PROGRESS REPORT
FOR
IOWA HIGHWAY RESEARCH BOARD
PROJECT HR-178

DYNAMIC PAVEMENT DEFLECTION MEASUREMENTS

by
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TABLE OF CONTENTS

DYNAMIC PAVEMENT DEFLECTION MEASUREMENTS

INTRODUCTION

In October, 1975, when project HR-178, "Dynamic Pavement Deflection Measurement" was approved, there were two commercially available systems that were considered. They were the Dynaflect and the Road Rater. After obtaining information from the manufacturers and other state highway departments, the advantages of each were considered and the decision was to purchase a Road Rater. The reasons for this decision are given in a November 11, 1975 progress report.

The Road Rater is an electronically controlled hydraulically powered unit mounted on the front of a van type vehicle (Figure 1). A servo valve allows a pulsating flow of hydraulic fluid that imparts a movement into a large mass mounted in the center of the unit. The resultant movement of this mass produces a force that is applied to the pavement. This dynamic loading varies from 800 to 2000 pounds. The force being applied to the pavement is monitored by a velocity sensor (Figure 2) attached to the top of the two-way hydraulic ram that produces the movement. The resultant movement of the roadway surface is measured by identical sensors that are lowered to the surface (Figures 3 and 4). An electronic console (Figure 5) containing the controls to regulate the magnitude and frequency of the loading is located next to the driver inside of the vehicle. The resultant movement as indicated by the roadway velocity sensors is displayed on meters contained in the console. The hydraulic power is supplied by an auxiliary engine mounted in the rear of the unit (Figure 6).

Figure 1. The Road Rater

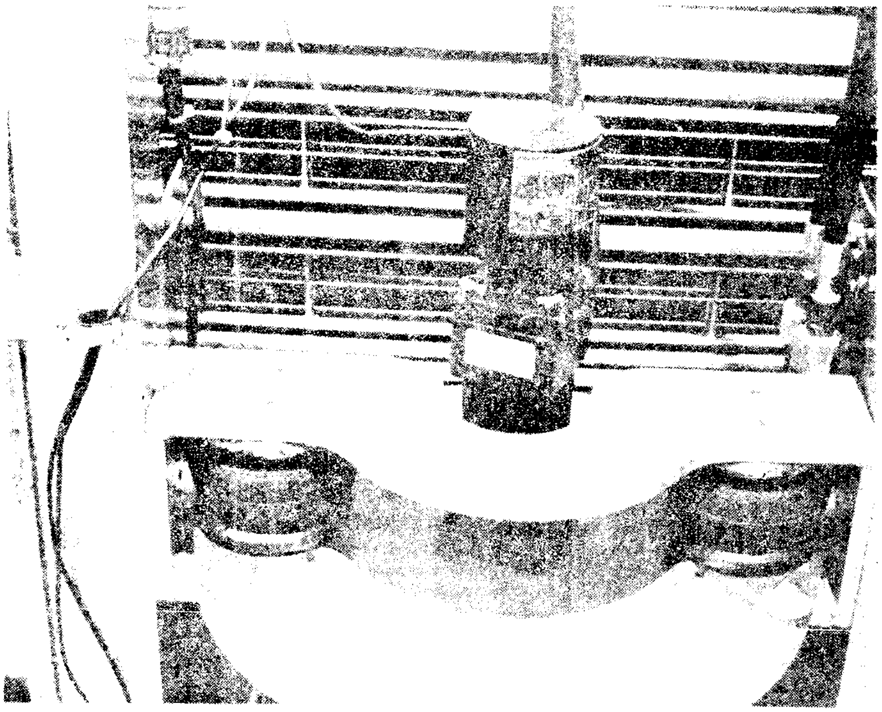

Figure 2. The Velocity Sensor on Top of the Hydraulic Ram.

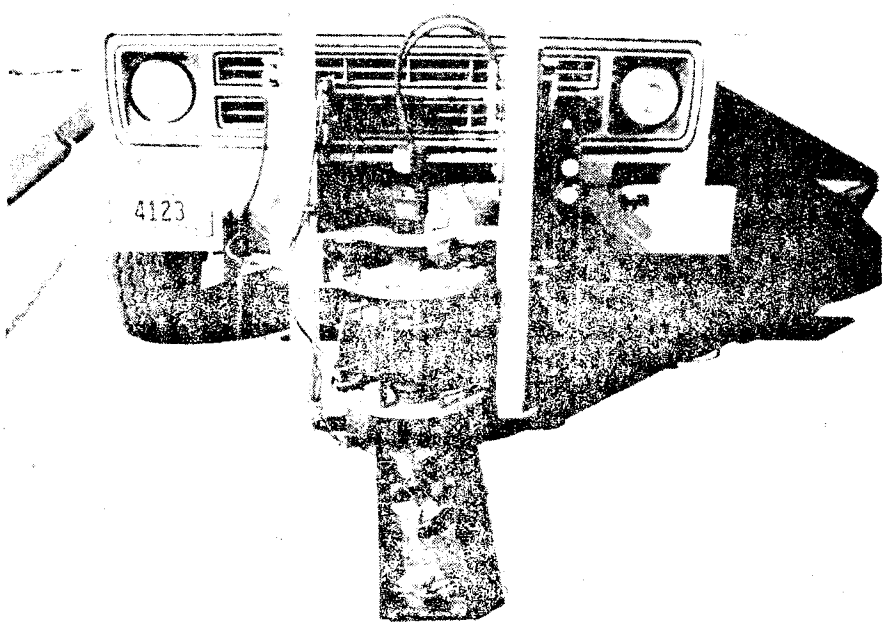

Figure 3. The Road Rater Test Unit Lowered to the Surface.

