Research Report
KTC-90-22

ROAD RATER CORRELATION

by

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16. Abstract

In this study, a correlation has been conducted between the Model 400B and the Model 2000 Road Rater. Also contained in this study, is a study of the linearity of the Road Rater measurements. Information gained from this study will provide better understanding of Road Rater measurements.

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EXECUTIVE SUMMARY

A correlation has been conducted between the Model 2000 Road Rater used by the Kentucky Transportation Cabinet, Pavement Management Branch, and the Model 400B Road Rater used by the Kentucky Transportation Center. The data used were obtained as part of a correlation conducted by Purdue University in 1986.

The following analyses were performed, determination of linearity between loading levels of each machine and comparison between the Model 2000 and Model 400B.

Some non-linearity between loading levels on flexible pavements was observed for both models, but it was better defined with the Model 2000. Regression equations have been developed relating the various loading levels. These equations should be utilized when scaling from one loading level to another.

A direct correlation was found between the two machines; however, it was not a 1 to 1 relationship. Regression analysis was performed on each pavement type for each sensor location and regression equations were developed. These regression equations should be used when comparing deflections from the two machines.

Some seasonal variability was observed; however, due to the limited amount of data throughout the year a reliable conclusion cannot be made.

INTRODUCTION

The Kentucky Transportation Cabinet (KyTC) is currently using a Model 2000 Road Rater for routine non-destructive evaluation of in-situ pavements. The measurements obtained are used for overlay design rehabilitation procedures. These overlay design procedures are based on linear elastic theory, which states that there is a linear relationship between applied force and displacements of pavement systems.

Since previous research and development in Kentucky has been based on deflection measurements obtained with the Model 400B Road Rater, the correlation between these two machines is very important to the effective application of research. Experience in Kentucky has indicated that each testing device may have different characteristics. A direct correlation between the devices is of necessity.

Previous research in Kentucky indicated variable load-deflection characteristics within the dynamic range of the Road Rater. Therefore, it is necessary to evaluate the linearity of the two machines.

Linear elastic theory does not address the nonlinear stress-dependent characteristics of paving materials. A determination must be made from field data regarding the linearity of deflection measurements obtained from the Road Rater.

Previous research has also indicated that the properties of subgrade materials change on a seasonal basis. It is therefore necessary to evaluate the response of the Road Raters to different seasonal variations. The addition of seasonal data should help to better understand the seasonal behavior of pavement structures.

Various analyses have been performed to evaluate operation of the KyTC Road Rater in comparison with the KTC Road Rater. Determinations have been made regarding the linearity of the load-deflections relationships.

EQUIPMENT DESCRIPTION

The basic configurations of the Model 400B and the Model 2000 are the same. The Model 2000 has higher dynamic loading capabilities. The major differences between the two machines are as follows. The Model 400B, Figure 1, was mounted on the front of a crew cab pickup truck. The Model 2000, Figure 2, is mounted on a trailer. There is considerable difference between the static loads applied by the different models. The Model 400B has a static preload of 1,670 pounds force, while the Model 2000 has a static preload of 3,500 pounds force.

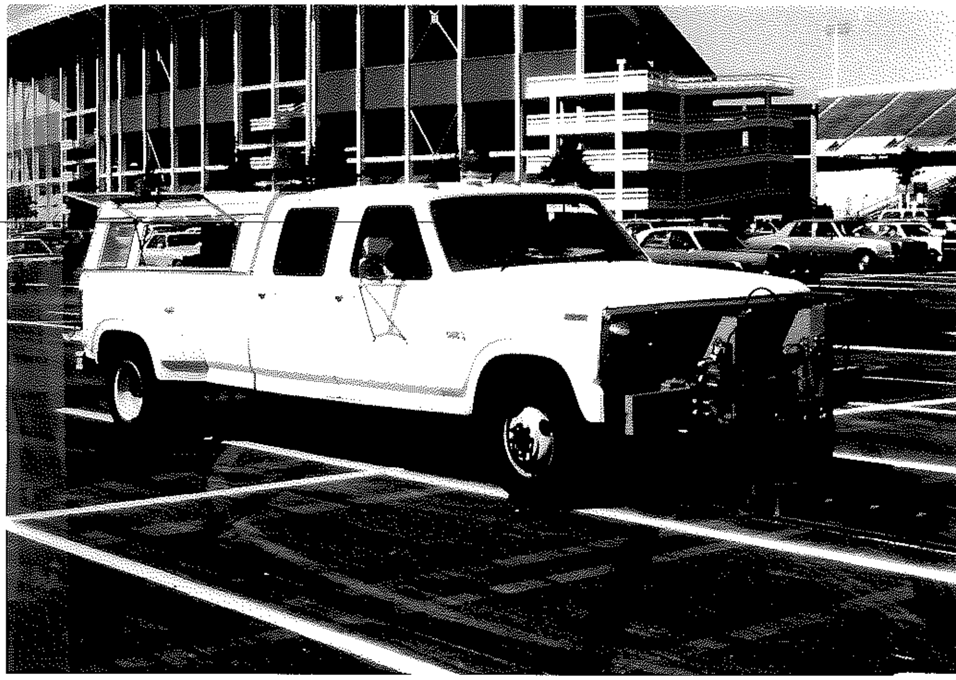

Figure 1. Kentucky Transportation Center Model 400B Road Rater

Figure 2. Kentucky Transportation Cabinet Model 2000 Road Rater

TEST LOCATION

All sites used in this study were included in the correlation conducted by Purdue University in 1986. Tests at each location were conducted in March and April 1986, then again in the fall of 1986. Each test section was approximately 1,000 feet in length. Six tests were conducted in each section at various loading levels. The test sections included 26 Asphaltic Concrete Pavements (AC), 30 Jointed Reinforced Concrete Pavements (JRCP), and 18 Continuously Reinforced Concrete Pavements (CRCP). A total of 468 tests were conducted on AC pavements with the Model 400B and 780 were conducted with the Model 2000. For JRCP pavements, 540 tests were conducted with the 400B and 900 tests were conducted with the 2000. Results from the AC and JRCP were analyzed in this study. Limited use of CRCP in Kentucky precluded analyses of those data.

There were six sites on flexible pavements and nine sites on rigid pavements for which data for both machines were available for spring and fall. Spring tests were conducted in late March and early April. Fall or late summer tests were all conducted in August.

TEST LOADS

Data were obtained with both the Model 400B and Model 2000 Road Rater using loads of 600, 1,200, and 1,800 lb. Additional tests were performed at 2,400 and 3,600 lb. using the Model 2000 since it has a higher loading capacity. These additional loading levels provide added information for evaluating the linearity of the data.

All measured deflections have been scaled to their nominal load values of 600, 1,200, 1,800, 2,400 and 3,600 lb., respectively. The scaling process consists of multiplying each deflection by the ratio of the nominal load divided by the actual applied load (nominal load/actual load). This process is necessary because there is some variability in the loading of the machines. The applied load tends to vary around the target load (nominal load). This process assumes linearity between the applied load and resulting deflection. All comparisons have been made using the 1,200 lb load as the reference load. Separate comparisons have been made for flexible pavements and rigid pavements due to their different behavior characteristics.

ANALYSIS

Statistical analyses were performed on all data. Two statistical parameters will be given in the following analysis. A brief description of each follows.

R Squared:	This is a measure of the goodness of fit, the closer to 1 the better the line fits the data.
Standard Error of the Y Estimate:	This is the standard error of the estimated Y values. It is actually the standard deviation of the regression line through the data.

CORRELATION BETWEEN LOAD LEVELS

In the analyses, the deflection at 1,200 lb was plotted as the independent variable. Deflections at other load levels were plotted as dependent variables. This yields two relationships between load levels for the Model 400B and four relationships for the Model 2000. The load relationships are as follows.

Model 400B	Model 2000
600 lb vs 1,200 lb	600 lb vs 1,200 lb
1,800 lb vs 1,200 lb	1,800 lb vs 1,200 lb
	2,400 lb vs 1,200 lb
	3,600 lb vs 1,200 lb

Flexible Pavements

Figures 3 and 4 contain plots of each of the loading relationships mentioned previously for flexible pavements. Also included on these plots are the linear regression lines for each set of data. Results of these regressions are presented in Tables 1 and 2. These tables indicate that at all loading levels the regression line has a very high R^2 value. This indicates the regression line fits the plotted data very well. The y intercept is small, in each case, therefore, the slope of the regression line is essentially the ratio between the actual load and the reference load of 1,200 lb.

Figure 5 depicts the relationship between the regression lines slopes and load levels for both devices. Also shown are slopes for lines which would be obtained using linear elastic theory. The pavement appears to behave less linearly with increasing load levels (slopes of the regression lines increase). The non-linear effects are less evident at the lower load levels. The assumption of a linear load - displacement relationship could be used at load levels below 1,800 lb. The non-linear effects should be recognized and evaluated at load levels above 1,800 lb.

