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STRUCTURAL ANALYSIS AND OVERLAY DESIGN OF PAVEMENTS USING THE ROAD RATER™

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ABSTRACT

In recent years the Iowa DOT has shifted emphasis from the construction of new roads to the maintenance and preservation of existing highways. A need has developed for analyzing pavements structurally to select the correct rehabilitation strategy and to properly design a pavement overlay if necessary. This need has been fulfilled by Road Rater testing which has been used successfully on all types of pavements to evaluate pavement and subgrade conditions and to design asphaltic concrete overlays. The Iowa Road Rater Design Method has been simplified so that it may be easily understood and used by the widely diverse groups of individuals which may be involved in pavement restoration and management.

Road Rater analysis techniques have worked well to date and have been verified by pavement coring, soils sampling and testing, and pavement removal by block sampling. Void detection testing has also been performed experimentally in Iowa, and results indicate that the Road Rater can be used to locate pavement voids and that Road Rater analysis techniques are reasonably accurate. The success of Road Rater research and development has made deflection test data one of the most important pavement management inputs.

INTRODUCTION

In recent years the Iowa DOT has shifted emphasis from the construction of new roads to the maintenance and preservation of the existing 10,000 Mile Primary Highway System. This shift in emphasis has been due to funding shortages, nearing completion of the Interstate Highway System, public sentiment against taking cropland out of production for new roads, and the overall age of the existing highway system. A need has developed for analyzing pavements structurally to select the correct rehabilitation strategy and to properly design a pavement overlay if necessary.

The Iowa DOT purchased a Model 400 Road Rater from Foundation Mechanics, Inc., A Wyle Company of El Segundo, California, in November 1975. This dynamic device which measures amplitude of movement (hereafter called deflection) replaced the Benkelman Beam, which was last used in Iowa in 1977 (1). A method for designing asphaltic concrete (a.c.) overlays for flexible pavements, utilizing Road Rater deflection measurements, was developed in 1979 and submitted to the Office of Road Design as operational in May 1980. This flexible pavement-a.c. overlay design method has worked well, but 4,560 miles of Iowa's Primary Highway System are portland cement concrete (p.c.c.). In addition, 3,700 miles of Iowa's a.c. pavements are composite (a.c. over p.c.c.) pavements rather than full depth flexible pavements. The flexible pavement-a.c. overlay design method, therefore, has had limited application in Iowa and has been more useful on the Secondary Highway System than on the Primary Highway System.

A rigid and composite pavement-a.c. overlay design method was developed in November 1982. Charts were also developed in 1983 to estimate Westergaard's modulus of subgrade reaction(K)(2). Experience gained since 1983 has verified the validity of the rigid and composite pavement-a.c. overlay design method and subgrade reaction (K) charts (3). A Road Rater structural analysis is now performed on all rehabilitation and resurfacing project candidates.

Since the deflection based a.c. overlay design methods were empirically derived, the purpose of this paper is to document research performed in Iowa. Development of the design methods, verification of the models, and application of the results are discussed. In addition, void detection testing has been performed experimentally in Iowa, and the results are also reviewed in this paper.

EQUIPMENT

The Iowa DOT purchased a Model 400 Road Rater mounted in a Ford E250 Van in 1975 from Foundation Mechanics, Inc., A Wyle Company of El Segundo, California. The Road Rater is a dynamic deflection measuring device used to determine the structural adequacy of pavements. A large mass is hydraulically lowered to the pavement and oscillated through a servo valve to produce a loading force (4). This force varies from 800 to 2,000 pounds on flexible pavements, and from 400 to 2,400 pounds on rigid and composite pavements. The resulting deflection is measured by four velocity sensors. One sensor is positioned directly under the ram, and the other three sensors are positioned at one foot, two feet and three feet respectively, from the ram.

The force applied to the pavement is also monitored by a velocity sensor. This velocity sensor is mounted on top of the hydraulic two-way ram and measures amplitude or peak to peak mass displacement. Force imparted to the pavement is expressed by the following equation:

$$F = 32.70 f^2 D$$

Where F is the peak to peak force in pounds, f is the frequency of the loading in Hertz, and D is the peak to peak displacement of the mass in inches. A force setting of 25 Hz and 0.058 inch mass displacement is used on flexible pavements and results in 1,185 pounds of peak to peak force.

$$F = 32.70\ (25)^2\ (0.058) = 1{,}185 \text{ pounds}$$

The force setting of 25 Hz and 0.058 inch mass displacement was recommended by the manufacturer for flexible pavements since that force setting correlated best to the Benkelman Beam (correlation coefficient = 0.89). A similar study in Iowa yielded a correlation coefficient of 0.83 between the Road Rater and Benkelman Beam.

The manufacturer recommended a force setting of 30 Hz and 0.068 inch mass displacement which produces a peak to peak force of 2,000 pounds.

$$F = 32.70\ (30)^2\ (0.068) = 2{,}000 \text{ pounds}$$

This is the maximum functional force output of the Model 400 Road Rater. Hydraulic and electrical power are provided by an auxilliary motor mounted in the rear of the van.

The control console mounted in the van has four display meters to indicate deflections from the four velocity sensors placed on the pavement. Display Meter Number 4 is also used to calibrate mass displacement when the power switch is in the "monitor" position (5). A rotary "level" control is used to adjust the mass displacement to the desired output. Other switches are used to raise, lower and vibrate the mass. A six-position "range" switch has settings of 1, 2, 3, 5, 10 and 20, which are multipliers of the display meter readings. If Display Meter Number 1 reads 52 (0.52 of full scale) at range setting 3, the pavement deflection would be 1.56 mils (0.52 x 3 = 1.56 mils). The five-position "frequency" control has settings for 10, 20, 25, 30 and 40 Hertz. This feature allows the load frequency to be changed for different types of pavements. The frequency control is used in conjunction with the monitor position of the power switch and level control to change the peak to peak force from 1,185 pounds on flexible pavements to 2,000 pounds on rigid and composite pavements. The Road Rater was originally purchased because of the load-varying versatility.

A Model R-380 RVF Raytek infrared gun is used to measure pavement temperatures. This instrument enables pavement temperatures to be taken quickly for pavement inventory purposes. Calibration of the infrared gun is performed by moving an adjustment knob while aiming at a metal block of known temperature. The metal calibration block is painted flat black and has a circular temperature dial mounted directly to it.

The original 1975 Ford E250 Van had 100,000 miles when it was replaced in the winter of 1984 and 1985 with a 1985 Ford E350 Van. Conversion work of the new van was performed in the Iowa DOT Materials Laboratory. The automatic transmission of the original van was rebuilt once, the brakes were rebuilt several times, and the engine had a valve job and new timing chain, but overall the van performed extremely well considering the abusive stop-go use. The Road Rater mechanism itself has also been very rugged and trouble-free. Most problems have been minor such as broken sensor wires at plug connections and frequent oil filter replacements for the hydraulic system.

The Iowa DOT paid $25,000 for its Model 400 Road Rater mounted in a van in 1975. Another Model 400 Road Rater is being purchased due to increased demand for deflection testing and costs $40,000 mounted in an Iowa DOT van. The purchase price of a new Road Rater and additional testing costs are extremely low relative to the amounts of money involved in design decisions. Two Road Rater testing crews will operate simultaneously in April and May 1986.

TEST PROCEDURE

Annual Road Rater testing is performed in the outside wheeltrack during the months of April and May when the roadways exhibit the greatest instability. Test data are recorded on coding sheets for processing by an IBM 3081 mainframe computer. All base relationships which convert pavement deflections and deflection basin shapes to Structural Ratings and Soil Support K Values, respectively, have been programmed into the computer.

Joints and mid-panel locations are tested on rigid and composite pavements. The ram is placed about one foot from the joint, and all sensors are positioned on the same pavement panel behind the joint. The condition of joints is evaluated by comparing the Structural Ratings and Soil Support K Values at joints with mid-panel values. In general, the mid-panel 80th Percentile Structural Rating is adequate basis for design to strengthen joints for asphaltic concrete overlay designs.

Thirty tests per control section are generally considered the minimum necessary to yield statistically valid information. For logistical reasons, only 10 joints are tested for each control section over 2 miles in length. Also due to logistical reasons, only 15 mid-panel locations and 6 joints are tested for control sections 2 miles or less in length.

Test data collected in this manner are used for inventory purposes in the matrix of the pavement management system. It is also used to determine the nominal thickness of a.c. overlay designs on individual projects. Detailed project design requires deflection readings every 100 to 200 feet and has never been done in Iowa due to the time required for the extensive evaluation.

Calibration procedures for the Model 400 Road Rater involve use of the monitor position of the power switch, the vibrate position of the function switch, the frequency control, and the level control to adjust the mass displacement to the desired setting. A daily repeatability check is also performed. Once a month, the monitor circuit (including the sensor and read-out equipment) and each of the ground deflection sensors and their read-out circuits are calibrated according to the manufacturer's recommended procedures.

The Model 400 Road Rater results are repeatable and machine calibration has never been a problem. The Road Rater is very forgiving from an operational standpoint to obtain good test data.

DEVELOPMENT OF FLEXIBLE PAVEMENT-ASPHALTIC CONCRETE OVERLAY DESIGN PROCEDURE

Development of the flexible pavement-asphaltic concrete overlay design procedure was completed and presented to the Iowa DOT Road Design Office as operational in May 1980. It was agreed upon early in the research and development phase that the goal would be to tie Road Rater deflection data to existing Iowa DOT pavement design methods. These Iowa DOT flexible pavement design methods are patterned closely after AASHTO design procedures (6).