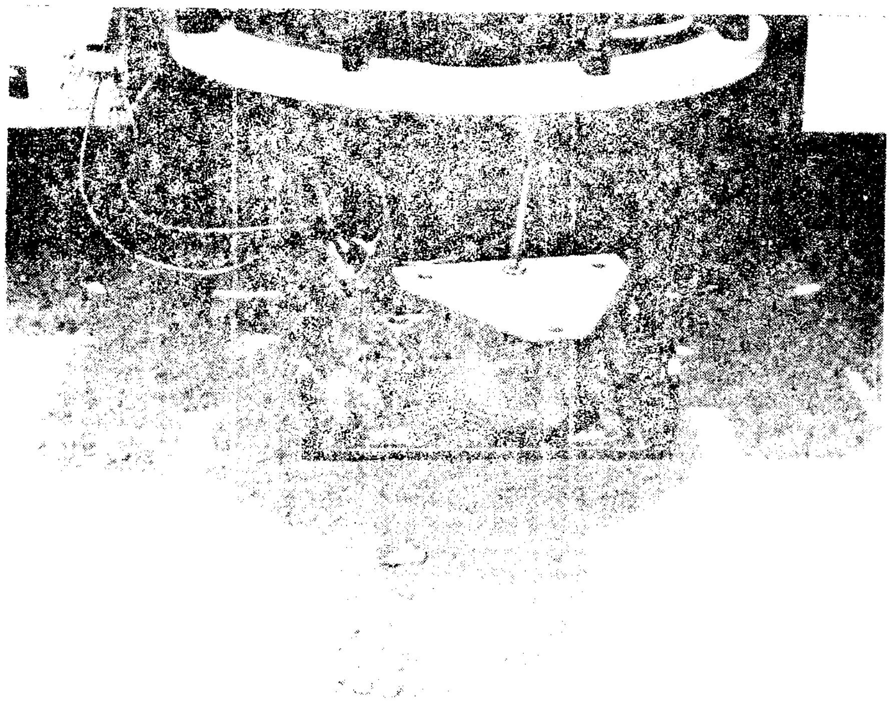

Figure 4. A Velocity Sensor to Measure Surface Movement

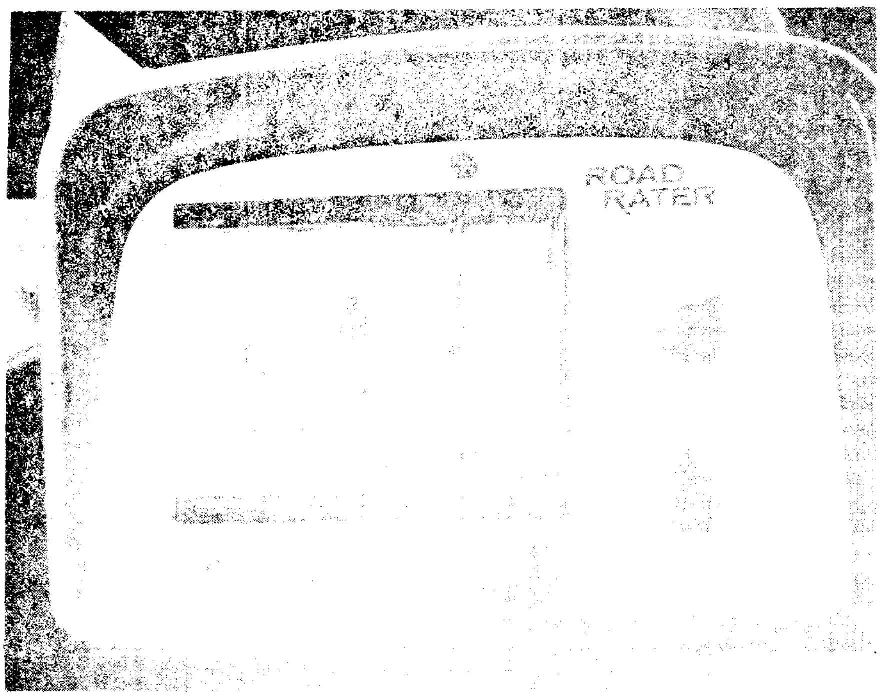

Figure 5. The Console with Controls and Display Meters.

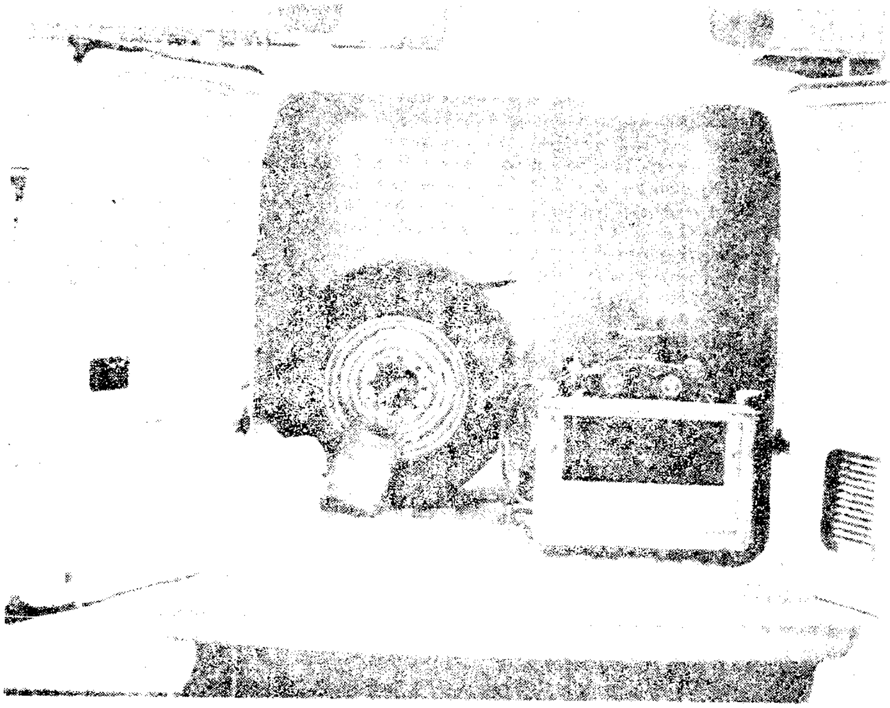

Figure 6. The Auxiliary Power Unit

CHANGES IN PAVEMENT DEFLECTION OPERATION USING THE ROAD RATER

One of the advantages of the Road Rater is its testing speed. Information from present owners indicated that a test could easily be completed in less than one minute. Also, after initial set up of the unit, there was no need for personnel to be outside of the unit in the traveled way. The Office of Traffic Engineering granted approval to a request to allow operation without a flagman. The new safety protection required flashing red lights on the test unit and sign changes on the three vehicles providing traveling safety. On this short test cycle, a flagman would be very ineffective due to the time it would take him to get in and out of the vehicle. The ability to easily observe and conduct the testing operation from the driver's seat is an improvement to safety.

Other benefits will result with the change from the Benkelman Beam to the Road Rater for pavement deflection testing. With the reduction in Iowa D.O.T. personnel, there is a continued demand to gain greater production with fewer people. The Road Rater is considerably faster as individual Benkelman Beam tests take at least five minutes. Including safety, the Benkelman Beam testing requires seven people whereas the Road Rater uses only four. There is an increasing demand for pavement deflection data to evaluate structural capability of the roadways. This improved testing efficiency allows for the testing of more roadways.

ROAD RATER TRAINING

A short three-day training course on operation and maintenance of the unit was conducted by Bill Johnson, a technical representative of Foundation Mechanics, Inc. There was a concern of how to assure that the unit would continue to yield consistent data. Mr. Johnson demonstrated a calibration procedure based upon determining the movement of the accelerometer mounted on top of the ram providing the dynamic load. The standard operating loading (58 mils of movement) and frequency (25 cps) were given.

CORRELATION OF THE ROAD RATER AND BENKELMAN BEAM

All of the Iowa D.O.T's previous pavement deflection data is available from Benkelman Beam studies which have proven to be reliable. If the Road Rater would also yield reliable data in regard to structural adequacy, there should be a good correlation.

The pavement deflection testing program includes roadways requested by either the Soils Design Engineer, the Materials Bituminous Engineer, the Construction Bituminous Engineer or the Research Engineer. These requests are made to evaluate roads of questionable structural capability, strength gain from resurfacing, experimental projects or performance of selected roadways. Roadways with a wide range of structural adequacy were selected from these requests for use in the correlation.

The Road Rater deflection value was determined in the outside wheelpath at a selected station or mile post. The Road Rater test procedure is given in Iowa Test Method No. 1009-A (Appendix A). For this testing, the values for sensors No. 1, No. 2 and No. 3 were recorded.

The Benkelman Beam deflection was determined a few minutes later at the same location as described in Test Method No. Iowa 1006-A (Appendix B).

The data for this correlation was taken from ten different roadways and includes 69 individual test locations. A linear correlation program was used. The Benkleman Beam data was compared separately to the data from each of the three sensors of the Road Rater. The correlation coefficients were 0.83 for Sensor #1, 0.64 for Sensor #2 and 0.79 for Sensor #3. Sensor #1 is located between the contact feet that apply the load to the pavement or we could say at the center of the applied load. Sensor #2 is 12" from the application of the load and Sensor #3 is 24" from the application of the load. Only the data from Sensor #1 was used as it yielded the best correlation coefficient. The plot of this correlation is shown in Figure 6. The conversion formulas from this correlation are:

$$RR = 0.0455\ BB + 0.54$$
$$BB = 22.0\ RR - 11.9$$

Both Road Rater (RR) and Benkelman Beam (BB) values are expressed in thousandths of an inch (0.001") or mils.

The correlation coefficient of 0.83 is not as good as desired, but a similar correlation in California yielded a correlation coefficient of 0.89. The inability to obtain a better correlation may be due to comparing a dynamic test to a static test. Proponents of dynamic testing claim that because traffic presents a dynamic loading that roadways should be tested dynamically. This correlation should be sufficient for comparing future Road Rater results with past Benkelman Beam studies. It also supports the reliability of the deflection data obtained by the Road Rater.