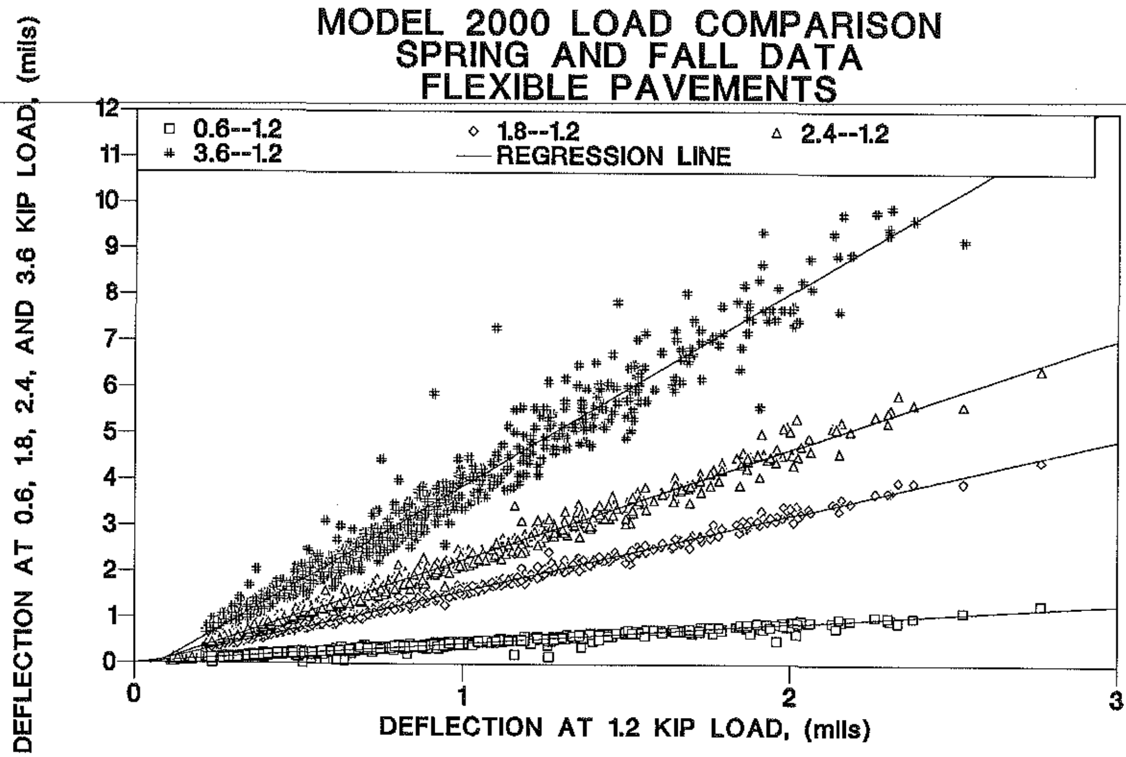

Figure 3. Deflection comparison, Model 2000, Flexible Pavements

Table 1. Statistical Analysis Model 2000, Flexible Pavements

Regression Analysis	Model 2000 AC Pavements			
	0.6 vs 1.2	1.8 vs 1.2	2.4 vs 1.2	3.6 vs 1.2
Slope	0.4324	1.651	2.3961	4.1827
Intercept	0.0198	-0.0467	-0.1153	-0.3032
R^2	0.964	0.9945	0.9890	0.9634
Std. Err. of Y Est.	0.0397	0.0586	0.1205	0.3872
Number of Observations	787	787	787	650

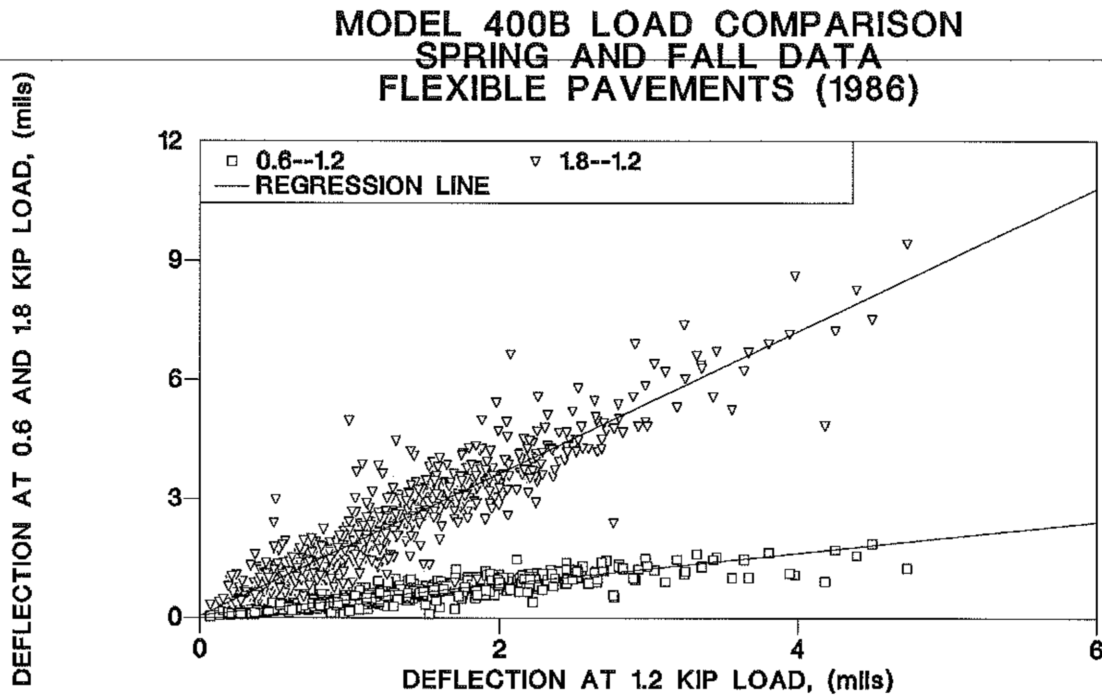

Figure 4. Deflection Comparison, Model 400B, Flexible Pavements

Table 2. Statistical Analysis Model 400B, Flexible Pavements

Regression Analysis	Model 400B AC Pavements	
	0.6 vs 1.2	1.8 vs 1.2
Slope	0.3939	1.7934
Intercept	0.0438	0.4679
R^2	0.8510	0.8896
Std. Err. of Y Est.	0.1169	0.4482
Number of Observations	1,025	1,025

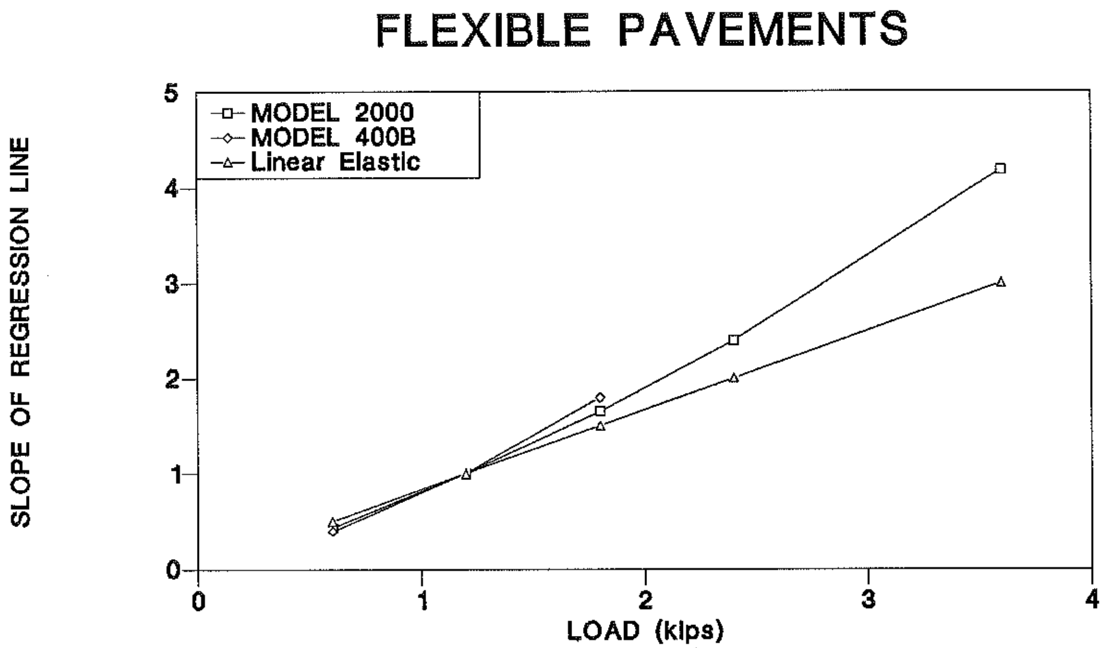

Figure 5. Relationship between Magnitude and slope of Regression Lines (Flexible Pavements)

RIGID PAVEMENTS

Similar plots for rigid pavements are shown in Figures 6 and 7, with the regression line for each. Results of the regression analyses are listed in Tables 3 and 4. The R^2 values for rigid pavements are lower than those of the flexible pavements. The wide variability may be due to the effects of temperature on the concrete slab. The slabs may have been tested in a curled or warped condition which would effect the load-displacement relationship. These tables indicate rigid pavements behave more linearly than flexible pavements. A comparison of the slopes from these tables indicates the rigid pavement regression slopes have better agreement with linear elastic slope values. If the system behaved as a linear elastic system it would have linear regression slopes of 0.5, 1.5, 2, and 3 for each load level, respectfully. A plot of slope vs load for rigid pavements is shown in Figure 8. A linear relationship appears to exist up to 2,400 lb. Nonlinear behavior becomes evident above 2,400 lb.