The base relationship for the flexible pavement-a.c. overlay design procedure is shown in Figure 1. This relationship was developed by Bernhard H. Ortgies, Materials Bituminous Field Engineer who has since been promoted to State Maintenance Engineer. Mr. Ortgies estimated the existing AASHTO Structural Number (SN) for a number of flexible pavements ranging from inverted penetration surfaces on minor primary routes through full-depth a.c. Interstate highways. These estimated Structural Numbers were called Structural Ratings (SR's) to distinguish them from direct usage of AASHTO Flexible Design Guide Values. Mr. Ortgies used his best judgment to assign SR values that would either relate to or be identical to AASHTO SN's developed by current Iowa DOT design procedures. The present condition of the pavement was considered when assigning SR values, and AASHTO values were depreciated as deemed appropriate to account for pavement deterioration, pavement performance, materials and traffic.

Estimated Structural Ratings were graphically related to average Sensor #1 deflection values in the flexible pavement base relationship. Average Sensor #1 deflection values were temperature corrected to 80°F using the principles developed by H. F. Southgate and R. C. Deen (7). A nomograph shown in Figure 2 was developed by Douglas M. Heins, Materials Asphalt Mix Design Engineer, who was Assistant Special Investigations Engineer when the nomograph was developed. This nomograph temperature corrects Sensor #1 deflection values to 80°F and converts them to Structural Ratings.

For design purposes, the 80th Percentile Structural Rating is used so that most or all weak areas are sufficiently strengthened by nominal a.c. overlay thickness design after normal surface preparation and patching procedures. The required Structural Number is determined from the AASHTO Design Chart for

Flexible Pavements, p_t=2.5, shown in Figure 3. A terminal Present Serviceability Index of 2.0 (p_t=2.0) is used for secondary pavements.

According to Iowa DOT design procedures a Regional Factor or Road Class Factor (R) of 1.0 is used for secondary pavements, R equals 2.0 for low-volume primary highways, and R equals 3.0 for high-volume primary, expressway and Interstate highways. The equivalent daily 18-kip single axle load applications are provided on a Primary Pavement Determination traffic appendix by the Office of Advance Planning.

The existing 80th Percentile Structural Rating is subtracted from the required Structural Number for a 15 year design life and the difference divided by the coefficient of asphaltic concrete (0.44) to determine the nominal a.c. overlay thickness needed.

A soil support value (S) of 2.5 is used for primary highways or S equals 2.0 for secondary highways when accurate soils information is unavailable. These soil support values were used until 1983 when the flexible pavement-a.c. overlay design procedure was refined by incorporating soil support S values determined from the Road Rater deflection basin. Development of soil support charts based on Road Rater deflection basins is discussed later in this paper.

Soil support values are expressed as Westergaard's modulus of subgrade reaction (K) on Road Rater computer printouts as shown in Figure 4. These subgrade reaction K values can be converted to soil support S values by using the following conversion table based on density and group index:

SOIL SUPPORT CONVERSION FACTORS

Modulus of Subgrade Reaction K	Soil Support S	Group Index GI	Standard Max. Density D
50	2	16-20	80-100
100	2 1/2	8-16	95-105
150	3	3-12	105-115
200	4	0-3	115-125
250	5	0	120-135

The Surface Curvature Index (SCI) is the difference in mils between Sensor #1 and Sensor #2. The SCI divided by average Sensor #1 deflection (SCI/SENS 1) provides a ratio which was incorporated into the computer program in 1978 for future study because of research performed by M. C. Wang and T. D. Larson of Pennsylvania State University and A. C. Bhajandas and G. Cumberledge of Pennsylvania Department of Transportation (8). Although use and application of the SCI/SENS 1 Ratio was not thoroughly understood in 1978, it was used later in 1983 to develop subgrade reaction K charts.

Flexible pavement-a.c. overlay design calculations are few and simple to perform when a Road Rater computer printout and Primary Pavement Determination traffic appendix are provided. This flexible pavement-a.c. overlay design procedure based on Road Rater deflection data has worked very well in Iowa. This may be explained by the close proximity of Iowa to the AASHO Road Test conducted at Ottawa, Illinois, in the late 1950's. Many pavements designed in Iowa since that study have now reached terminal serviceability, and the performance curves and concepts of the AASHO Road Test have been verified as reasonably correct.

DEVELOPMENT OF RIGID AND COMPOSITE PAVEMENT-ASPHALTIC CONCRETE OVERLAY DESIGN PROCEDURE

Since about 83 percent of Iowa's Primary Highway System consists of either rigid or composite pavements, there was a great need to develop a rigid and composite pavement-asphaltic concrete overlay design procedure. This was attempted prior to 1981 at the 25 Hertz and 58 percent mass displacement settings, but no pattern was found for the difference in deflection on sound concrete and the deflection on broken or unsound concrete. It was felt, therefore, that the Model 400 Road Rater had insufficient force to evaluate rigid and composite pavements. This thinking was prevalent until a FHWA short course entitled "Pavement Management Principles and Practices" by ARE, Inc. of Austin, Texas, was conducted in Ames, Iowa, from November 30 to December 2, 1981. The instructors were W. Ronald Hudson and John P. Zaniewski. Dr. Zaniewski indicated that the Dynaflect had been favorably compared with the U.S. Army Corps of Engineers' Waterways Experiment Station (WES) Vibrator in a study conducted by H. J. Treybig (9). This paper revised our thinking that light load Nondestructive Testing (NDT) equipment could simulate heavy load NDT equipment.

A work plan was developed in January 1982 to evaluate Road Rater application to rigid pavements. The basic strategy was to search for correlations between Road Rater deflection readings and various rigid pavement performance variables. The Road Rater was correlated to the FHWA "Thumper" in April 1982 as proposed in the work plan. Unfortunately, the 30 Hertz frequency was the only Road Rater frequency which would not function properly. Since the 30 Hertz frequency was inoperative, the 25 Hertz and 58 percent mass displacement setting was used to correlate the Road Rater to the FHWA "Thumper".

Road Rater deflections at the 1,185 pound peak to peak force correlated very well to 9,000 pound FHWA Thumper deflections (Figure 5). Data to perform this correlation was obtained from 39 different pavement sections ranging from 10" of p.c.c. pavement or 25" of a.c. pavement to a newly graveled unpaved road (10). The FHWA "Thumper" tested most of the 39 pavement sections at the 3,000, 6,000 and 9,000 pound force settings. A linear relationship existed among deflections at these force settings. That is, the 6,000 pound deflection was twice the 3,000 pound deflection, and the 9,000 pound deflection was three times the 3,000 pound deflection. This information provided the confidence that the Model 400 Road Rater had sufficient force to evaluate rigid and composite pavements.

An expert panel was proposed to estimate depreciated SN coefficients and nominal a.c. overlay thicknesses required on 23 test sections (each 1/2 mile in length), but the panel could not be assembled in 1982 since the persons involved were too busy with other activities. The determination of structural composition and crack and patch survey of 23 test sections was accomplished, however, as was Road Rater deflection testing at the 30 Hertz frequency when it was repaired in September 1982. An unusually wet summer and fall in 1982 permitted valid Road Rater test information to be obtained in October and November 1982.

The crack and patch survey of the work plan was performed according to Iowa Test Method No. 1004-C. Cracking (C), is the linear feet of cracking 1/4" wide or sealed per 1,000 square feet of pavement. Patching (P), is the square feet of surface or full depth patches per 1,000 square feet of pavement. The crack and patch deduction on rigid pavements is 0.09 multiplied by the square root of the sum of C plus P. This crack and patch deduction is subtracted from the Longitudinal Profile Value (LPV) to determine the Present Serviceability Index (PSI). The LPV is determined by the Iowa Johannsen Kirk (IJK) Roadmeter which is correlated annually to the CHLOE Profilometer on 50 one-half mile test sections in late May or early June. In this manner, Iowa PSI values tie directly into the performance curves and concepts from the AASHO Road Test.

The Road Rater rigid pavement analysis procedure was developed in four weeks in November and December 1982 due to the urgent need to evaluate Interstate pavements. A spread sheet was used to analyze the test data, and attempts were made to obtain the best correlation between Road Rater deflection data and pavement performance variables. The coefficient of new portland cement concrete was assumed to be 0.50 Structural Numbers per inch of material. Also, it was assumed that badly cracked p.c.c. pavements would deflect more than uncracked p.c.c. pavements. It was known that Sensor #1 deflection and thickness of p.c.c. pavement should correlate well from the study done by E. O. Lukanen (11).

The base relationship to evaluate rigid pavements with the Road Rater is shown in Figure 6 and was verified with additional test data obtained in 1983. These additional data points are shown added to the base relationship in Figure 7. Some badly cracked pavements deflected less than expected, and this may be due to unusually good subgrade support, interlocking pavement pieces because of tighter cracks or joints, or collapsed pavement pieces into voids beneath the pavement. If pavements behaved in a totally predictable manner based on thickness and amount of cracking, there would be no need to perform Road Rater deflection testing. As it is, the Road Rater can be used to identify a "rubble" condition in the lower portion of a rigid or composite pavement. The Road Rater tends to read the inches of sound material from the top of the pavement to the first delamination plane. This was illustrated by pavement cores drilled on Iowa's 21 Long Term Monitoring (LTM) Sections for a FHWA Study. The Road Rater can also be used to determine the subgrade support values for each individual pavement in the critical spring-thaw period annually.

The rigid and composite pavement-asphaltic concrete overlay design procedure was reported on December 14, 1982, and used the nomograph in Figure 3 in a similar manner as was used in the flexible pavement-a.c. overlay design procedure. The mid-panel 80th percentile structural rating is sufficient in most cases to design an a.c. overlay which will adequately strengthen the joints. Comments were solicited on January 4, 1983, on the new deflection-based a.c. overlay design procedure, and a presentation was given on February 10, 1983. At the presentation, it was suggested that verification data be collected to develop confidence as was done with the flexible pavement-a.c. overlay design procedure. A Soil Support K Value Chart for rigid and composite pavements had also been developed at this time, but was as yet unproven. The work plan to evaluate rigid and composite pavements was considered completed.