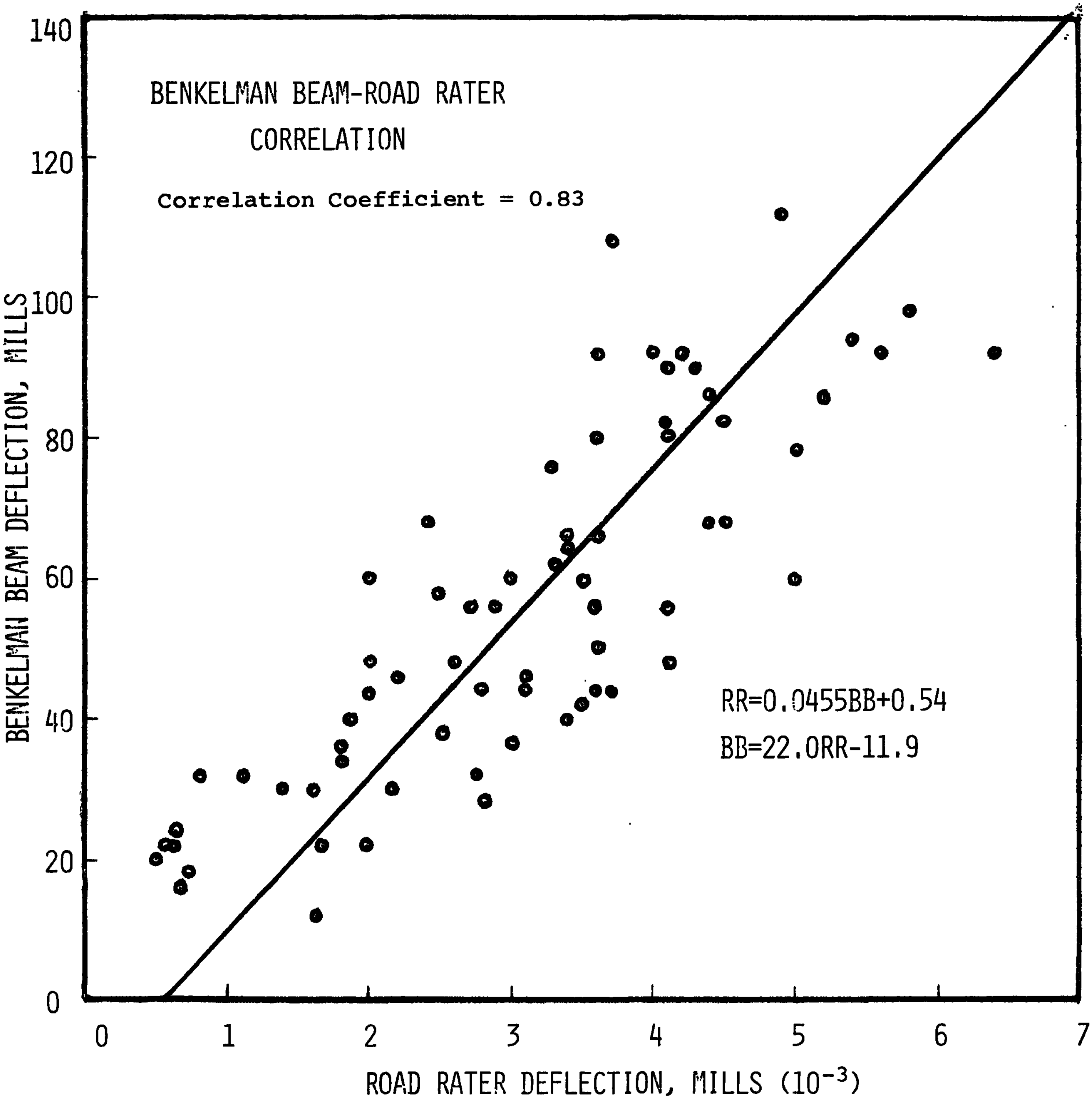

Figure 6. Correlation of The Road Rater and Benkelman Beam.

CORRELATION OF ROAD RATER DEFLECTION AND AASHTO STRUCTURAL NUMBERS

All Road Rater data obtained from the 1976 Spring pavement deflection program was used to determine a correlation with structural ratings (Figure 7). The deflection data was available for 63 different flexible pavements. Determining structural values for some of these roadways was difficult due to lack of records, subsequent resurfacing or other changes. These problems prevented the direct usage of AASHTO Flexible Design Guide values in all cases but the general concept appeared feasible. Structural ratings for each pavement section were selected that either would relate to or be identical to the AASHTO structural numbers developed by currently used design procedures. Where it was not practical to use AASHTO values directly, a structural rating was assigned by comparing the layer types and thicknesses with other pavements while taking into account performance, materials and traffic.

Observed field performance is not always consistent with the rather rigid character of the AASHTO procedures. This is probably due to material variability (particularly soils, traffic volumes, construction variability and other environmental factors). Although inconsistencies are encountered, the overall design-performance comparison has been shown to be related and can be relied upon in most instances. A sound relationship between pavement structural ratings and in service measurements of structural ability would improve the reliability of the AASHTO procedure.

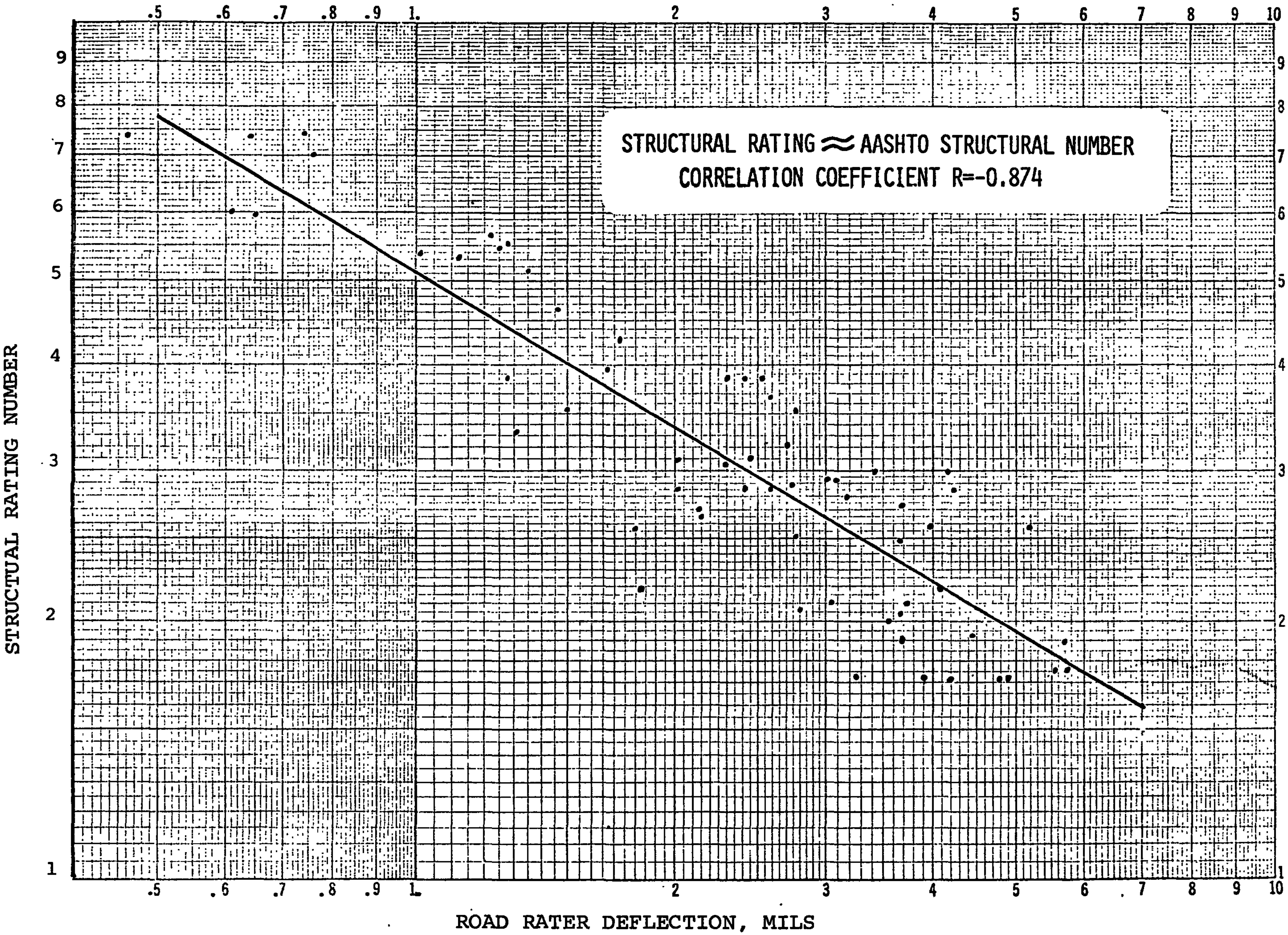

Figure 7. Structural Rating Number vs. Road Rater Deflection from Spring, 1976 data.

The correlation of this data indicated confidence in the AASHTO procedure can be strengthened. After trials with other plots, a log-log basis was selected to avoid a nonlinear regression line. The correlation shown in Figure 7 resulted in a correlation coefficient of -0.874. There appears to be no major inconsistencies in the data points.