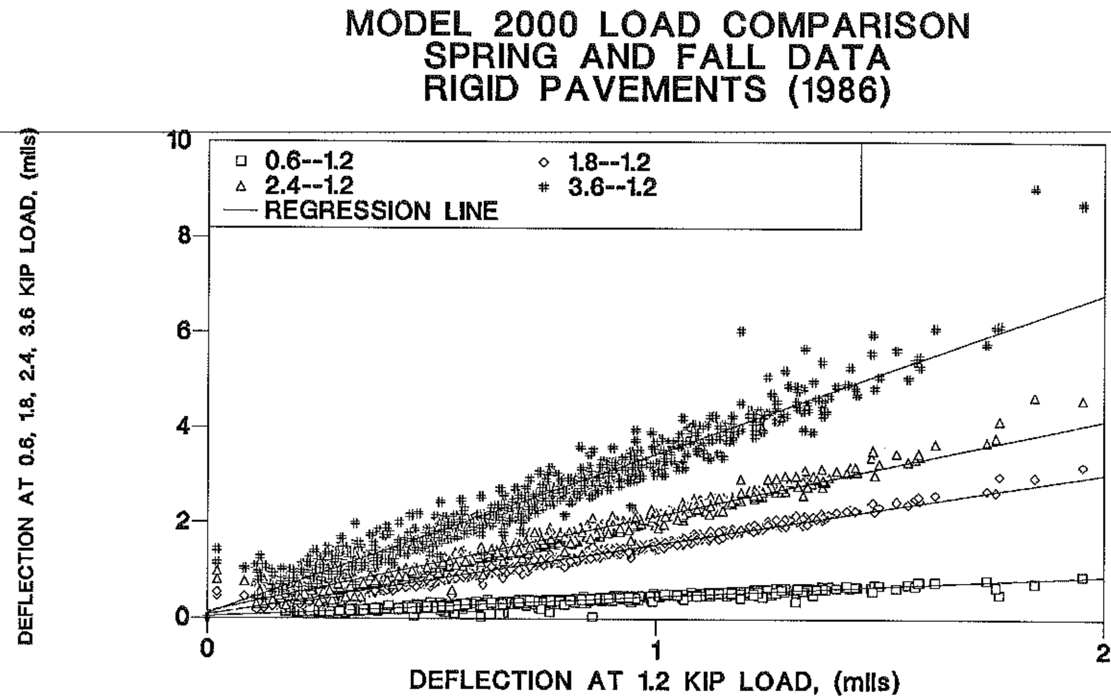

Figure 6. Deflection Comparison, Model 2000, Rigid Pavements

Table 3. Statistical Analysis Model 2000, Rigid Pavements

Regression Analysis	Model 2000 AC Pavements			
	0.6 vs 1.2	1.8 vs 1.2	2.4 vs 1.2	3.6 vs 1.2
Slope	0.4306	1.4833	2.0087	3.348
Intercept	0.278	0.0724	0.1389	0.0972
R^2	.9239	0.9803	0.9558	0.9456
Std. Err. of Y Est.	0.0399	0.0747	0.1534	0.2855
Number of Observations	673	849	849	775

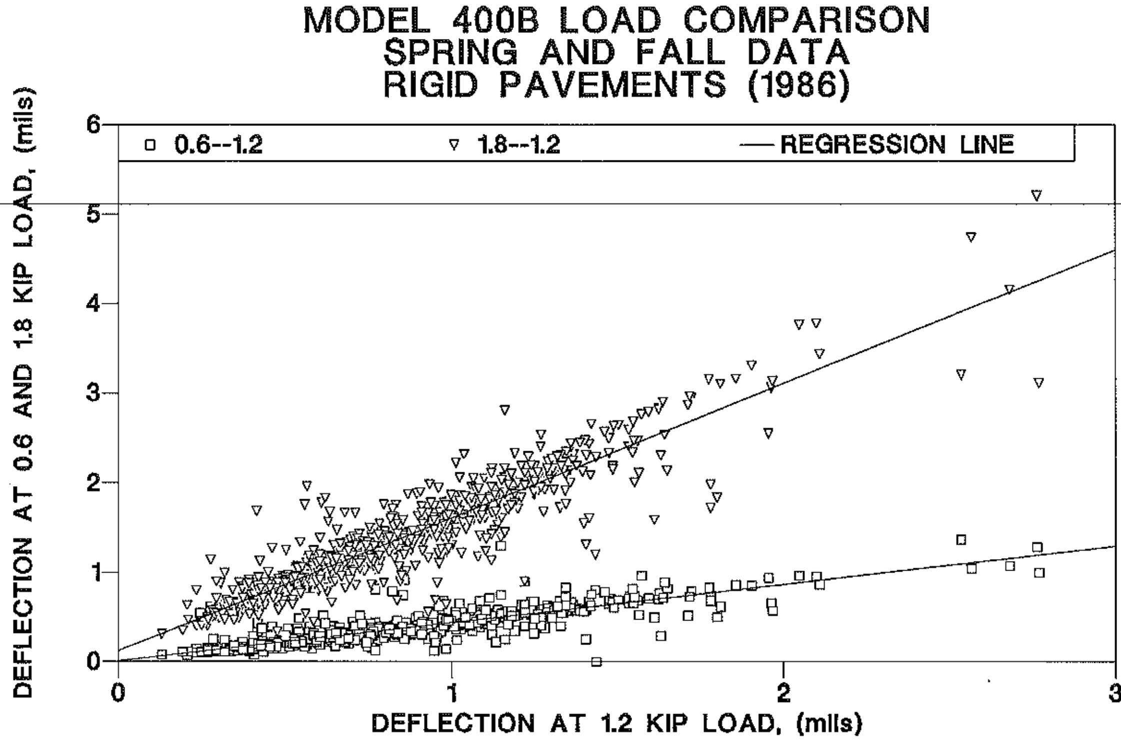

Figure 7. Deflection Comparison, Model 400B, Rigid Pavements

Table 4. Statistical Analysis Model 400B, Rigid Pavements

Regression Analysis	Model 400B JRCP Pavements	
	0.6 vs 1.2	1.8 vs 1.2
Slope	0.4279	1.4912
Intercept	0.0162	0.1214
R^2	0.7871	0.8745
Std. Err. of Y Est.	0.0834	0.2117
Number of Observations	962	962

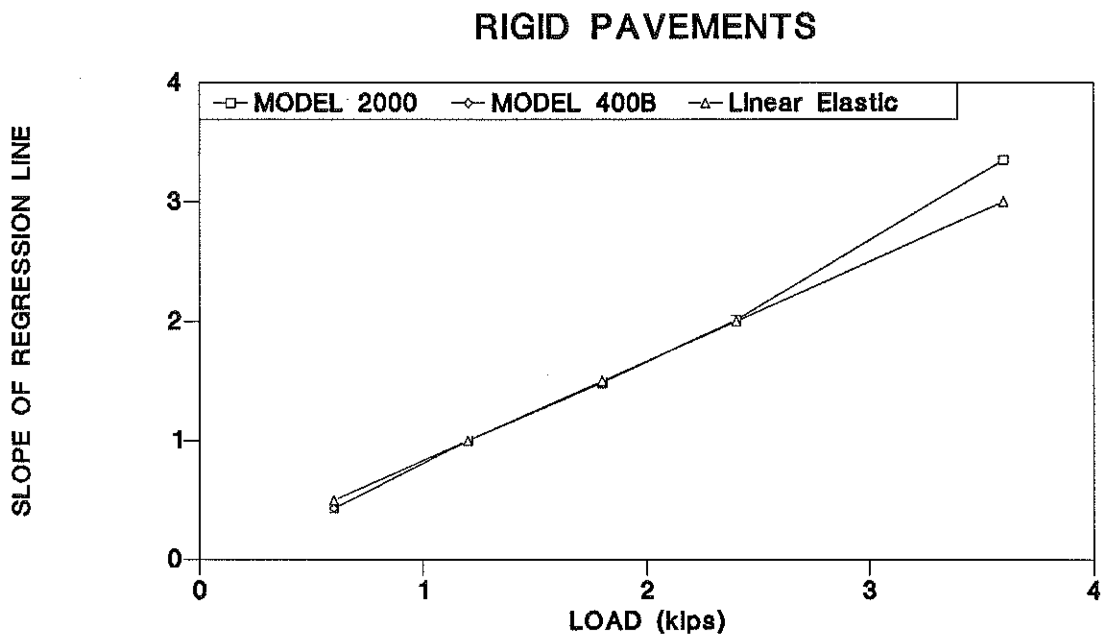

Figure 8. Relationship Between Load Magnitude and Slope of Regression Lines (Rigid Pavements)

COMPARISON BETWEEN DEVICES

COMPARISON BY SENSOR

A comparison was made between the 2000 and 400B at load levels of 600, 1,200, and 1,800 lb. The comparisons were made by plotting the 400B deflections as the independent variable and the 2000 deflections as the dependant variable. When there was more that 100 percent difference between the deflections of the two machines, that particular set of deflections was not used in the analysis. It was assumed such large differences were due to mechanical error.