DEVELOPMENT AND VERIFICATION OF SOIL SUPPORT K VALUE CHARTS FOR RIGID, COMPOSITE AND FLEXIBLE PAVEMENTS

Soil Support K Value Charts were developed since it was recognized that the existing subgrade soil support could affect the a.c. overlay thickness required by several inches when using the AASHTO Design Chart for Flexible Pavements, P_t=2.5. It was also recognized that subgrade moisture could affect Road Rater deflection readings, but that this effect could be normalized by annual testing in April and May (only) when the pavements are in their weakest condition after the frost is out. Subgrades are generally saturated in April and May and can be identified by soil type or density through Road Rater deflection testing in this condition. At other times of the year, all subgrades are firm and deflect in a similar manner when tested with the Road Rater. It is extremely difficult or impossible to seasonally adjust Road Rater deflection data taken at other times of the year to a springtime condition unless detailed soils information is available. The only exception is a wet fall following an unusually wet and cool summer when Road Rater testing conditions may be very similar to springtime conditions. Since detailed soils information is not always available and since soil types can vary somewhat on the same pavement section, all Road Rater testing is conducted in April and May. This also restricts pavement temperatures to a lower range to prevent joint lockup on rigid and composite pavements, and to prevent large temperature corrections to deflections on flexible pavements.

The base relationship for Soil Support K Values for Rigid and Composite Pavements From Road Rater Deflection Dishes is shown in Figure 8. This relationship was developed using a similar approach as was used by R. W. Kinchen and W. H. Temple in Louisiana (12). The Louisiana DOT was one of the few states in early 1983 that had done much research and development work on rigid pavements using lightweight NDT equipment. Dynaflect was used in Louisiana DOT research, and Spreadability or Percent Spread versus Dynaflect Sensor #1 Deflection was used to determine the subgrade strength (modulus of elasticity, Es). Spreadability conveyed as percent was the average of five Dynaflect sensor readings divided by the Sensor #1 deflection reading. The Louisiana DOT pavement evaluation chart was a modified version of a chart developed by N. K. Vaswani (13).

Soil subgrade factors, as used by the Iowa Department of Transportation rigid and flexible pavement design, were developed by correlating Plate Load test information to standard Proctor Density and AASHTO Soil Group Index. These values have provided a basis for Iowa designs since the adaptation of the AASHO Road Test Guides during the late 1950's.

These historical subgrade values were applied for the development of the current Road Rater deflection basin derived "K" charts. Initial testing for this portion of the program was done on new roadways which contained known subgrade soils and subbase treatments. Deflection basins were developed for typical soil types and combinations of various soils and granular subbases. These first comparisons produced marginal results. It was apparent that a greater number of soil and subbase factors were needed. Load testing data for Illinois soils, published by Michael I Darter(14), compared AASHTO soil types and their strengths at various states of saturation. This information was incorporated with Iowa "standard" subgrade design information. Using these new "expected" values, Road Rater K values were developed to provide answers for the various deflection basin problems.

In 1983 extensive pavement and subgrade testing was done for a selected study group of Iowa pavements. Soil core samples were obtained at individual Road Rater test points. These samples were tested for in place density, moisture content and AASHTO classification. Items investigated included moisture and in place density effects for various soil types, values for glacial clay treatments commonly used in Iowa, common values for sand and gravel or crushed stone "special" treatments and effects of high saturation levels on silts and granular subbase. Sample comparisons of values are shown in Tables 1-5.

The results obtained by this testing verified that individual materials and specific conditions yield reproducable, predictable Road Rater deflection basins. The necessary load testing to obtain companion "Westergaard" information was not performed; however, the assigned values provide a reasonable design range and that the relationships for various materials are acceptable.

DEVELOPMENT OF TEMPERATURE CORRECTIONS FOR RIGID AND COMPOSITE PAVEMENTS

Temperature correction factors for Road Rater deflection data were more difficult to determine for rigid and composite pavements than for flexible pavements. This was due to discontinuities because of joints, joint lockup during high pavement temperatures, and slab curling due to temperature differentials on rigid pavements. Temperature corrections for composite pavements were originally thought to be functions of the a.c. overlay thickness, materials properties of the a.c. overlay, and the condition of the underlying p.c.c. pavement. A study of the effects of temperature on Iowa's rigid pavement study sections is shown in Figure 10. A full range of temperatures could not be obtained at one time and, therefore, the seasonal effects and influence of different subgrade conditions complicated attempts to develop a general temperature correction factor or equation which could be applied to all rigid pavements. Most of the rigid pavement temperature study sections in Figure 10 had very flat slopes indicating very little influence on the Structural Ratings from temperature. Some rigid pavements do have a tendency to deflect more at high pavement temperatures, however, and this is attributed to slab curling at mid-panel which is concave in shape and results in higher Road Rater deflections. Since no well-defined trends could be established from Figure 10, no temperature correction factors are applied to rigid pavements. This is a logical strategy since all Road Rater testing is conducted in April and May only when the average pavement temperature is about 70^{O}F, and the range of temperatures is relatively small. Composite pavement temperature study sections are shown in Figure 11. The slopes of most composite pavement lines were similar and resulted in the following temperature correction equation:

Temp. Corrected SR = Non-Temp. Corrected SR

+ (70^{O}F-Pave. Temp.)(-0.0145SR/^{O}F)

where the pavement temperature is in degrees Fahrenheit. This temperature correction equation was developed in December 1983, and it was incorporated into the Road Rater computer program in 1984. Many of the data points in Figure 11 have been collected since December 1983, and they have generally supported this equation.

VERIFICATION OF COEFFICIENT OF ASPHALTIC CONCRETE

The AASTO design coefficient for asphaltic concrete for a Type A or Type B surface course was 0.44 Structural Numbers per inch of material. This coefficient for asphaltic concrete of 0.44 was verified on flexible pavements by a study of Road Rater deflections before and after placing asphaltic concrete overlays. The results of this study are shown in Table 6. The average coefficient for asphaltic concrete was 0.52 structural numbers per inch of material which compares favorably with the AASHTO value of 0.44. Extra asphaltic concrete overlay thickness in wheeltracks to remove rutting may be responsible for study coefficients greater than 0.44

The results of a similar study to verify the coefficient for asphaltic concrete of 0.44 on rigid and composite pavements are shown in Table 7. The average coefficient for asphaltic concrete on rigid pavements was 0.20 structural numbers per inch of material. Although a study of Long Term Monitoring pavement cores indicated that rigid and composite pavements could be evaluated similarly by the Road Rater, it is possible that an asphaltic concrete overlay has not sufficiently set and aged after one year to be compared to a rigid pavement. If this theory is correct, the coefficient for asphaltic concrete may be close to 0.44 on rigid pavements several years after resurfacing. On I-680 in Pottawattamie County, the pavement crown was corrected by tapering the a.c. overlay thickness from 3" at centerline to 1" or 2" at the pavement edges. This helps explain the coefficient of 0.20 on I-680, and there may be other reasons such as different subgrade conditions which explain lower coefficients on other projects.

Only one composite pavement has been studied to date to verify the coefficient for asphaltic concrete. No structural improvement was noted on Iowa 128 in Clayton County after adding three inches of a.c. resurfacing. This may be due to reasons previously discussed, and it also emphasizes the need for more research on rigid and composite pavements to study the coefficient for asphaltic concrete.

APPLICATION OF ROAD RATER VALUES FOR ASPHALTIC CONCRETE OVERLAY DESIGN

The Iowa Road Rater Design Method has been simplified so that it may be easily understood and used by the widely diverse groups of individuals who may be involved in pavement restoration and management. Basic "effective thickness" values were established by testing various new pavements. Standard AASHTO flexible coefficients were used to describe these design sections and applied as a scale for the Road Rater deflection information. Thus, all test information is displayed in effective new pavement units. These values may be easily converted for percent of deterioration or remaining life calculations.

The designer may determine a required thickness by any preferred design method. It is only required that the Road Rater subgrade values or their equivalent be applied to the new design. The existing effective thickness is subtracted from the required thickness or total required structure to arrive at a desired overlay thickness. This procedure has been cross checked with recommended AASHTO Interim Guidelines since the system was first introduced in Iowa on secondary pavements in 1979. Correlation has been excellent when the roadway conditions are "normal" or average. Investigations have been made by other test methods when Road Rater values have differed significantly from the required AASHTO values. In all cases to date, the additional testing has verified the information provided by the Road Rater. These verifications have ranged from cases of hidden deterioration to pavement sections which are significantly different from that indicated by existing records.

Current Iowa Asphaltic Concrete Overlay Design guides are shown in Table 8.

VOID DETECTION TESTING

Experimental void detection testing using the Road Rater was conducted in October 1984 on an I-80 subsealing project in Scott County. The purpose of this study was: 1) To determine if the Road Rater could locate voids under a pavement, and 2) to determine how well the contractor was filling voids.

Road Rater testing to locate voids must be done at cool temperatures when the joints are not locked up. Therefore, this type of Road Rater testing is normally done in the morning hours - especially in the summer months. Testing was conducted in the outside wheeltrack going against traffic at all joints and at midpanel cracks in the test section. This requires lane closure with cones to protect the testing crew and traveling public. The purpose of testing against traffic is: 1) To string the sensors out on the down-stream panel where voids are located so that Road Rater K Value Soil Support Charts can be used, and 2) to place the weight of the Road Rater van on the up-stream panel to reduce the effects of any pre-loading which may close the voids prior to testing. The static load of the Road Rater in this configuration is 1,480 pounds.