Determination of Seasonal Deflection Variation of Flexible Pavement

In the work plan for this project, the seasonal variation study was scheduled to begin in March, 1976. Many problems have prevented acceptable collection of data for this purpose. First, the Road Rater arrived later than planned. Next, due to correlation and routine testing priorities, sufficient spring data was not obtained. Due to the abnormally dry fall of 1976, the data obtained is not considered to be typical and will not be used.

The roadway section selected for seasonal variation study are:

	Highway	County	From	To
1.	Ia. 175	Hamilton	I-35	Hardin County Line
2.	Ia. 7	Webster	US. 169	Calhoun County Line
3.	Ia. 4	Guthrie	Panora	Ia. 141
4.	Ia. 89	Boone-Dallas	Woodward	Madrid
5.	Ia. 210	Story	Slater	US. 69
6.	US. 71	Cass.	N. Jct. Ia. 92	Atlantic
7.	Ia. 3	Wright-Franklin	US. 69	Hampton
8.	Ia. 107	Franklin	Alexander	Meservey

The seasonal variation data will be obtained during 1977 to develop factors for different times of the year so all data may be related to the unstable spring deflections. Testing could be conducted any time except when the ground is frozen and multiplied by an appropriate factor to be related to the "standard" time of year.

Determination of Increased Structural Capability Due to Resurfacing

The Road Rater deflection data will be very useful in determining the thickness of resurfacing needed to achieve a desired structural capability. Testing of one resurfacing project was included in 1976 where data was obtained before and after. More resurfacing projects will be tested in 1977 to establish or support previously established methods of determining overlay requirements.

ROAD RATER EQUIPMENT PROBLEMS

There has been a continuous problem of leakage from the air-spring system. This did not cause a problem with testing or the results, but made it necessary to check and adjust the air pressure periodically. A pressurized air tank was purchased so that the pressure in the air system could be adjusted in the field at any time.

There has been some trouble with the hydraulic system. The hydraulic filter developed a leak and had to be replaced. Late in the 1976 testing season a hydraulic servo valve became inoperable and was replaced.

During the winter of 1976-77, it was noted that the front axle suspension of the van was showing some distortion caused by the weight of the Road Rater unit. A subsequent investigation of the front axle problem showed that Foundation Mechanics, Inc. had not met a Federal requirement for certification of the load carrying capacity of the front axle after modification.

Foundation Mechanics was contacted about the front suspension and indicated a willingness to aid in correcting the problem. They contacted Ford Motor Company and requested information and assistance. Ford personnel were very helpful in giving advice on the suspension needs considering the particular loading application. Ford Motor Company, however, has a policy that they will not recertify any unit.

Stronger springs were installed at the front axle. During this installation and inspection of the front suspension, both front suspension assemblies were found to be bent and required straightening.

After consideration of all aspects including mounting the test unit at the rear of the unit, a decision was made to use the Road Rater as originally constructed with the modification of the stronger springs and the straightened axles. This suspension problem rendered the Road Rater unit inoperable for March and April, 1977. This has caused the testing program to be delayed and some proposed testing may not be completed as scheduled. A careful surveillance of this problem will be necessary and the condition will be reviewed continually.

Deflection Variation Caused by Pavement Temperature

Pavement temperature has a definite bearing on the resultant deflection of flexible pavements. Higher temperatures caused greater deflections and lower temperatures yield decreased deflections. Again, the objective would be to establish this relationship so all data could be related to a "standard" temperature. A Raytek remote reading infrared surface temperature gun has been purchased to obtain pavement temperature. The gun has been tested for accuracy against a thermocouple both in the laboratory and in the field. There is good correlation at pavement temperatures above 90° F and below 60° F the infrared gun yields poor results.

Summary of 1976 Road Rater Deflection Data

The 1976 summary of deflection data is given in Appendix C. The Road Rater has demonstrated its ability to increase the quantity of testing. With this greater capacity for testing, an inventory program can be initiated. The goal will be to establish structural ratings for all primary flexible roadways in Iowa. Specific requests for pavement deflection testing will, however, continue to be given priority. As can be noted from the summary, only a limited amount of testing has been conducted on the secondary system.

Appendix A

Method of Test for Determining Pavement Deflection Using The Road Rater

Test Method No. Iowa 1009-A
June 1977

IOWA DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION

Office of Materials

METHOD OF TEST FOR DETERMINING PAVEMENT DEFLECTION USING THE ROAD RATER

Scope

The Road Rater is an electronically controlled, hydraulically powered unit mounted on the front of a van type vehicle. The unit inputs a dynamic force into the pavement and measures the movement of the surface using velocity sensors. This velocity is integrated to show displacement which is referred to as pavement deflection which is a measure of structural adequacy. The pavement deflection data can be used to predict the performance of the surface, the probable maintenance required, and the resurfacing needed to restore the surface to required structural capability.

Procedure

A. Apparatus

1. Road Rater (Figure 1)
2. Air Pressure Gauge
3. Temperature equipment (Raytek Infrared gun or thermocouple)
4. Safety Support Vehicles

B. Test Record Form

Original data is recorded on a data processing input form (see example on Page 4). If available the following data should be recorded:

1. The numeric designation of the county
2. The highway system: P-primary, S-secondary, I-interstate
3. The state or county route designation
4. Beginning and ending milepost on the primary system or mileage designation on the secondary system.
5. Direction of the lane being tested
6. Pavement Type: PC-Portland cement concrete, AC-Asphaltic concrete, SC-seal coat
7. Date tested: May 4, 1977 - 050477
8. Time: When testing begins based on a 24 hr. clock
9. Lab Number and Year Built
10. Observer: The person operating the Road Rater
11. Weather: Cl-cloudy, S-sunny, PC-partly cloudy, C-clear
12. History by year and structural rating
13. The location (by milepost or odometer), range (Road Rater console selection), sensor 1 (per cent of meter), sensor 2 and remarks (an identification of a complete remark shown at the bottom).
14. Remarks should include: lane designation on multilane roadways, air and surface temperatures, fixed references and unusual conditions.

C. Test Procedures

1. Determination of testing frequency

   a. A minimum of 30 individual tests shall be obtained per test section when inventorying. A minimum of 50 individual tests are needed for special evaluation of a given roadway.

      1. Under 3 miles adjust spacing to obtain 30 tests.

      2. For test sections of 3 to 5 mile lengths, use a 0.2 mile interval that is offset so the tests in one lane are between the tests in the adjacent lane.

      3. For 5 to 8 mile lengths use a 0.3 mile interval.

4. For test sections greater than 8 miles in length, use a 0.5 mile interval.

b. Testing frequency shall be as noted or as directed by the engineer for special test sections.

2. Preparation prior to testing

a. Open overhead engine compartment vent.

b. Check engine oil level.

c. Start the engine and allow to run for a five minute warm-up period.

d. Check air pressure in the two upper air springs with a good tire air pressure gauge. Add air if required to bring the spring pressure to 50±5 psi.

e. Check air pressure in the six center air springs. This check must be made with the small valve that separates the two sets of air springs in the open position (clockwise to open). Add air as may be required to bring this pressure to 40±5 psi. Close the small valve (counter-clockwise) until finger-tight.

f. Install the channel that holds the sensors in the recess at the base of the foot. Lock the channel in place with set screws. For normal operation, only sensor No. 1 and No. 2 will be used. Secure the electrical connections to the recepticles designated for No. 1 and No. 2.

g. On the console (figure 2) within the vehicle place the power switch to "monitor". Hold the function switch to "elevate". Hold the movement switch in the "raise" position until the elevator cylinders are "full up" against the stops.

h. With the unit in the "full up" condition lift the upper lock rings on the elevator cylinders and remove the two sets of mechanical locking tubes.

i. With the power switch to "monitor" and the function switch held to "elevate", hold the movement switch to "lower" until the unit has been lowered sufficiently to elevate the van. Maintain these switch positions until no motion is evident (allow about 5 seconds).

j. With the function switch held to "elevate" and the movement switch held to "lower", read the system hydraulic pressure on the gauge. The pressure should be 600±25 psi.

k. Set the frequency control at 25 Hertz.