Deflection data for all sensors and all loads from the Model 400B were combined into one data set and were compared with the equivalent data from the Model 2000. This was performed for flexible and rigid pavements. These comparisons are illustrated in Figures 9 and 10, respectively. A linear regression analysis was performed on the data in each figure and the results are listed in Tables 5 and 6. These tables indicate good correlation between the machines for both pavement types (both R^2 are greater that 0.8).

The solid lines in Figures 11 through 18 are the regression lines. The dashed lines are the 90 percent confidence limits of the data. This is defined as 1.645 standard deviations from the mean value or this is 1.645 times the standard error of the Y estimate for the regression analysis. These lines define an area for which there is 90 percent confidence that actual data are contained in this range.

It may also be seen that there is some variability between the two machines at different sensor locations. Good correlation may be achieved on a sensor- by-sensor basis.

Table 5. Deflection Comparison, All Loads (Flexible Pavement)

Regression Analysis	2000 - 400B Deflection Comparison				
	All	Sensor 1	Sensor 2	Sensor 3	Sensor 4
Slope	0.719	0.7256	0.6303	0.6863	0.7000
Intercept	0.1078	0.2418	0.1629	0.1004	0.0745
R^2	0.9047	0.9251	0.8862	0.8592	0.8352
Std. Err. of Y Est.	0.2276	0.2576	0.2289	0.1777	0.1434
Number of Observations	1,874	458	473	483	447

Table 6. Deflection Comparison, All Loads (Rigid Pavements)

Regression Analysis	2000 - 400B Deflection Comparison (Rigid)				
	All	Sensor 1	Sensor 2	Sensor 3	Sensor 4
Slope	0.7259	0.8409	0.6169	0.6832	0.6399
Intercept	0.1173	0.1420	0.1734	0.1113	0.1145
R^2	0.8177	0.8472	0.8252	0.8416	0.8551
Std. Err. of Y Est.	0.2128	0.2422	0.1964	0.1567	0.1303
Number of Observations	1,815	471	453	454	439

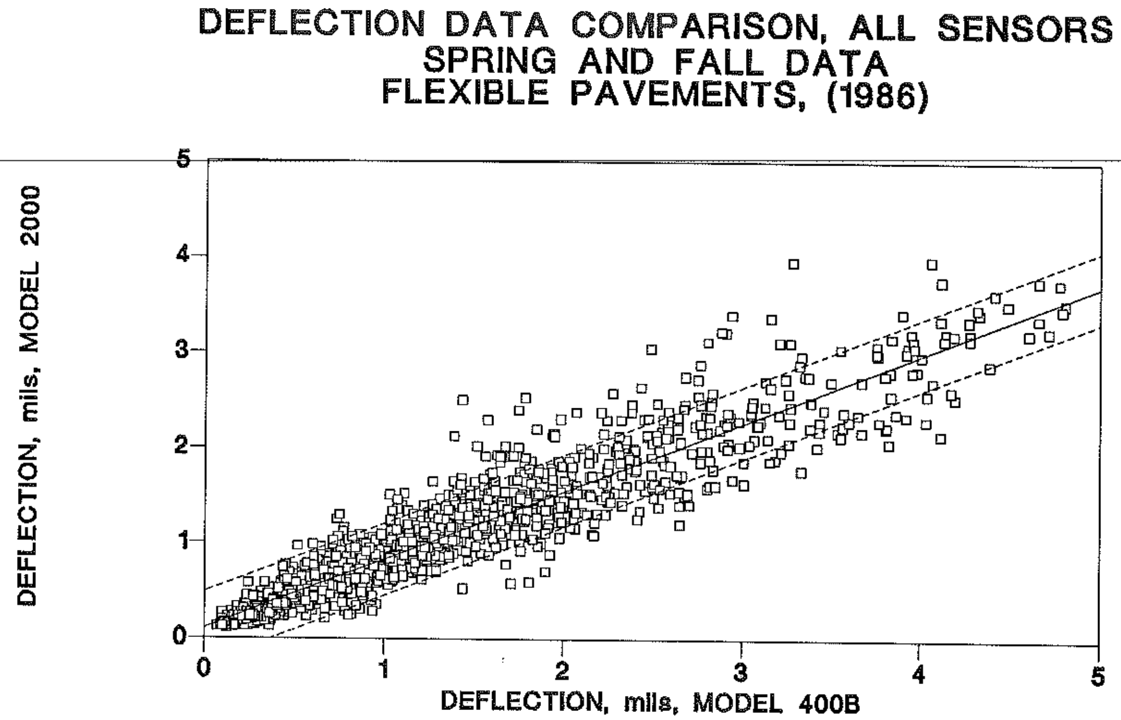

Figure 9. Deflection Comparison, Model 400B vs. Model 2000, All Sensors, Flexible Pavements

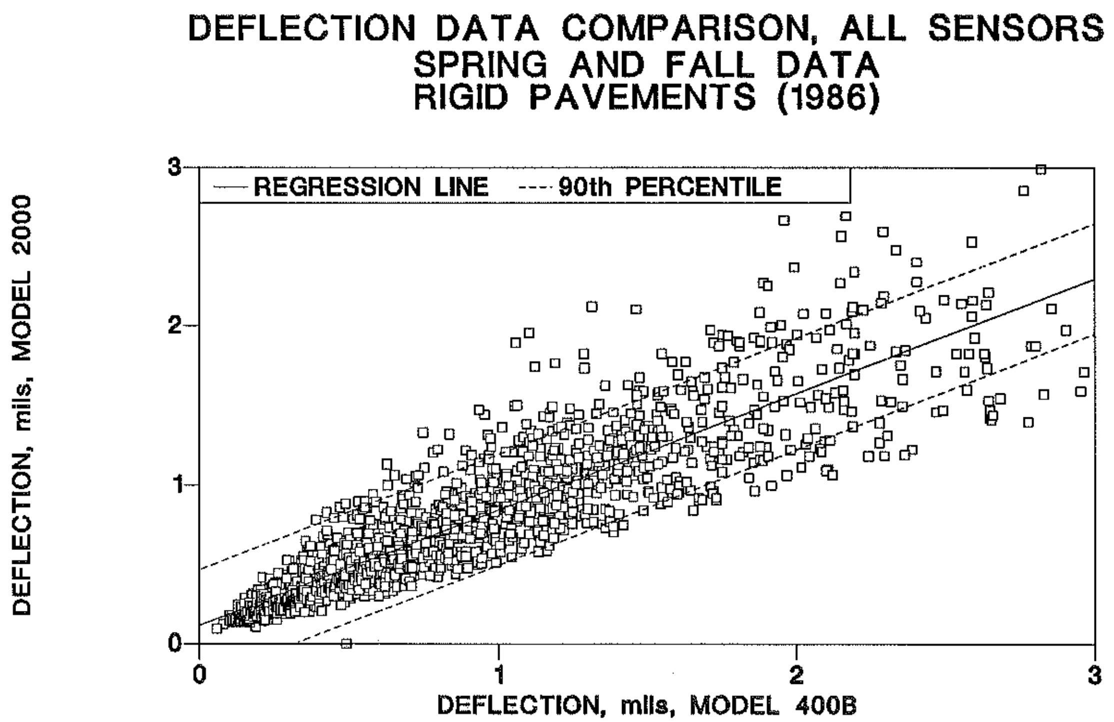

Figure 10. Deflection Comparison, Model 400B vs. Model 2000, All Sensors, Rigid Pavements