The minimum Road Rater soil support K value possible from the data evaluation program is K = 50. This was estimated to be the lowest K value possible on saturated clays in springtime friable conditions. Therefore, a sound 10" p.c.c. pavement over a void would be expected to have an unusually low Structural Rating and a soil support value of K = 50.

The results of this study are illustrated by Table 9. Road Rater testing was conducted on a section of I-80 at the joints on October 10, 1984, at 9:30 a.m. and a pavement temperature of 60°F before subsealing. The same joints were tested on October 11, 1984, at 10:35 a.m. and a pavement temperature of 60°F two hours after subsealing. For a sound 10" p.c.c. pavement, the joints before subsealing had unusually low Structural Ratings and soil support K values, but showed dramatic improvement two hours after subsealing. From this study it was concluded that: 1) The Road Rater can be used to locate voids beneath a p.c.c. pavement, and 2) the contractor was doing a good job of subsealing on this project. Further research using the Road Rater for void detection testing is being conducted.

CONCLUSIONS

This paper summarizes our experience to date with the Road Rater. Conclusions are as follows:

(1) The Road Rater has been an effective tool to evaluate pavement and subgrade conditions for both flexible and rigid pavements.

(2) An asphaltic concrete overlay design procedure based on Road Rater deflection data has been developed and has worked well to date.

(3) Experimental void detection testing has been performed with encouraging results both in the Road Rater's ability to locate voids and in the verification of our analysis techniques.

(4) Successful Road R ter research and development has made deflection data one of the more important pavement management inputs.

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TABLE TITLES

Table 1

Moisture - Density - Silt Content Relationships

Pavement Type	Core #	Field Density	K Value	Silt Content	Moisture Content	Layer	Description
PC	133	111	205	35	16.2	B	Gr Br Glacial Clay
PC	134	109	180	48	16.5	B	Dk Br Silty Clay Loam
PC	134	111	200	42	17.4	B	Gr Br Glacial Clay
PC	136	108	205	37	18.3	B	Gr Br Glacial Clay
PC	138	100	130	61	21.6	B	Br Gr Silty Clay
PC	139	95	65	48	25.2	B	Gr Br Silty Glacial Clay
PC	140	108	200	40	17.8	B	Gr Br Glacial Clay
PC	141	118	200	41	12.7	B	Dk Br Sandy Silty Clay
PC	142	104	180	41	19.6	B	Br Gr Glacial Clay

Table 2

Glacial Clay Subgrade Treatment

Pavement Type	Core #	Field Density	K Value	Silt Content	Moisture Content	Layer	Description
PC	211	118	200	36	14.0	B	Gr Br Clay Loam
PC	212	124	200			B	Br Gr Clay Loam
PC	213	118	190	42	12.2	B	Gr Br Glacial Clay
PC	214	120	215	36	12.3	B	Gr Br to Br Gr Glacial Clay
PC	215	115	125		11.8	B	Br Sandy Clay Loam w/Sand Seams
PC	216	123	200	44	13.5	B	Br Sandy Clay Loam
PC	217	112	210		14.9	B	Dk Br Silty Clay Loam w/Gravel
PC	218	123	125	57	11.3	B	Br Sandy Loam
PC	219	115	185	36	10.6	B	Gr Br Sandy Clay Loam
PC	220	119	220	36	12.1	B	Br Gr Glacial CLay
PC	221	119	185	39	12.2	B	Gr Br silty Glacial Clay
PC	222	112	210	35	15.7	B	Gr Br Glacial Clay
PC	223	115	190	35	13.5	B	Dk Br Clay Loam
PC	225	105	220	41	19.7	B	Br Gr Clay Loam
PC	225	105	200	43	17.7	B	Dk Br Clay w/Gravel + Sand Seams
PC	226	118	190	49	12.5	B	Gr Br Glacial Clay

Table 3

Silty Sand and Gravel Subgrade Treatment

Pavement Type	Core #	K Value	Silt Content	Layer	Description
PC	169	185	10	B	Sand + Gravel
PC	170	215	10	B	Sand + Gravel
PC	171	185	8	B	Sand + Gravel
PC	172	185	9	B	Sand + Gravel
PC	173	130	10	B	Sand + Gravel
PC	174	180	9	B	Sand + Gravel
PC	175	195	17	B	Sand + Gravel
PC	176	150	20	B	Sand + Gravel
PC	177	160	19	B	Sand + Gravel
PC	178	180	14	B	Sand + Gravel
PC	191	145	14	B	Sand + Gravel
PC	192	150	19	B	Sand + Gravel
PC	193	225+	15	B	Sand + Gravel
PC	194	140	21	B	Sand + Gravel
PC	195	155	21	B	Sand + Gravel
PC	196	185	26	B	Sand + Gravel
PC	197	180	25	B	Sand + Gravel
PC	198	180	23	B	Sand + Gravel
PC	199	180	28	B	Sand + Gravel
PC	200	205	28	B	Sand + Gravel
PC	201	205	26	B	Sand + Gravel
PC	202	180		B	Sand + Gravel
PC	203	175	3	B	Sand + Gravel
PC	204	190	21	B	Sand + Gravel

Table 4

Saturated Silty Clays and Various Granular Treatments

Pavement Type	Core #	Field Density	K Value	Silt Content	Moisture Content	Layer	Description
PC	253		215	2		B	Br Sand w/Occ Gravel
PC	254		200	2		B	Br Sand w/Occ Gravel
PC	255	113	155	33	13.8	B	Gr Br Clay Loam
PC	256		155	8		B	Br Sand w/Gravel
PC	275	102	50	73	19.9	B	Br Gr Silty Clay
PC	276	104	90	73	20.0	B	Br Gr Silty Clay
PC	277		165	9		B	Gravel (Limestone)
PC	278	106	115	63	19.0	B	Br Gr Silty Clay
PC	279		155	12		B	Gravel (Limestone)
PC	280	98	125	73	22.5	B	Br Gr Silty Clay

Table 2

Glacial Clay Subgrade Treatment

Pavement Type	Core #	Field Density	K Value	Silt Content	Moisture Content	Layer	Description
PC	211	118	200	36	14.0	B	Gr Br Clay Loam
PC	212	124	200			B	Br Gr Clay Loam
PC	213	118	190	42	12.2	B	Gr Br Glacial Clay
PC	214	120	215	36	12.3	B	Gr Br to Br Gr Glacial Clay
PC	215	115	125		11.8	B	Br Sandy Clay Loam w/Sand Seams
PC	216	123	200	44	13.5	B	Br Sandy Clay Loam
PC	217	112	210		14.9	B	Dk Br Silty Clay Loam w/Gravel
PC	218	123	125	57	11.3	B	Br Sandy Loam
PC	219	115	185	36	10.6	B	Gr Br Sandy Clay Loam
PC	220	119	220	36	12.1	B	Br Gr Glacial CLay
PC	221	119	185	39	12.2	B	Gr Br silty Glacial Clay
PC	222	112	210	35	15.7	B	Gr Br Glacial Clay
PC	223	115	190	35	13.5	B	Dk Br Clay Loam
PC	225	105	220	41	19.7	B	Br Gr Clay Loam
PC	225	105	200	43	17.7	B	Dk Br Clay w/Gravel + Sand Seams
PC	226	118	190	49	12.5	B	Gr Br Glacial Clay

Table 4

Saturated Silty Clays and Various Granular Treatments

Pavement Type	Core #	Field Density	K Value	Silt Content	Moisture Content	Layer	Description
PC	253		215	2		B	Br Sand w/Occ Gravel
PC	254		200	2		B	Br Sand w/Occ Gravel
PC	255	113	155	33	13.8	B	Gr Br Clay Loam
PC	256		155	8		B	Br Sand w/Gravel
PC	275	102	50	73	19.9	B	Br Gr Silty Clay
PC	276	104	90	73	20.0	B	Br Gr Silty Clay
PC	277		165	9		B	Gravel (Limestone)
PC	278	106	115	63	19.0	B	Br Gr Silty Clay
PC	279		155	12		B	Gravel (Limestone)
PC	280	98	125	73	22.5	B	Br Gr Silty Clay

Table 5

High Silt Content in Granular Subbase

Pavement Type	Core #	K Value	Silt Content	Layer	Description	Thickness	Layer C Density - Moisture
PC	329	150	10	B	Sand and Gravel	6"	111 lb. @ 15.9
PC	330	160	8	B	Sand and Gravel	4.5"	118 lb. @ 15.3
PC	331	105	16	B	Sand and Gravel	5"	111 lb. @ 16.7
PC	332	105	11	B	Sand and Gravel	6"	118 lb. @ 15.3
PC	333	160	8	B	Sand and Gravel	6"	111 lb. @ 15.8
PC	334	125	11	B	Sand and Gravel	5"	
PC	335	90	13	B	Sand and Gravel	4"	110 lb. @ 17.5
PC	336	65	14	B	Sand and Gravel	6"	102 lb. @ 19.8
PC	337	85	12	B	Sand and Gravel	5"	108 lb. @ 17.6
PC	338	135	12	B	Sand and Gravel	5"	111 lb. @ 16.9

Table 6

Flexible Pavement Coefficient of Asphaltic Concrete

From Road Rater Deflection Testing

County	Route	From Milepost	To Milepost	Nominal AC Overlay Thickness	Year Resurf.	Road Rater Before Resurf. Ave.SR	Road Rater Before Resurf. Year	Road Rater After Resurf. Ave.SR	Road Rater After Resurf. Year	Coefficient of Asphaltic Concrete
Boone	IA 210	1.90	6.87	3"	1979	2.70	1978	4.62	1980	0.64
Hamilton	IA 175	159.04	164.53	4 1/2"	1977	2.20	1977	3.90	1978	0.38
Story	IA 210	15.15	20.19	3"	1978	3.30	1978	4.33	1979	0.34
Kossuth	IA 91	0.47	3.71	3"	1978	1.80	1978	3.66	1979	0.62
Jasper	IA 117	6.49	17.43	3"	1978	3.88	1977	5.09	1979	0.40
Marshall	IA 233	0.63	5.30	3"	1977	2.34	1977	3.43	1978	0.36
Keokuk	IA 78	0.00	13.31	3"	1980	3.16	1980	5.92	1984	0.92
									Average	0.52