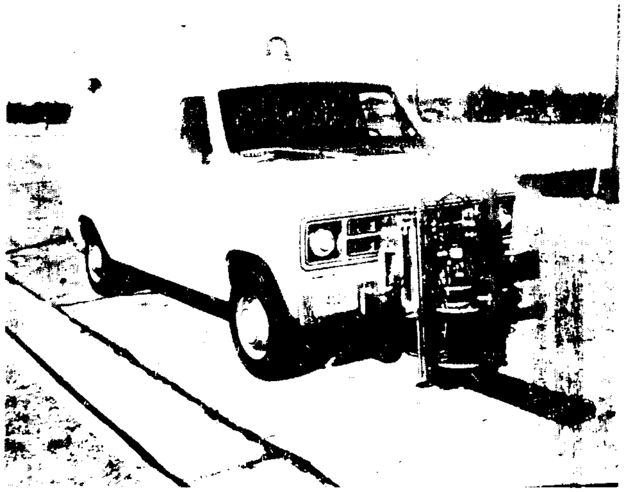

Figure 1

The Road Rater

l. Place the function switch to vibrate and set meter No. 4 to read 58 by adjusting with the "level" control.

m. Observe the reading on Meter No. 1.

n. Repeat steps g, i, l and m to check the repeatability of the setting

o. Raise the unit to the "full up" position.

p. Stop the engine and check the level of hydraulic oil in the reservoir. Use clean "Aeroshell Fluid 4" to bring the level to between 1 and 2 inches from the top of the reservoir.

3. Testing Operation

a. With the engine running, position the Road Rater foot over the outside wheel track at the predetermined longitudinal location.

b. Place the vehicle in the "park position".

c. Lower the unit sufficiently to elevate the van, maintain the switch positions for about 5 seconds until no motion is evident.

d. With the power switch in "monitor" and the function switch in "vibrate" verify a 58 per cent reading on meter No. 4.

e. Select a range that will yield a reading between 50 and 100 on meter No. 1.

f. Record the lane, milepost, range and readings for sensor #1 and #2. Note any changes in surface type.

g. Raise the unit and proceed to the next test location.

4. After testing operation

a. When traveling between testing locations assure that the elevator cylinders remain in the up position. If traveling more than 2 miles without testing, engage the mechanical locking tubes and "lower" the unit to secure them.

b. Upon completion of testing, remove the channel holding the sensors.

D. Precautions

1. Do not move the vehicle with the unit in the down position. A red light on the console indicates that the testing unit is too low to travel.

2. Before moving onto the traveled portion of the roadway, insure that all traveling safety is as required by the Traffic Engineering layout. Be sure that the required signs are in position and that all warning lights are functioning.

3. Read the Road Rater "Owners Manual Operations and Maintenance Guide" before operating the unit.

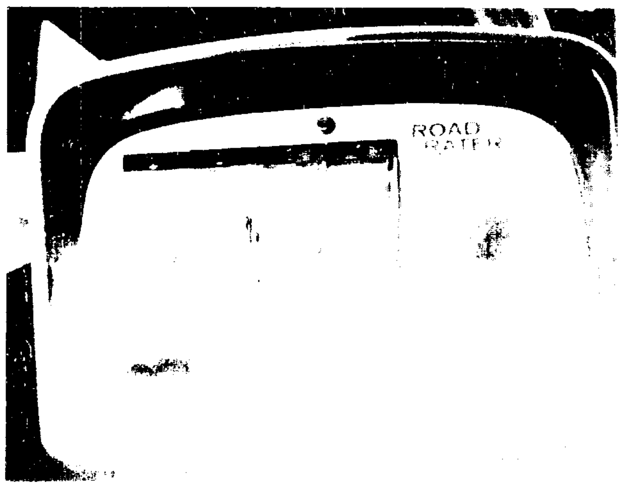

Figure 2

The control console of the Road Rater showing the selection controls and display meters.

OFFICE OF MATERIALS
ROAD RATER TESTS

SHEET NO. ___ (79)

1 COUNTY ___ (2) HIGHWAY SYS. ___ (4) ROUTE ___ (5) BEGINNING MP ___ . ___ (9) ENDING MP ___ . ___ (14) DIRECTION ___ (19)

PAVEMENT TYPE ___ (20) DATE TESTED ___ (24) TIME ___ (30) LAB NUMBER RR ___ (35) – ___ (36) YEAR BUILT ___ (40)

OBSERVER ___ (42) WEATHER ___ (59) ___ (64) SR ___ (66) ___ (69) SR ___ (71) ___ (74) SR ___ (76)

1	LOCATION (2)	RANGE (8)	READING SENSOR1 (10)	READING SENSOR2 (12)	REMARKS (14)	LOCATION (18)	RANGE (24)	READING SENSOR1 (26)	READING SENSOR2 (28)	REMARKS (30)	LOCATION (34)	RANGE (40)	READING SENSOR1 (42)	READING SENSOR2 (44)	REMARKS (46)	77
2	.		.	.		.		.	.		.		.	.		01
2	.		.	.		.		.	.		.		.	.		02
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2	.		.	.		.		.	.		.		.	.		11
2	.		.	.		.		.	.		.		.	.		12

REMARKS

STNN–SURFACE TEMPERATURE *PINT*–PRIMARY INTERSECTION *SINT*–SECONDARY INTERSECTION *DINT*–INTERSECTION W/DRIVEWAY *XX*–OTHER

1	2	6	77
3			01
3			02
3			03
3			04

Appendix B

Method of Test for Determing Pavement Deflection Using the Benkelman Beam

IOWA STATE HIGHWAY COMMISSION

Materials Department

METHOD OF TEST FOR DETERMINING PAVEMENT DEFLECTION USING THE BENKLEMAN BEAM

Scope

The Benkelman Beam is used to determine the deflection of road surfaces under an 18,000 pound axle load. Information gathered from the Benkelman Beam studies is an indication of structural adequacy. The resulting information can be used to predict the performance of the surface, the probable maintenance required, and the resurfacing needed to restore the surface to required structural adequacy.

Procedure

A. Apparatus

1. Benkelman Beam (Fig. 1)
2. Truck with 18,000 pound axle load.
3. Watch with sweep hand.
4. Thermometer or thermocouple.
5. Safety support vehicles (3).

B. Test Record Form

Original data is recorded in a field book having the following columns:

1. Station or miles.
2. Lane.
3. Position (inside or outside wheel track).
4. L_o (initial reading).
5. L_1 (intermediate reading).
6. L_f (final reading).
7. $\triangle$ (vertical displacement of front legs).
8. True Deflection.

Entries of the air and surface temperature, date, time and remarks are also made in the field book.

C. Test Procedure

The test is conducted according to the Canadian Good Roads Association (CGRA) method as follows (Fig. 2):

1. The rear wheels of the truck are stopped on the selected station or odometer reading.
2. The probe point of the Benkelman Beam is placed between the rear dual wheels of the truck in the wheel track being tested.
3. The dial is observed until the rate of movement is less than 0.001 inch per minute at which time the initial reading (L_o) is noted and recorded.
4. The truck is then moved ahead 8'-4-1/2" (the distance from the probe point to the front legs) and again the reading (L_1) is not taken and recorded until the movement is less than 0.001 inch per minute.
5. The rear wheels are then moved 30 ft. ahead of the probe point and the final reading (L_f) is taken and recorded in the same manner as above.

D. Precautions

1. The beam should be vibrated to relieve any friction by lightly tapping it near the pivot on top with the fingers.
2. The beam is quite sensitive and should not be used when the wind is adversely affecting the readings.
3. A constant (K) should be determined for each Benkelman Beam. The constant for the I.S.H.C.'s present beam is 2.90.

E. Calculation

The true deflection is calculated from the following formula:

$D = D_a + K \cdot \triangle$

Where:

D = true deflection

$D_a = 2(L_f - L_o)$ apparent deflection

$\triangle = 2(L_f - L_i)$ = vertical displacement of front legs.

L_f = final reading

L_i = intermediate reading

L_o = initial reading

K = beam constant

Notes

The spacing and location of test sections are determined by the engineer in charge of the operation.

A more complete explanation of the CGRA method is given in "Highway Research Record" Number 129.

Reporting of Results

Resulting true deflections are tabulated from the field book and submitted to data processing for a standard statistical analysis program. The average deflection, maximum deflection, minimum deflection, standard deviation, coefficient of variation, date tested and location of the test section are reported.