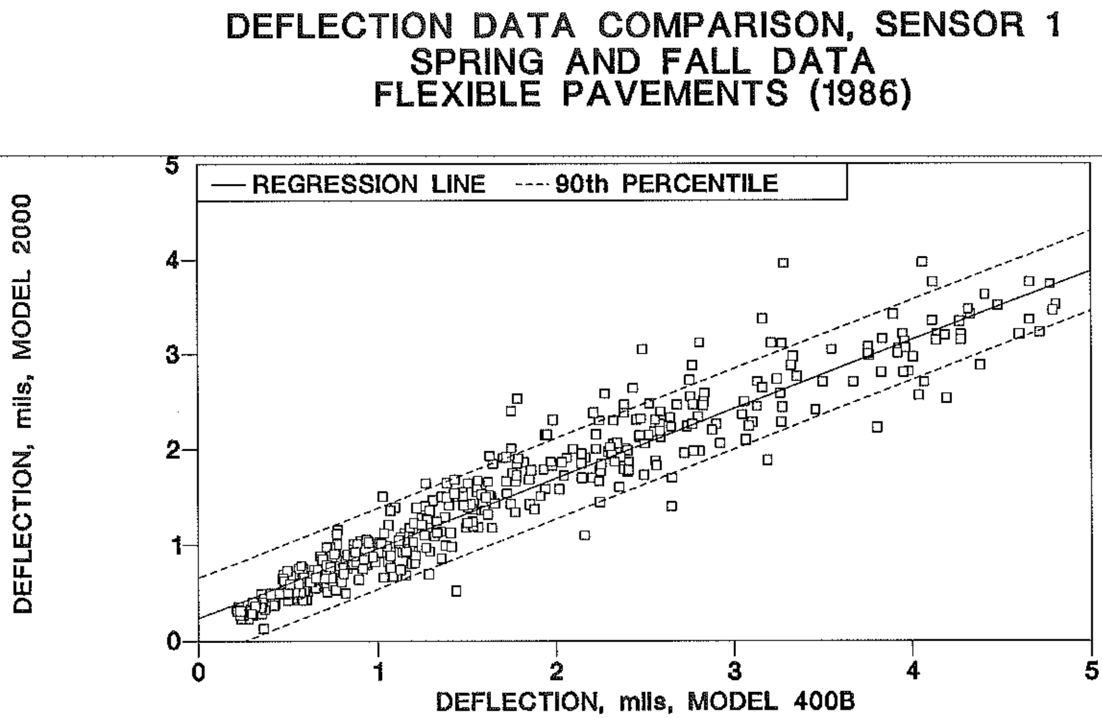

Figure 11. Deflection Comparison, Model 400B vs. Model 2000, Sensor 1, Flexible Pavements

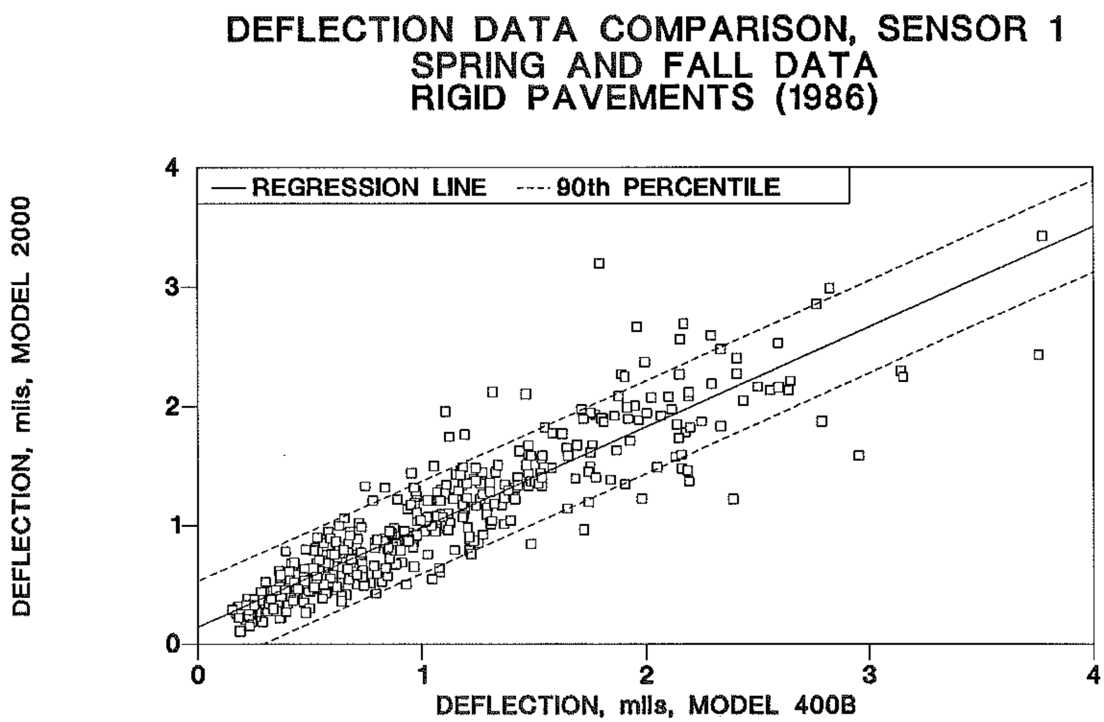

Figure 12. Deflection Comparison, Model 400B vs. Model 2000, Sensor 1, Rigid Pavements

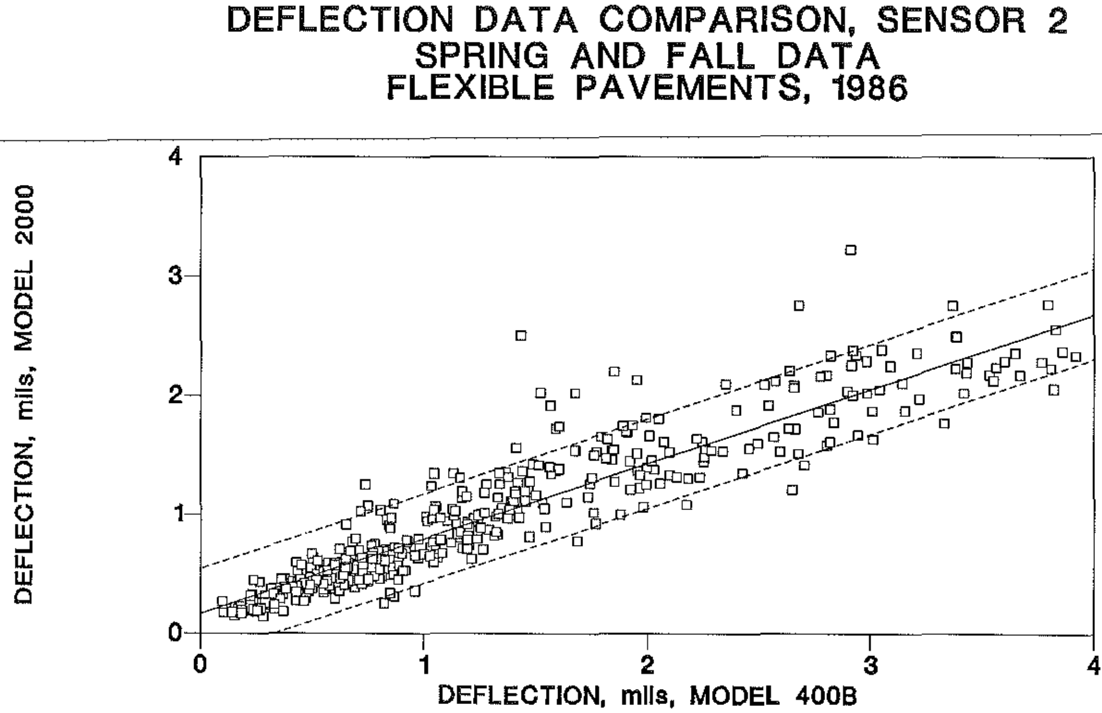

Figure 13. Deflection Comparison, Model 400B vs. Model 2000, Sensor 2, Flexible Pavements

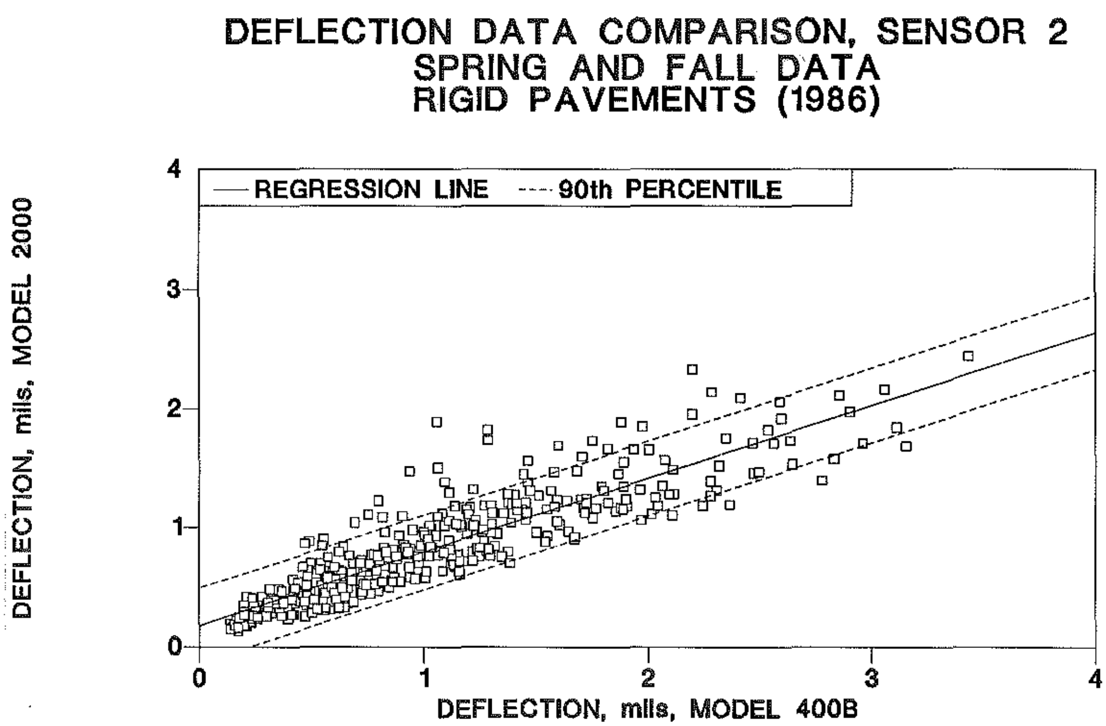

Figure 14. Deflection Comparison, Model 400B vs. Model 2000, Sensor 2, Rigid Pavements