Table 7

Rigid And Composite Pavement Coefficient of Asphaltic Concrete

From Road Rater Deflection Testing

County	Route	From Milepost	To Milepost	Pavement Type	Nominal AC Overlay Thickness	Year Resurf.	Road Rater Before Resurf. Ave.SR	Road Rater Before Resurf. Year	Road Rater After Resurf. Ave.SR	Road Rater After Resurf. Year	Coefficient of Asphaltic Concrete
Mills Montgomery & Adams	US 34	21.88	63.73	PC	3"	1983	3.95	1983	5.12	1984	0.39
Pottawattamie	I-680	13.05	29.21	PC	3"	1983	3.64	1982	4.25	1984	0.20
Black Hawk	US 20	233.71	242.52	PC	3"	1984	4.71	1983	4.77	1985	0.02
Taylor	IA 148	0.00	7.52	PC	3"	1984	3.53	1983	4.31	1985	0.26
Wayne	IA 14	2.31	9.79	PC	3"	1984	3.77	1983	4.14	1985	0.12
										Average	0.20
Clayton	IA 128	0.00	6.97	Comp.	3"	1984	2.83	1983	2.72	1985	0.00

Table 5

High Silt Content in Granular Subbase

Pavement Type	Core #	K Value	Silt Content	Layer	Description	Thickness	Layer C Density - Moisture
PC	329	150	10	B	Sand and Gravel	6"	111 lb. @ 15.9
PC	330	160	8	B	Sand and Gravel	4.5"	118 lb. @ 15.3
PC	331	105	16	B	Sand and Gravel	5"	111 lb. @ 16.7
PC	332	105	11	B	Sand and Gravel	6"	118 lb. @ 15.3
PC	333	160	8	B	Sand and Gravel	6"	111 lb. @ 15.8
PC	334	125	11	B	Sand and Gravel	5"	
PC	335	90	13	B	Sand and Gravel	4"	110 lb. @ 17.5
PC	336	65	14	B	Sand and Gravel	6"	102 lb. @ 19.8
PC	337	85	12	B	Sand and Gravel	5"	108 lb. @ 17.6
PC	338	135	12	B	Sand and Gravel	5"	111 lb. @ 16.9

Table 6

Flexible Pavement Coefficient of Asphaltic Concrete

From Road Rater Deflection Testing

County	Route	From Milepost	To Milepost	Nominal AC Overlay Thickness	Year Resurf.	Road Rater Before Resurf. Ave.SR	Road Rater Before Resurf. Year	Road Rater After Resurf. Ave.SR	Road Rater After Resurf. Year	Coefficient of Asphaltic Concrete
Boone	IA 210	1.90	6.87	3"	1979	2.70	1978	4.62	1980	0.64
Hamilton	IA 175	159.04	164.53	4 1/2"	1977	2.20	1977	3.90	1978	0.38
Story	IA 210	15.15	20.19	3"	1978	3.30	1978	4.33	1979	0.34
Kossuth	IA 91	0.47	3.71	3"	1978	1.80	1978	3.66	1979	0.62
Jasper	IA 117	6.49	17.43	3"	1978	3.88	1977	5.09	1979	0.40
Marshall	IA 233	0.63	5.30	3"	1977	2.34	1977	3.43	1978	0.36
Keokuk	IA 78	0.00	13.31	3"	1980	3.16	1980	5.92	1984	0.92
									Average	0.52

Table 7

Rigid And Composite Pavement Coefficient of Asphaltic Concrete

From Road Rater Deflection Testing

County	Route	From Milepost	To Milepost	Pavement Type	Nominal AC Overlay Thickness	Year Resurf.	Road Rater Before Resurf. Ave.SR	Road Rater Before Resurf. Year	Road Rater After Resurf. Ave.SR	Road Rater After Resurf. Year	Coefficient of Asphaltic Concrete
Mills Montgomery & Adams	US 34	21.88	63.73	PC	3"	1983	3.95	1983	5.12	1984	0.39
Pottawattamie	I-680	13.05	29.21	PC	3"	1983	3.64	1982	4.25	1984	0.20
Black Hawk	US 20	233.71	242.52	PC	3"	1984	4.71	1983	4.77	1985	0.02
Taylor	IA 148	0.00	7.52	PC	3"	1984	3.53	1983	4.31	1985	0.26
Wayne	IA 14	2.31	9.79	PC	3"	1984	3.77	1983	4.14	1985	0.12
										Average	0.20
Clayton	IA 128	0.00	6.97	Comp.	3"	1984	2.83	1983	2.72	1985	0.00

Table 8

Road Rater: A.C. Overlay Design

Step 1:	DO: Standard AASHTO Design to determine flexible pavement weighted structural requirement for 15 years. Use the average road rater indicated soil support value for these calculations. Safety factors for Road Class (regional factor) are applied (attached charts for road class factor and soil support value).
Step 2:	Subtract 80 percentile road rater value from required value. This gives required needed structure.
Step 3:	Use standard coefficients for materials to determine required overlay thickness. (Surface coarse values are used for the top 3 inches; base values for all required material in excess of 3 inches.)
Considerations:	1. Longitudinal subdrainage improvements: Increase the average K value by 50 and recalculate. 2. Patching or selective strengthening areas: What is the needed structure if selected "low" individual road rater readings are not considered. When this is done, the superelevated curve readings must also be disregarded. 3. Milling reductions of existing structural values: 75% of the material removed by milling must be replaced. 4. Joint values: The proposed overlay must add sufficient structure to meet 1.0 regional value design.

Table 9

Road Rater Void Detection Testing

I-80 EB SCOTT COUNTY

Station	Before Subsealing		2 Hours After Subsealing	
	SR	Soil K	SR	Soil K
529+00	1.73	50	2.22	122
529+25	1.77	50	3.46	207
529+50	1.57	50	2.75	198
529+75	1.33	50	2.30	179
529+00	1.77	50	3.33	173
530+25	1.57	50	2.75	183
530+50	1.51	50	3.21	192
530+75	1.73	50	3.68	197
531+00	1.46	50	3.46	197
531+25	1.37	50	2.48	161
531+50	1.44	50	2.48	161
531+75	1.70	50	2.22	144
532+00	1.25	50	3.21	192
532+50	2.15	137	2.88	219
533+00	1.73	50	3.53	188
534+00	1.46	50	3.10	194

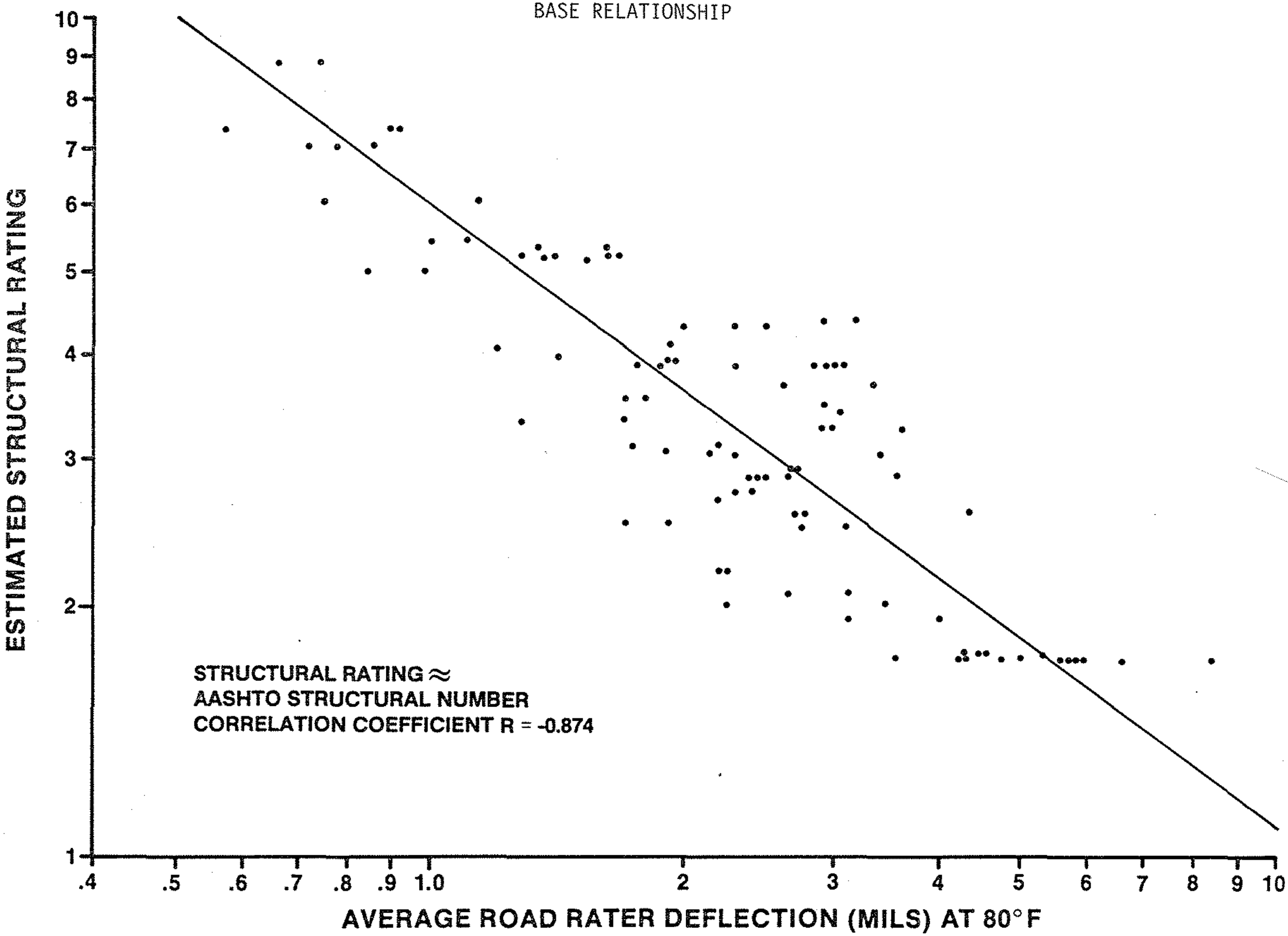
NOTE: Artwork on all figures will be redone before final submission to meet TRB requirements