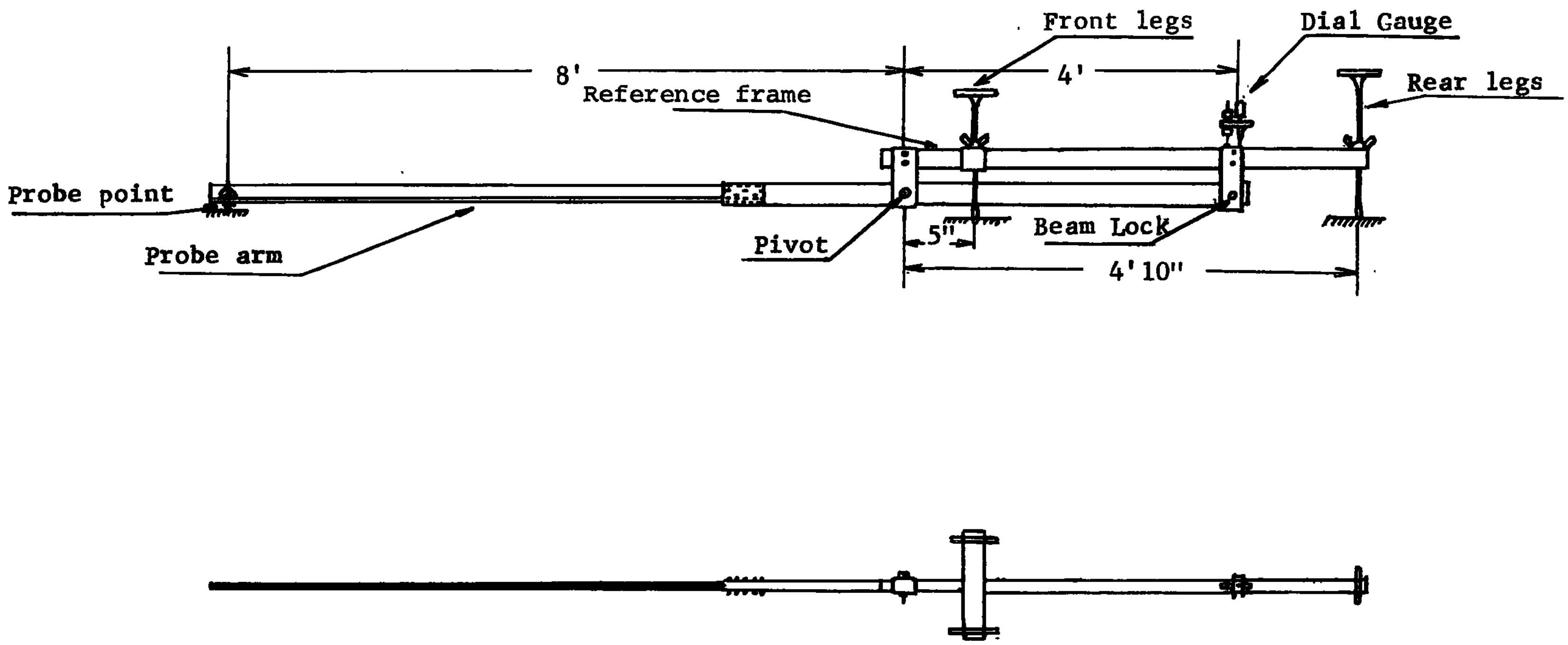

Figure 1. BENKELMAN BEAM

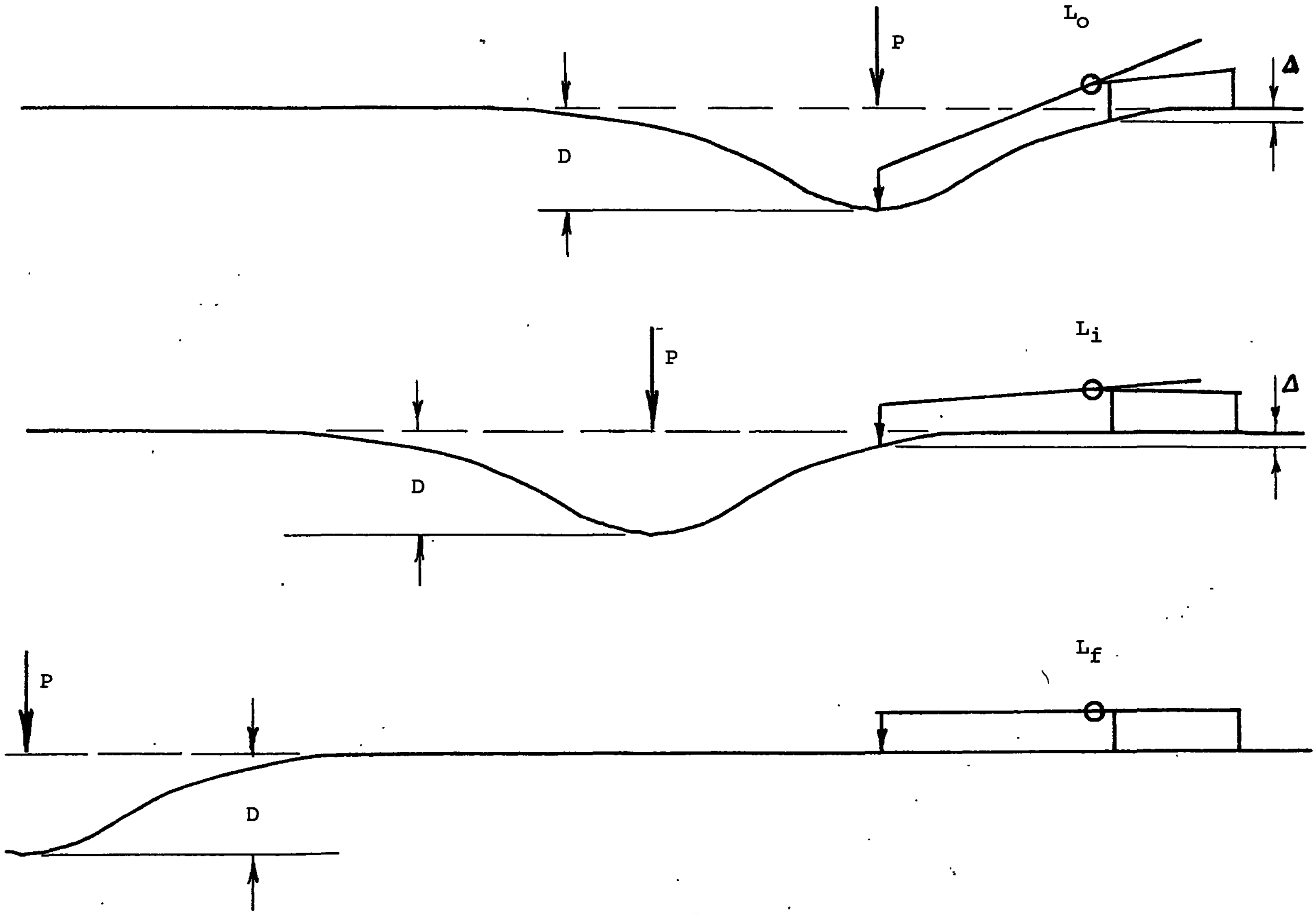

FIGURE 2. CGRA method of deflection measurement.

Appendix C

Summary of the 1976 Road Rater Pavement Deflection Data

ROAD RATER APRIL 19 TO MAY 27, 1976
PRIMARY & SECONDARY ROADS

Hwy. No.	County	From	To	Direction	No. of Tests	Mean Value (Mils)	Upper Test Value (Mils)	Lower Test Value (Mils)	Standard Deviation	Coef. of Variatio
I-80	Adair	MP 74	MP 85.5	EB	25	1.21	1.68	0.76	0.289	24.0
				WB	24	1.22	1.84	0.74	0.278	22.7
				EB & WB	49	1.22	1.84	0.74	0.281	23.1
I-80	Adair	MP 86	MP 99	EB	27	0.84	1.20	0.52	0.152	18.2
				WB	27	0.69	0.90	0.54	0.085	12.3
				EB & WB	54	0.76	1.20	0.52	0.143	18.8
I-80	Jasper & Poweshiek	Kellogg	Grinnell	EB	18	0.65	1.12	0.40	0.164	25.4
				WB	16	0.62	0.88	0.48	0.108	17.3
				EB & WB	34	0.64	1.12	0.40	0.139	21.9
I-80	Johnson	MP 226	MP 240	EB	28	0.47	0.56	0.32	0.060	12.9
				WB	28	0.46	0.70	0.30	0.091	19.5
				EB & WB	56	0.46	0.70	0.30	0.076	16.4
I-80	Cedar	MP 258	MP 266	EB	16	0.75	1.04	0.50	0.129	17.2
				WB	16	0.72	0.96	0.46	0.161	22.4
				EB & WB	32	0.74	1.04	0.46	0.145	19.7
I-35	Clarke	Osceola	Warren Co. Line	NB	19	1.08	1.36	0.54	0.181	16.7
				SB	20	0.94	1.24	0.58	0.192	20.5
				NB & SB	39	1.01	1.36	0.54	0.198	19.6
Ia. 107	Franklin	Alexander	Meservey	NB	13	4.97	6.80	3.00	1.24	24.9
				SB	15	5.39	8.00	3.80	0.996	18.5
				NB & SB	28	5.19	8.00	3.00	1.11	21.4

All Testing in Outside Wheeltrack.