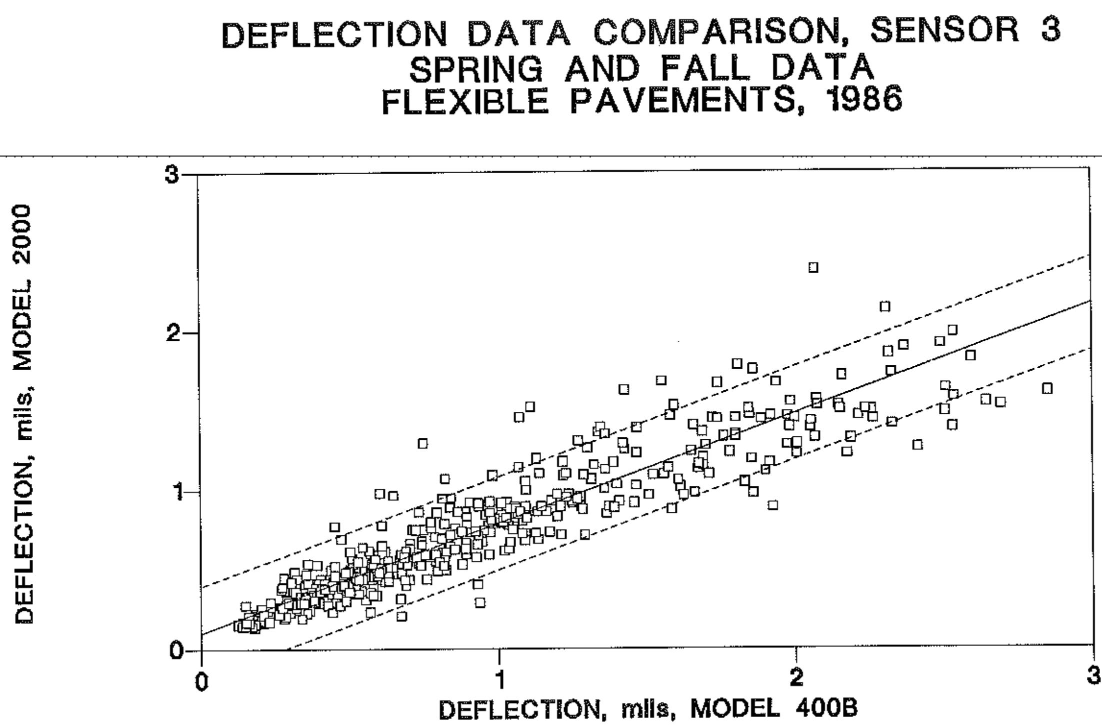

Figure 15. Deflection Comparison, Model 400B vs. Model 2000, Sensor 3, Flexible Pavements

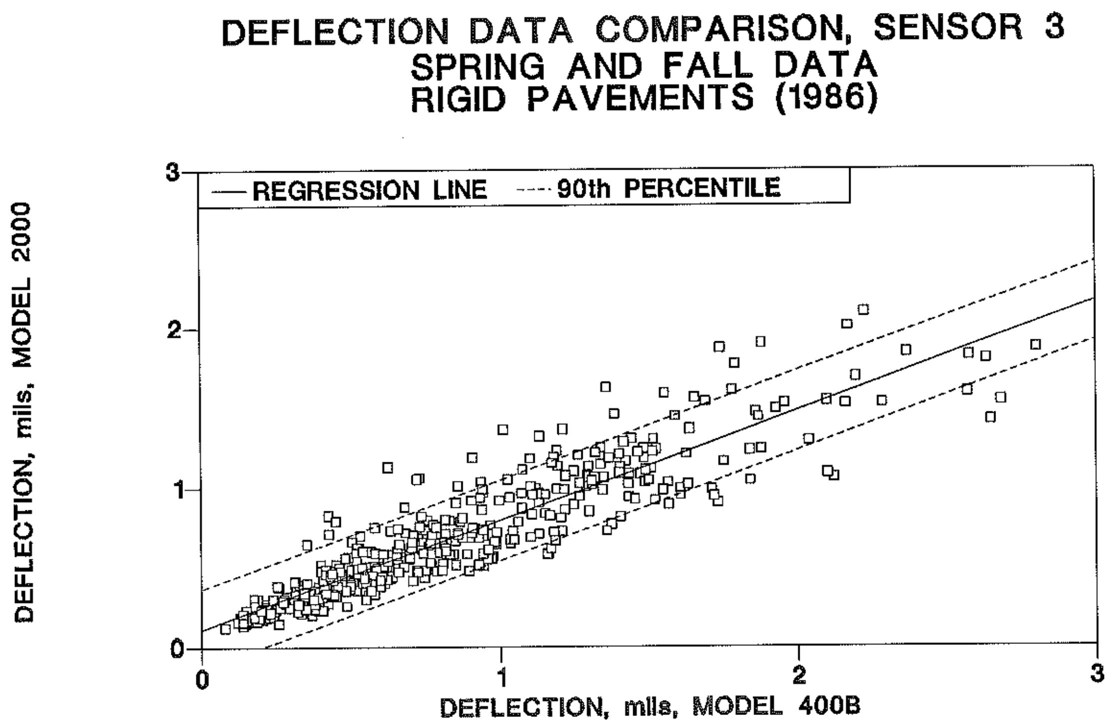

Figure 16. Deflection Comparison, Model 400B vs. Model 2000, Sensor 3, Rigid Pavements

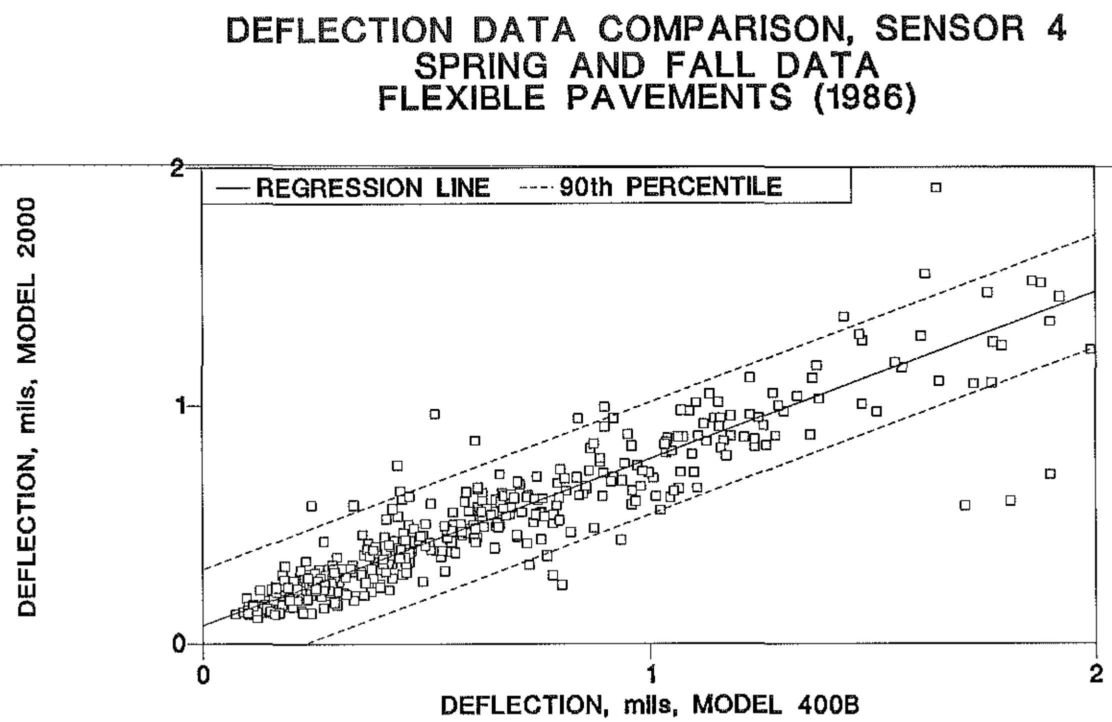

Figure 17. Deflection Comparison, Model 400B vs. Model 2000, Sensor 4, Flexible Pavements