FIGURE CAPTIONS

Figure 1

FLEXIBLE PAVEMENT

BASE RELATIONSHIP



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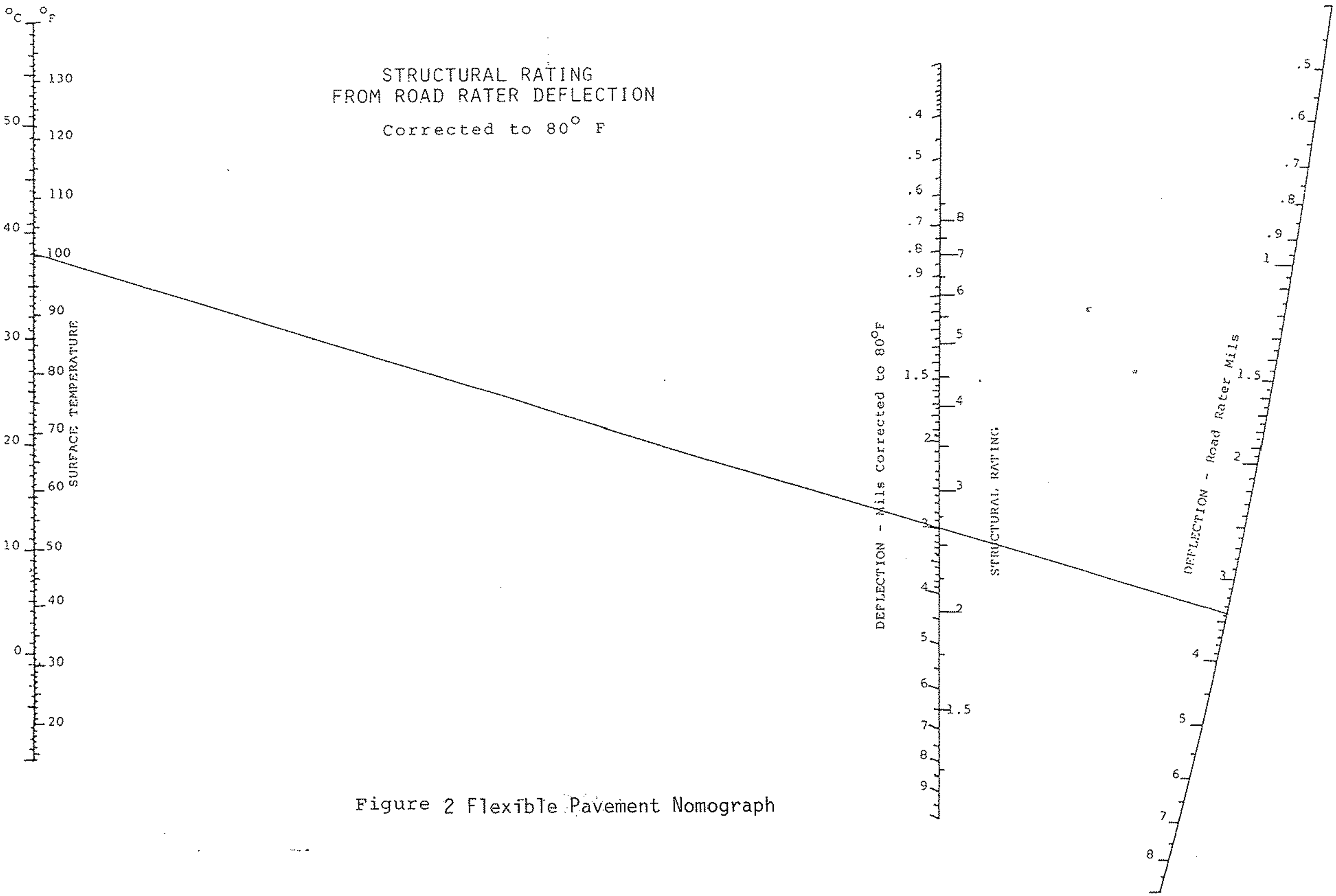

Figure 2 Flexible Pavement Nomograph

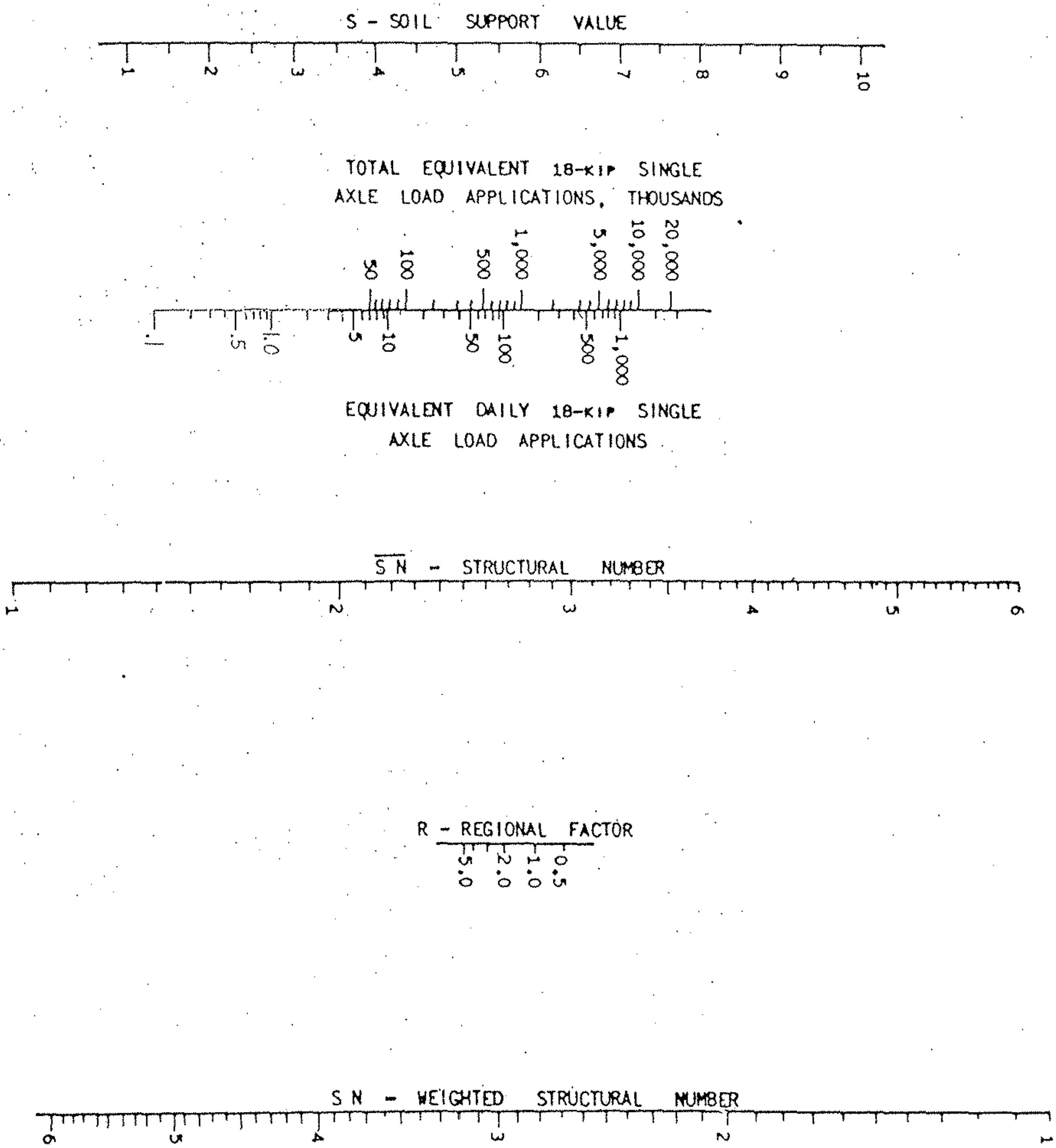

Figure 3 Design Chart for Flexible Pavements, $p_t = 2.5$

Figure 4

Road Rater Computer Printout

PROGRAM NUMBER- P2220050
COMPUTER RUN DATE- 11-29-84

OFFICE OF MATERIALS
ROAD RATER TESTS

COUNTY- BLACK HAWK	BEGINNING MP.... 3.00	LAB NO...... RA4-0268	WEATHER CLEAR	FREQ. HZ... 25
COUNTY ROUTE.... V-27	ENDING MP....... 8.50	YEAR BUILT.. 1959	OBS.... FRETTE JONES	DISP %..... 58
PAVEMENT TYPE... AC	COMPUTED MILES.. 5.50	DATE TESTED. 05-30-84	TIME... 12:40	TEST TYPE.. ST

ROAD RATER DEFLECTION (MILS)