Hwy. No.	County	From	To	Direction	No. of Tests	Mean Value (Mils)	Upper Test Value (Mils)	Lower Test Value (Mils)	Standard Deviation	Coef. of Variatic
Ia. 107	Cerro Gordo	Meservey	Thornton	NB	12	3.77	5.00	2.90	0.629	16.7
				SB	13	3.53	4.50	2.60	0.571	16.2
				NB & SB	25	3.64	5.00	2.60	0.599	16.4
Co. Rd.	Franklin	Chapin	Sheffield	NB	17	3.87	5.80	2.00	1.111	28.7
				SB	16	3.93	5.60	2.40	1.012	25.8
				NB & SB	33	3.90	5.80	2.00	1.048	26.9
Ia. 326	Butler	Ia. 3	Bristow	NB	10	4.09	5.60	3.00	0.677	16.6
				SB	10	4.60	9.20	3.40	1.671	36.3
				NB & SB	20	4.35	9.20	3.00	1.268	29.2
Ia. 54	Floyd	Marble Rock	Ia. 14	EB	10	3.24	5.40	1.70	1.154	35.6
				WB	10	3.84	5.80	2.50	0.860	22.4
				EB & WB	20	3.54	5.80	1.70	1.037	29.3
Ia. 227	Mitchell	US 218	Stacyville	NB	11	1.56	2.20	1.02	0.366	23.5
				SB	10	1.44	1.80	1.08	0.230	16.0
				NB & SB	21	1.50	2.20	1.02	0.307	20.5
Ia. 312	Mitchell	Ia. 9	McIntire	NB	11	3.07	3.90	1.80	0.789	25.7
				SB	10	3.07	5.00	2.00	0.990	32.2
				NB & SB	21	3.07	5.00	1.80	0.867	28.2
US 63	Chickasaw	New Hampton	Ia. 289	NB	15	1.27	1.72	0.80	0.280	22.1
				SB	15	1.65	3.20	0.92	0.615	37.4
Full Depth AC Sections Only				NB & SB	30	1.46	3.20	0.80	0.507	34.8
Ia. 188	Butler & Bremer	Clarksville	US 63	EB	40	3.47	6.40	1.00	1.19	34.3
				WB	43	3.36	6.00	1.00	1.09	32.4
				EB & WB	83	3.41	6.40	1.00	1.13	33.2

[illegible] Testing in Outside Wheeltrack.

Hwy. No.	County	From	To	Direction	No. of Tests	Mean Value (Mils)	Upper Test Value (Mils)	Lower Test Value (Mils)	Standard Deviation	Coef. of Variation
Ia. 139	Howard	Protivin	Cresco	NB	21	2.17	2.80	1.38	0.435	20.0
				SB	22	1.88	3.10	1.08	0.536	28.5
				NB & SB	43	2.02	3.10	1.08	0.505	25.0
Ia. 325	Winneshiek	Spillville	US 52	EB	10	1.27	1.64	1.00	0.215	16.8
				WB	10	1.36	1.72	1.04	0.243	17.9
				EB & WB	20	1.31	1.72	1.00	0.227	17.2
Ia. 296	Fayette	Wadena	Ia 56	NB	10	3.28	5.20	1.90	0.931	28.4
				SB	10	2.73	3.40	2.20	0.371	13.6
				NB & SB	20	3.01	5.20	1.90	0.745	24.8
Ia. 112	Clayton	Volga	Ia. 13	EB	10	4.14	6.20	2.60	1.090	26.3
				WB	10	4.25	5.80	2.80	0.961	22.6
				EB & WB	20	4.20	6.20	2.60	1.001	23.9
US 520	Buchanan & Delaware	Ia. 187	Ia. 13	EB	16	0.62	0.82	0.44	0.121	19.5
				WB	12	0.60	0.80	0.46	0.118	19.5
				EB & WB	28	0.61	0.82	0.44	0.116	19.0
US 20	Delaware	Ia. 13	Delaware	EB	13	0.61	0.78	0.44	0.094	15.4
				WB	14	0.68	1.24	0.36	0.263	38.8
				EB & WB	27	0.65	1.24	0.36	0.200	30.9
US 20	Delaware	Ia. 38	Dyersville	EB	20	1.19	2.52	0.60	0.502	42.3
				WB	19	1.07	1.88	0.64	0.380	35.4
				EB & WB	39	1.13	2.52	0.60	0.445	39.3
Ia. 101	Benton	Vinton	Ia. 150	NB	27	1.88	2.94	0.82	0.579	30.8
				SB	28	2.03	3.00	0.70	0.543	26.7
				NB & SB	55	1.96	3.00	0.70	0.561	28.6

All Testing in Outside Wheeltrack.

Hwy. No.	County	From	To	Direction	No. of Tests	Mean Value (Mils)	Upper Test Value (Mils)	Lower Test Value (Mils)	Standard Deviation	Coef. of Variatio[n]
Ia. 198	Benton	Garrison	US 218	NB	12	3.57	5.80	1.72	1.235	34.6
				SB	11	3.80	5.00	1.80	0.980	25.8
				NB & SB	23	3.68	5.80	1.72	1.101	29.9
Ia. 200	Benton	US 30	Keystone	NB	11	2.96	3.90	2.40	0.433	14.6
				SB	12	2.54	3.10	1.84	0.327	12.9
				NB & SB	23	2.74	3.90	1.84	0.430	15.7
Ia. 96	Tama	Gladbrook	US 63	EB	12	3.94	7.00	2.70	1.266	32.2
				WB	12	4.04	6.60	2.70	1.057	26.1
				EB & WB	24	3.99	7.00	2.70	1.142	28.6
Ia. 185	Grundy	Ia. 14	Conrad	EB	10	7.66	9.40	5.60	1.079	14.1
				WB	10	7.66	13.60	5.60	2.247	29.3
				EB & WB	20	7.66	13.60	5.60	1.716	22.4
Ia. 233	Albion	Ia. 14	Marshall	EB	10	6.25	9.40	4.40	1.919	30.7
				WB	11	5.25	7.00	3.90	0.839	16.0
				EB & WB	21	5.73	9.40	3.90	1.506	26.3
Ia. 22	Keokuk	Ia. 21	Webster	EB	20	2.68	3.40	1.24	0.567	21.1
				WB	19	2.71	3.70	1.80	0.509	18.8
				EB & WB	39	2.70	3.70	1.24	0.535	19.8
Ia. 22	Keokuk	South English	Kinross	EB	11	2.46	3.20	1.52	0.517	21.0
				WB	10	2.40	3.20	1.36	0.508	21.1
				EB & WB	21	2.43	3.20	1.36	0.500	20.6
Ia. 22	Washington	Kinross	Wellman	EB	14	2.43	4.10	1.40	0.658	27.1
				WB	14	2.59	3.30	1.80	0.414	16.0
				EB & WB	28	2.51	4.10	1.40	0.546	21.8

All Testing in Outside Wheeltrack.