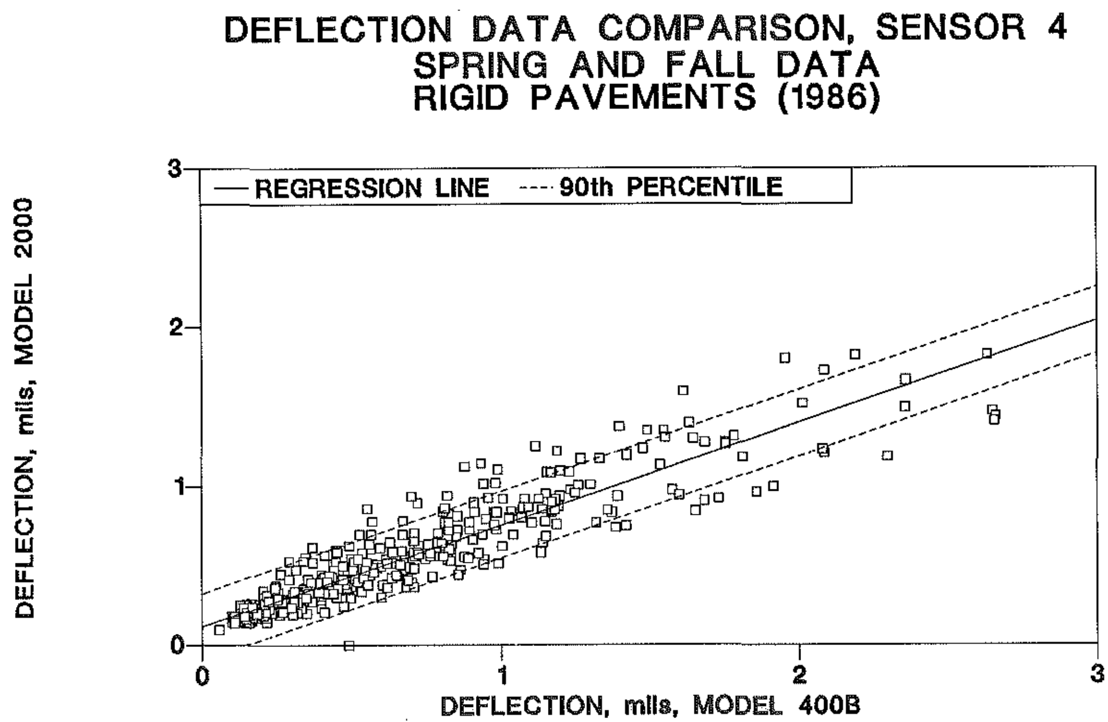

Figure 18. Deflection Comparison, Model 400B vs. Model 2000, Sensor 4, Rigid Pavements

COMPARISON BY SEASON

There were six sites on flexible pavements and nine sites on rigid pavements where both spring and fall data were obtained for both machines. Each pavement type was analyzed separately for both spring and fall data. The spring tests were conducted in late March and early April. The fall or late summer tests were conducted in August. A linear regression analysis was performed separately on the spring and fall data. Tables 7 and 8 contain results of these analyses.

The following analysis was conducted to determine if the number of sites which were available were adequate for proper statistical analysis. A regression analysis was conducted for increasing numbers of observations. The calculated slope of the regression line was plotted versus the number of observations. This result is shown in Figure 19. Similar plots of the R^2 and standard error of the Y estimate are shown in Figures 20 and 21, respectively. The slope of the regression line does not change above 40 observations. The standard error of the Y estimate does not change above 80 observations and R^2 does not change significantly above 50 observations. In all cases, there were sufficient observations for the regression parameters to reach nearly constant values. Based on this analysis, it is concluded that the number of sites available was sufficient to accurately characterize the relationship between the two machines.

Table 7. Regression Analysis for Flexible Pavements (Spring and Fall 1986)

Regression Analysis	2000 - 400B Deflection Comparison				
	Date	Sensor 1	Sensor 2	Sensor 3	Sensor 4
Slope	Spring	0.7118	0.5997	0.6111	0.7073
	Fall	0.7625	0.6547	0.6918	0.7921
Intercept	Spring	0.2058	0.1577	0.1457	0.0958
	Fall	0.2469	0.1683	0.1293	0.0808
R^2	Spring	0.9474	0.9257	0.8794	0.7249
	Fall	0.9221	0.9009	0.8794	0.7920
Std. Err. of Y Est.	Spring	0.1623	0.1702	0.1641	0.2194
	Fall	0.2168	0.1719	0.1382	0.1590
Number of Observations	Spring	33	82	79	60
	Fall	102	99	96	91

Table 8. Regression Analysis for Rigid Pavements (Spring and Fall 1986)

Regression Analysis	2000 - 400B Deflection Comparison				
	Date	Sensor 1	Sensor 2	Sensor 3	Sensor 4
Slope	Spring	0.8182	0.6129	0.7130	0.7406
	Fall	0.9874	0.6576	0.6872	0.6815
Intercept	Spring	0.1651	0.1616	0.0977	0.0905
	Fall	0.1467	0.1779	0.1195	0.1171
R^2	Spring	0.8210	0.8282	0.8549	0.9002
	Fall	0.8877	0.8319	0.8604	0.8787
Std. Err. of Y Est.	Spring	0.2600	0.2026	0.1669	0.3692
	Fall	0.1954	0.1886	0.1534	0.1277
Number of Observations	Spring	81	103	101	96
	Fall	146	145	143	141