M-P	NORTHBOUND SENS 1	SENS 2	SENS 3	SENS 4	S.R.	SOIL K	SOUTHBOUND SENS 1	SENS 2	SENS 3	SENS 4	S.R.	SOIL K	REMARKS
3.200							4.80	2.00	1.00	0.60	1.94	207.	
3.400	6.00	3.00	1.60	1.00	1.62	81.							
3.600							5.60	3.00	1.80	1.00	1.71	80.	
3.800	3.70	2.00	1.00	0.80	2.39	190.							
4.000							6.00	4.00	2.20	1.40	1.62	50.	
4.200	5.40	3.00	1.40	0.80	1.76	79.							
4.400							5.80	3.60	1.80	1.00	1.66	50.	
4.600	7.20	3.60	2.00	1.40	1.39	50.							
4.800							5.80	3.00	1.60	1.00	1.66	81.	
5.000	5.80	3.60	2.00	1.20	1.66	50.							
5.200							4.20	2.20	1.10	0.80	2.16	174.	
5.400	6.00	3.40	1.80	1.00	1.62	57.							
5.600							4.80	2.50	1.30	0.90	1.94	139.	
5.800	6.40	3.00	1.60	1.00	1.53	80.							
6.000							4.90	2.40	1.30	0.80	1.91	157.	
6.200	6.80	3.60	2.00	1.20	1.46	50.							
6.400							6.00	3.00	1.80	1.00	1.62	81.	
6.600	7.00	4.00	2.00	1.40	1.42	50.							
6.800							6.00	2.80	1.40	1.00	1.62	96.	
7.000	5.60	2.80	1.40	0.80	1.71	96.							
7.200							4.60	2.50	1.20	0.80	2.01	133.	
7.400	7.60	3.60	1.80	1.00	1.33	50.							
7.600							6.00	4.00	2.00	1.00	1.62	50.	
7.800	6.00	3.60	2.00	1.00	1.62	50.							
7.900							4.70	2.50	1.20	0.80	1.98	136.	
8.000	7.00	4.00	2.00	1.20	1.42	50.							
8.100							4.80	2.40	1.10	0.60	1.94	155.	
8.200	9.60	5.60	3.00	2.00	1.09	50.							
8.300							7.40	4.20	2.40	1.60	1.36	50.	
8.400	7.00	4.00	2.20	1.40	1.42	50.							

* S U M M A R Y O F D A T A *

DIRECTION	SENS1 STD.DEV.	SENS1 MAX.	SENS1 MIN.	SENS1 AVE.	SENS1 80%	SENS2 AVE.	SENS3 AVE.	SENS4 AVE.	SCI	SCI/SENS1	AVE. SR	80% SR	AVE. SOIL K	BEG. TEMP	END TEMP
NORTH	1.29	9.60	3.70	6.47	7.56	3.52	1.85	1.15	2.95	0.456	1.56	1.32	69.	85.	85.
SOUTH	0.83	7.40	4.20	5.43	6.13	2.94	1.55	0.95	2.49	0.458	1.78	1.60	109.	85.	85.
COMB	1.19	9.60	3.70	5.95	6.95	3.23	1.70	1.05	2.72	0.457	1.67	1.44	89.		