Hwy. No.	County	From	To	Direction	No. of Tests	Mean Value (Mils)	Upper Test Value (Mils)	Lower Test Value (Mils)	Standard Deviation	Coef. of Variation
Ia. 22	Washington	Wellman	Kalona	EB	13	1.94	2.52	1.40	0.391	20.1
				WB	14	1.53	2.04	0.84	0.341	22.3
				EB & WB	27	1.73	2.52	0.84	0.415	24.0
Ia. 22	Johnson	US 218	Ia. 405	EB	12	4.67	5.40	3.00	0.706	15.1
				WB	11	6.43	9.80	4.50	1.854	28.8
				EB & WB	23	5.51	9.80	3.00	1.619	29.4
Ia. 22	Johnson & Muscatine	Ia. 405	Nichols	EB	13	2.27	2.76	1.64	0.301	13.3
				WB	13	2.64	3.10	1.76	0.427	16.2
				EB & WB	26	2.45	3.10	1.64	0.408	16.6
Ia. 22	Muscatine	Nichols	E. Jct. Ia. 70	EB	8	2.03	2.90	1.32	0.517	25.5
				WB	8	2.24	2.70	1.64	0.424	18.9
				EB & WB	16	2.14	2.90	1.32	0.470	22.0
Ia. 22	Muscatine	E. Jct. Ia. 70	Muscatine	EB	18	2.87	3.80	1.80	0.627	21.9
				WB	18	2.77	5.00	1.40	0.970	35.0
				EB & WB	36	2.82	5.00	1.40	0.807	28.6
Ia. 16	Lee	US 218	Denmark	EB	25	3.63	5.00	2.10	0.671	18.5
				WB	26	3.54	5.40	2.22	0.667	18.9
				EB & WB	51	3.58	5.40	2.10	0.664	18.5
Ia. 88	Lee	Ft. Madison	Ia. 16	NB	15	3.45	4.80	2.10	0.932	27.0
				SB	15	3.61	5.00	2.52	0.568	15.7
				NB & SB	30	3.53	5.00	2.10	0.763	21.6
Ia. 303	Jefferson	Libertyville	US 34	NB	16	3.07	4.90	2.34	0.685	22.3
				SB	15	3.22	4.50	2.52	0.591	18.4
				NB & SB	31	3.14	4.90	2.34	0.635	20.2

1. Testing in Outside Wheeltrack.

Hwy. No.	County	From	To	Direction	No. of Tests	Mean Value (Mils)	Upper Test Value (Mils)	Lower Test Value (Mils)	Standard Deviation	Coef. of Variation
Ia. 23	Wapello	Ottumwa	Eddy-	NB	25	1.94	3.70	1.04	0.609	31.4
			ville	SB	25	1.66	2.34	1.16	0.344	20.8
				NB & SB	50	1.80	3.70	1.04	0.510	28.4
Ia. 97	Lucas	Russell	US 34	NB	10	5.16	8.60	3.40	1.525	29.6
				SB	10	4.64	6.80	2.58	1.229	26.5
				NB & SB	20	4.90	8.60	2.58	1.374	28.1
Ia. 294	Decatur	Ia. 2	Grand	NB	12	2.11	3.80	1.20	0.758	36.0
			River	SB	12	2.47	3.50	1.64	0.578	23.4
				NB & SB	24	2.29	3.80	1.20	0.685	29.9
Ia. 148	Taylor	Bedford	Gravity	NB	11	1.34	1.76	0.92	0.261	19.5
				SB	11	1.17	1.40	0.92	0.180	15.4
				NB & SB	22	1.25	1.76	0.92	0.236	18.8
Ia. 148	Taylor & Adams	Gravity	Corning	NB	28	2.77	5.60	1.38	0.914	33.0
				SB	29	2.38	4.10	1.32	0.695	29.1
				NB & SB	57	2.58	5.60	1.32	0.825	32.0
US 71	Montgomery & Cass	US 34	Atlantic	NB	58	1.64	3.40	0.84	0.518	31.7
				SB	56	1.74	3.60	0.80	0.415	23.8
				NB & SB	114	1.69	3.60	0.80	0.471	27.9
Ia. 48	Montgomery & Cass	US 34	Griswold	NB	35	1.34	1.88	0.92	0.248	18.5
				SB	32	1.23	1.76	0.84	0.265	21.6
				NB & SB	67	1.28	1.88	0.84	0.260	20.2
Ia. 48	Cass	Griswold	US 6	NB	12	1.42	1.80	1.16	0.189	13.3
				SB	11	1.13	1.52	0.88	0.172	15.2
				NB & SB	23	1.28	1.80	0.88	0.230	18.0

All Testing in Outside Wheeltrack.

Hwy. No.	County	From	To	Direction	No. of Tests	Mean Value (Mils)	Upper Test Value (Mils)	Lower Test Value (Mils)	Standard Deviation	Coef. of Variation
US 59	Pottawattamie	Ia. 244	Oakland	NB	20	1.39	1.92	1.08	0.267	19.2
				SB	20	1.33	1.64	1.04	0.209	15.7
				NB & SB	40	1.36	1.92	1.04	0.238	17.5
Ia. 145	Fremont	Thurman	US 275	EB	19	4.22	7.60	1.92	1.319	31.2
				WB	18	5.71	8.00	3.80	1.260	22.1
				EB & WB	37	4.95	8.00	1.92	1.479	29.9
Ia. 243	Woodbury	Ia. 140	Pierson	EB	14	3.39	4.80	1.80	1.024	30.2
				WB	15	3.43	5.40	2.22	0.972	28.3
				EB & WB	29	3.41	5.40	1.80	0.979	28.7
Ia. 374	Clay	US 71	Webb	EB	16	2.35	5.00	1.44	0.958	40.8
				WB	15	2.26	3.20	0.50	0.713	31.5
				EB & WB	31	2.31	5.00	0.50	0.836	36.2
Co. Rd. A-14	Kossuth	Emmet Co. Line East 1 Mile		EB	10	2.70	3.70	1.48	0.760	28.2
				WB	11	2.83	4.20	1.24	0.917	32.4
				EB & WB	21	2.77	4.20	1.24	0.828	29.9
Ia. 91	Kossuth	Ledyard	US 169	EB	13	5.55	7.20	4.20	0.942	17.0
				WB	13	5.99	7.80	4.30	1.152	19.2
				EB & WB	26	5.77	7.80	4.20	1.055	18.3
Ia. 144	Boone	Dallas Co.	Greene County	NB	12	4.32	5.40	3.40	0.562	13.0
				SB	12	3.86	4.60	3.00	0.533	13.8
				NB & SB	24	4.09	5.40	3.00	0.585	14.3
Ia. 144	Greene	Boone Co.	Rippey	NB	15	4.14	5.80	2.50	0.842	20.3
				SB	15	4.31	5.00	3.60	0.401	9.3
				NB & SB	30	4.23	5.80	2.50	0.654	15.5

[illegible] sting in Outside Wheeltrack.

Hwy. No.	County	From	To	Direction	No. of Tests	Mean Value (Mils)	Upper Test Value (Mils)	Lower Test Value (Mils)	Standard Deviation	Coef. of Variation
Ia. 144	Greene & Webster	US 30	Ia. 175	NB	32	3.85	5.80	2.40	0.746	19.4
				SB	32	3.93	5.80	2.30	0.831	21.1
				NB & SB	64	3.89	5.80	2.30	0.784	20.2
Ia. 89	Boone	Woodward	Madrid	EB	10	2.85	4.40	1.38	0.916	32.2
				WB	11	2.71	5.00	1.50	0.912	33.6
				EB & WB	21	2.77	5.00	1.38	0.894	32.2
Ia. 210	Story	Slater	US 69	EB	10	2.30	3.30	1.80	0.562	24.4
				WB	11	2.50	3.40	1.68	0.495	19.8
				EB & WB	21	2.41	3.40	1.68	0.524	21.8
Ia. 210	Story	US 69	Ia. 211	EB	31	2.46	3.50	1.70	0.444	18.0
				WB	17	2.81	4.10	1.90	0.600	21.2
				EB & WB	48	2.59	4.10	1.70	0.525	20.3
Ia. 210	Story	Ia. 211	Maxwell	EB	67	2.59	3.80	1.70	0.488	18.9
				WB	44	2.60	4.50	1.80	0.603	23.2
				EB & WB	111	2.59	4.50	1.70	0.534	20.6
Ia. 117	Jasper	I-80	US 65	NB	21	2.28	4.40	0.80	0.985	43.2
				SB	19	2.01	4.60	1.00	1.036	51.4
				NB & SB	40	2.15	4.60	0.80	1.005	46.7

All Testing in Outside Wheeltrack.