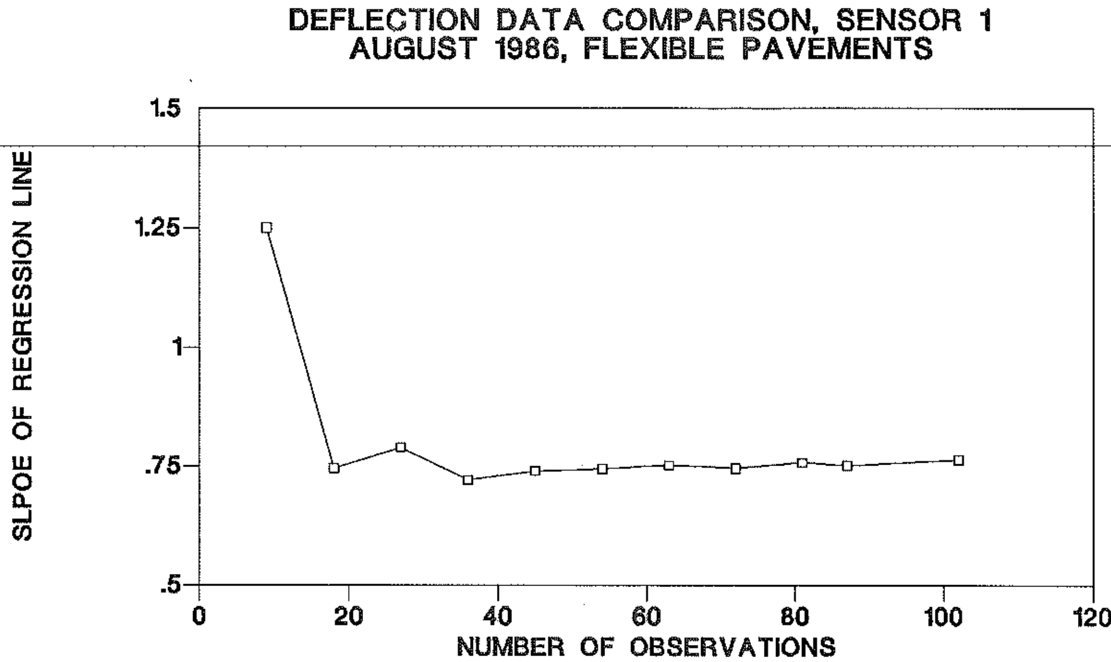

Figure 19. Slope of the Regression Line vs Number of Observations

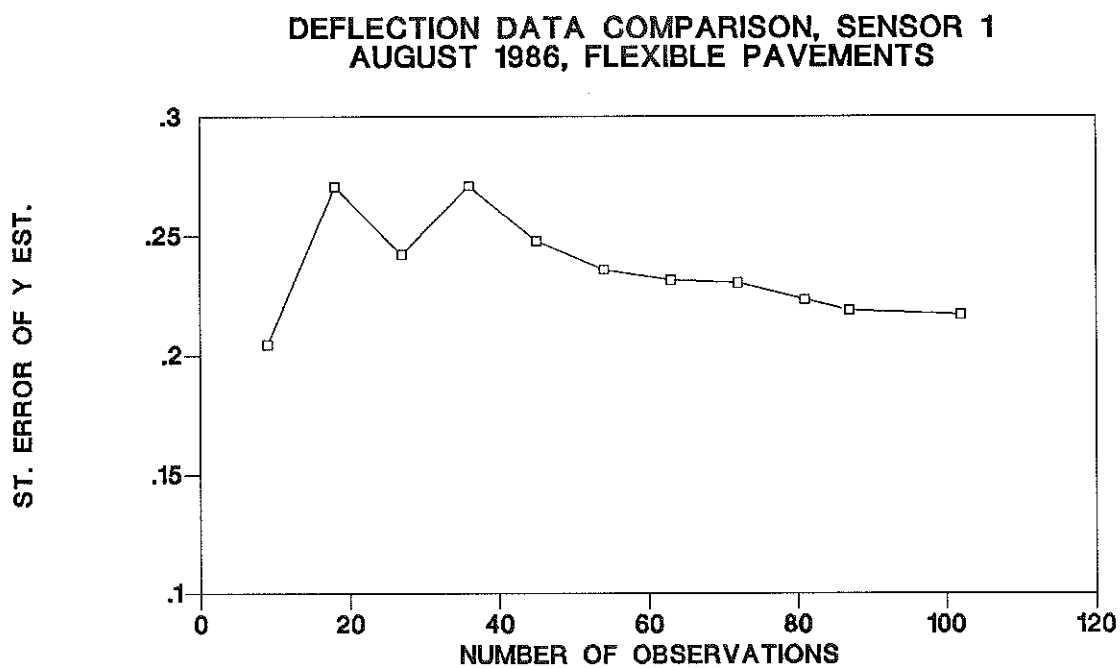

Figure 20. Standard Error of the Y Estimate vs Number of Observations

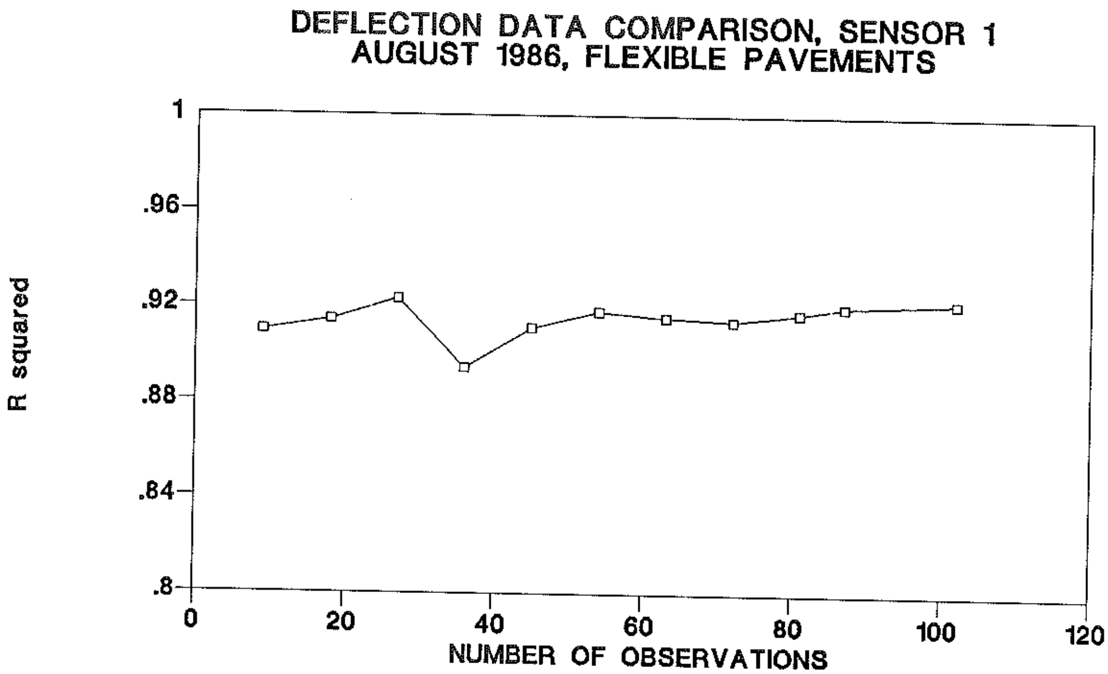

Figure 21. R Squared vs Number of Observations.

It may be noted from the previous tables that there are considerable differences between the calculated slope values for the spring and fall data. These differences vary from a increase in slope of 20.68 percent to a decrease of 3.6 percent. Since data were only obtained during these months, a relationship of seasonal variation cannot be determined.

CORRELATION EQUATIONS

A direct ratio may be used when scaling the deflection measurements to their nominal load, i.e. 1.21 kips to 1.2 kips. The results of the regression analysis must be used. Equations have been developed for the regression analysis relating the various load levels when scaling from one load level to another 0.6 to 1.2 kips),.

The equations are in a linear form of,

$$Defl_{600} = \text{Slope} \times Defl_{1,200} + \text{Intercept},$$

where $Defl_{1,200}$ is the independent variable, $Defl_{600}$ is the dependant variable, Slope is the slope of the linear regression line, and Intercept is the intercept on the y axis. The regression equations are as follows.

Model 2000, Flexible Pavements

600 lb vs. 1,200 lb	600 lb, Defl. = 0.4324 x (1,200 lb, Defl.) + 0.0198
1,800 lb vs. 1,200 lb	1,800 lb, Defl. = 1.651 x (1,200 lb, Defl.) - 0.0467
2,400 lb vs. 1,200 lb	2,400 lb, Defl. = 2.3961 x (1,200 lb, Defl.) - 0.1153
3,600 lb vs 1,200 lb	3,600 lb, Defl. = 4.1827 x (1,200 lb, Defl.) - 0.3032

Model 400B, Flexible Pavements

600 lb vs. 1,200 lb	600 lb, Defl. = 0.3939 x (1,200 lb, Defl.) + 0.0438
1,800 lb vs. 1,200 lb	1,800 lb, Defl. = 1.7934 x (1,200 lb, Defl.) + 0.4679

Model 2000, Rigid Pavements

600 lb vs. 1,200 lb	600 lb, Defl. = 0.4306 x (1,200, lb Defl.) + 0.2780
1,800 lb vs. 1,200 lb	1,800 lb, Defl. = 1.4833 x (1,200, lb Defl.) + 0.0724
2,400 lb vs. 1,200 lb	2,400 lb, Defl. = 2.0087 x (1,200, lb Defl.) + 0.1389
3,600 lb vs 1,200 lb	3,600 lb, Defl. = 3.3480 x (1,200, lb Defl.) + 0.0972

The following equations have been developed from the regression analysis to correlate the two Road Raters.

Flexible Pavements

Sensor 1	Model 2000 Defl.1 = 0.7256 x (Model 400B Defl.1) + 0.2418
Sensor 2	Model 2000 Defl.2 = 0.6303 x (Model 400B Defl.2) + 0.1629
Sensor 3	Model 2000 Defl.3 = 0.6863 x (Model 400B Defl.3) + 0.1004
Sensor 4	Model 2000 Defl.4 = 0.7000 x (Model 400B Defl.4) + 0.0745

Rigid Pavements

Sensor 1	Model 2000 Defl.1 = 0.8409 x (Model 400B Defl.1) + 0.1420
Sensor 2	Model 2000 Defl.2 = 0.6169 x (Model 400B Defl.2) + 0.1734

Sensor 3	Model 2000 Defl.3 = 0.6832 x (Model 400B Defl.3) + 0.1113
Sensor 4	Model 2000 Defl.4 = 0.6399 x (Model 400B Defl.4) + 0.1145

These equations should be used in any comparison of deflection data between the two pieces of equipment.

CONCLUSIONS

Some nonlinear behavior was observed for both models. A measure of its linearity cannot be determined due to the limited loading range of the Model 400B. The Model 2000 has some nonlinear behavior above 1,800 lb for flexible pavements. It is much more linear for rigid pavements which would be expected.

The regression analysis demonstrated that the two machines may be correlated for both flexible and rigid pavements. The correlation should be on a sensor by sensor basis and not the lumping of all sensors. The two machines do not correlate on a 1 to 1 basis; however, suitable correlation can be achieved. The Model 400B generlly yields larger deflections than the Model 2000.

The reasons for these variations is not fully understood. One possible cause for the differences may be that the Model 2000 is a trailer mounted unit whereas the Model 400B is mounted on the front of a pickup truck. This difference leads to different static preload conditions. Each unit may be applying different amounts of energy to the pavement system, therefore causing differences in the resulting deflections.

There is some variability between the spring and fall measurements. The reason for this difference is not fully understood. It could be due to each machine reacting differently to seasonal changes of the pavement system.

Since the data on seasonal variation are limited to two months, it is recommended that the analysis using both the spring and fall data combined be used for comparison of the two machines. Data for the rigid pavements and flexible pavements should not be combined.