10^-3 inches) and 84 percent were within ±7.62 x 10^-2 mm (3 x 10^-3 inches) of the theoretical deflections. The remaining points were analyzed individually using Road Rater deflection data for Sensors 1, 2, and 3 [1, 2]. When the Road Rater deflection basins were evaluated, every point indicated some type of abnormal behavior. In most cases, a foundation material problem was indicated. Only ten percent of the abnormal points indicated a problem in the bound layer. This was not surprising since the pavement was only 1 year old at the time of testing.

In most cases when Benkelman beam deflections were plotted versus Road Rater deflections, most points indicating foundation problems plotted below the theoretical line. On the other hand, deficiencies in the bound layer normally plotted above the line. There were only three exceptions noted in this general pattern. Circled points indicate foundation material deficiencies and points inside squares indicate possible bound-layer problems.

One possible explanation for the separation of the two problem types may be related to the deflection basin. The Road Rater applies a relatively small load and measures surface deflections at specified distances from the load. A plot of the deflection basin for the Road Rater can readily be developed. Benkelman beam deflections are measured as the vehicle creeps past the tips of the beams. A surface deflection is measured, but the location of that deflection on the deflection bowl is not known. For the Kentucky test procedure, rebound is considered and sufficient time is allowed for the dial to cease moving. Therefore, the deflection approaches a maximum deflection.

One example of an abnormal situation resulted from concurrent Road Rater and Benkelman beam tests for a site in Kentucky. Tests were taken on a layer of compacted subgrade overlying a layer of soft soil of known high moisture content overlying bedrock. Geologic and topographic conditions of the area made drainage less than adequate. Road Rater tests indicated abnormally high deflection values, but Benkelman beam deflections at the same site were relatively low. Cracking and subsidence of the entire testing area was observed when the truck for the Benkelman beam test was driven onto the test site. When the truck was removed, the Benkelman beam indicated very little movement, yet rebound of the compacted subgrade could be visually observed. The load due to the test truck was distributed over a very large area such that both the truck and the Benkelman beam were completely within the deflection bowl.

5. References
2. SHARPE, G. W.; and SOUTHGATE, H. F.; Road Rater and Benkelman Beam Pavement Deflections, Division of Research, Kentucky Department of Transportation, Research Report 523, June 1979.
Figure 1. Theoretical Deflections for Penkelman Beam Tests.
Figure 2. Theoretical Deflections: Benkelman Beam Deflections for an 80-kN (18-kip) Axleload versus Road Rater No. 1 Sensor Deflections.

NOTE: CONDITIONS AT 21.1°C (70°F)
E₁ = 8.27 GPa (1,200,000 PSI) FOR THE ROAD RATER
E₁ = 3.31 GPa (480,000 PSI) FOR THE BENKELMAN BEAM
Figure 3. Benkelman Beam Deflections for an 80-kN (18-kip) Axleload versus Road Rater No. 1 Sensor Deflections: Dashed Lines Represent Theoretical Deflections and Points Represent Field Measurements.

Figure 4. Plot of Road Rater No. 1 Deflection versus Benkelman Beam Deflections for 173 mm (6.8 inches) of Asphaltic Concrete on 483 mm (19 inches) Dense-Graded Aggregate.
Figure 5. Plot of Road Rater No. 1 Deflection versus Benkelman Beam Deflections for 254 mm (10 inches) of Full-Depth Asphaltic Concrete.

Figure 6. Plot of Road Rater No. 1 Deflection versus Benkelman Beam Deflections for 356 mm (14 inches) of Full-Depth Asphaltic Concrete.
Figure 7. Plot of Road Rater No. 1 Deflection versus Benkelman Beam Deflections for 406 mm (16 inches) of Full-Depth Asphaltic Concrete.

Figure 8. Plot of Road Rater No. 1 Deflection versus Benkelman Beam Deflections for 457 mm (18 inches) of Full-Depth Asphaltic Concrete.