* * * * * H I S T O R Y * * * * * REMARKS: SECL- SUPERELEVATED CURVE, LOW SIDE. SECH- SUPERELEVATED CURVE, HIGH SIDE

* DATE TESTED	AVE.SR	AVE.SOIL K *

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FIGURE 5

COMPARISON OF THE IOWA DOT ROAD RATER DEFLECTION AND THE FHWA THUMPER DEFLECTION

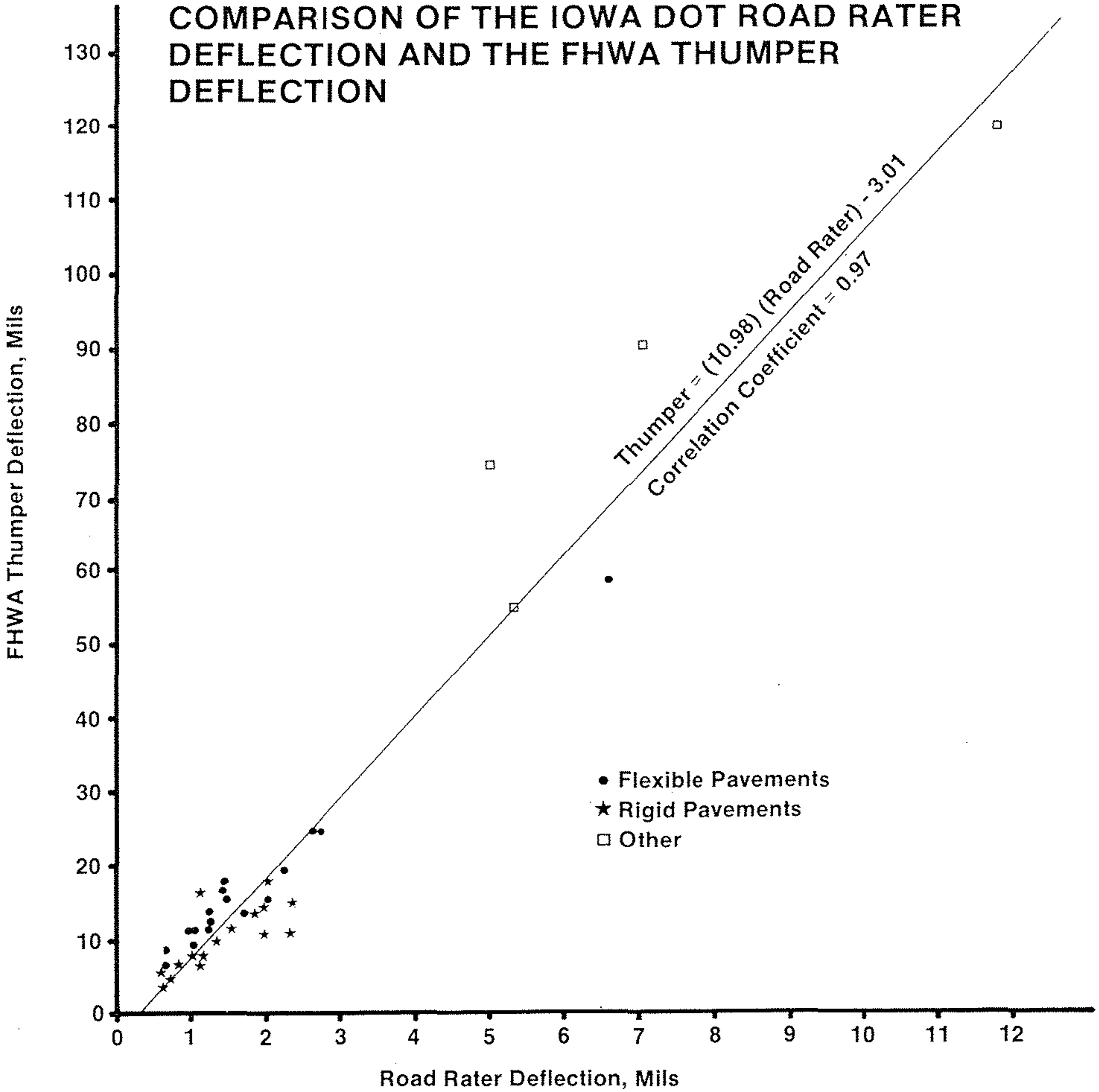

Figure 6

AVERAGE ROAD RATER DEFLECTION VERSUS ESTIMATED STRUCTURAL RATING

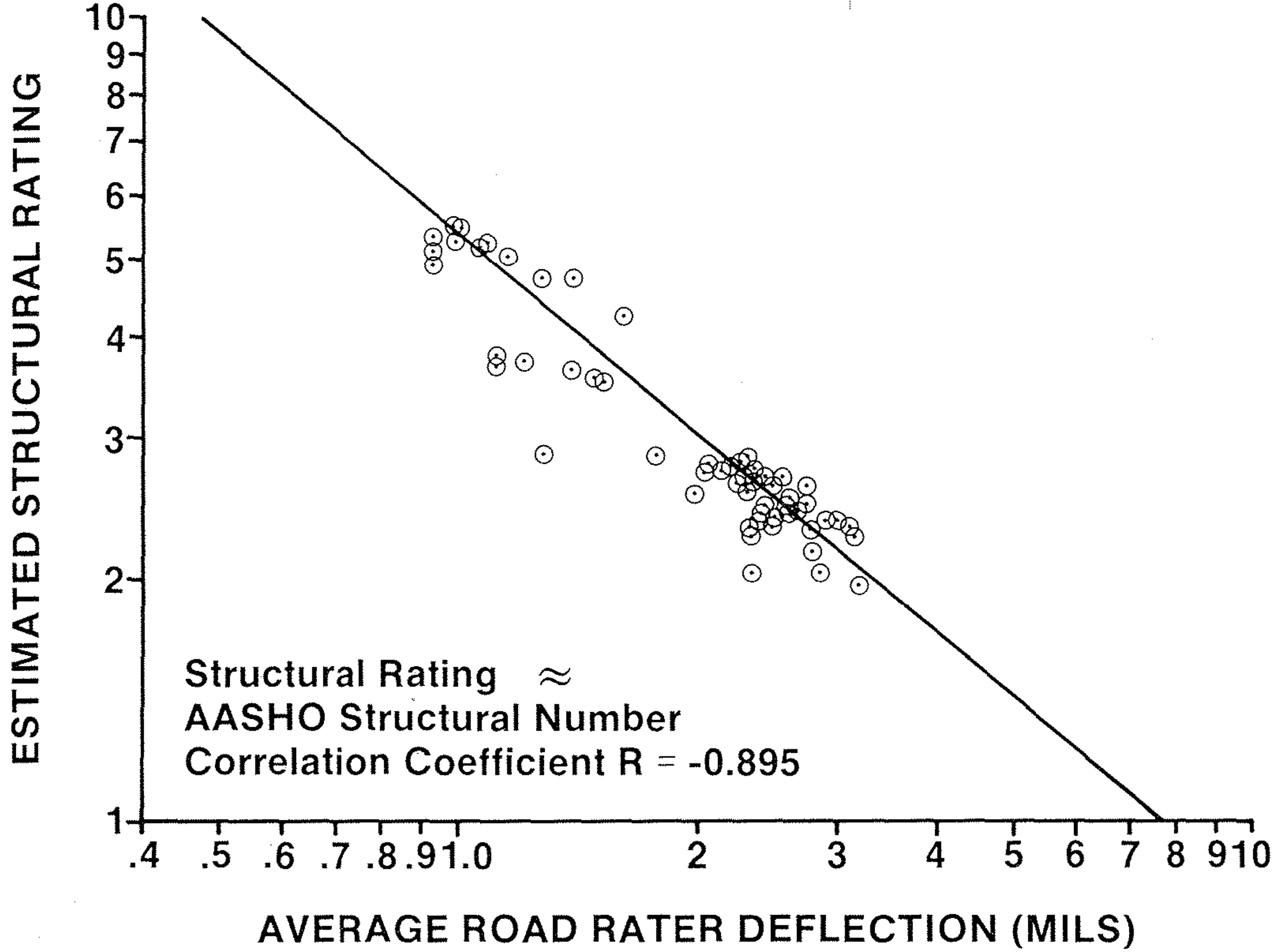

Figure 7

AVERAGE ROAD RATER DEFLECTION
VERSUS
ESTIMATED STRUCTURAL RATING

NOVEMBER 22, 1982

ESTIMATED STRUCTURAL RATING

$$\left(\frac{\left(1-\frac{\frac{SCI}{SENSI}}{0.90}\right)+\left(1-\frac{c}{60}\right)}{2}\right)(\text{NEW SN})$$

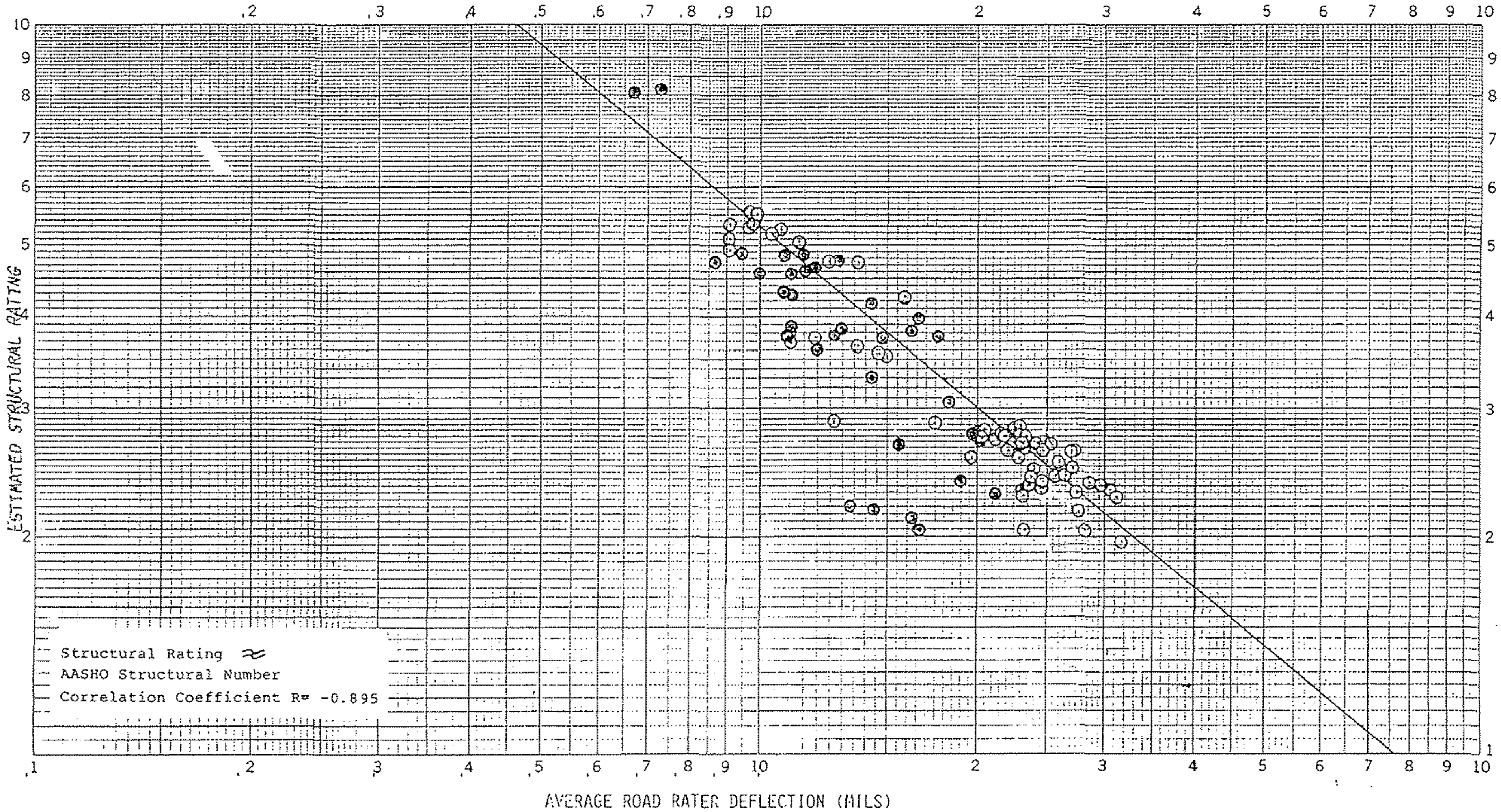

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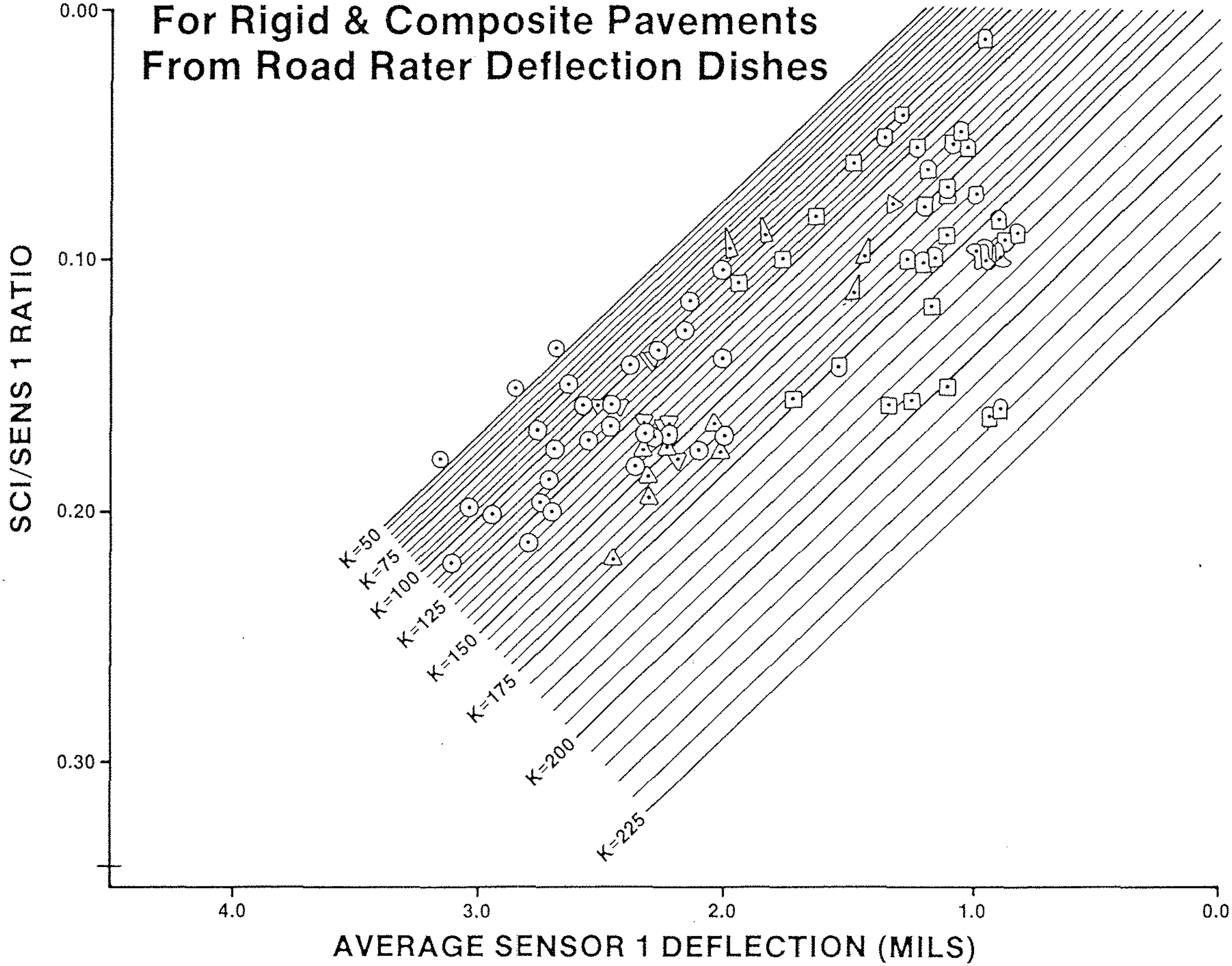
Figure 8

Soil Support K Values For Rigid & Composite Pavements From Road Rater Deflection Dishes



Potter, C.J. & Dirks, K.L.

Figure 9

Soil Support K And S Values For Flexible Pavements From Road Rater Deflection Dishes

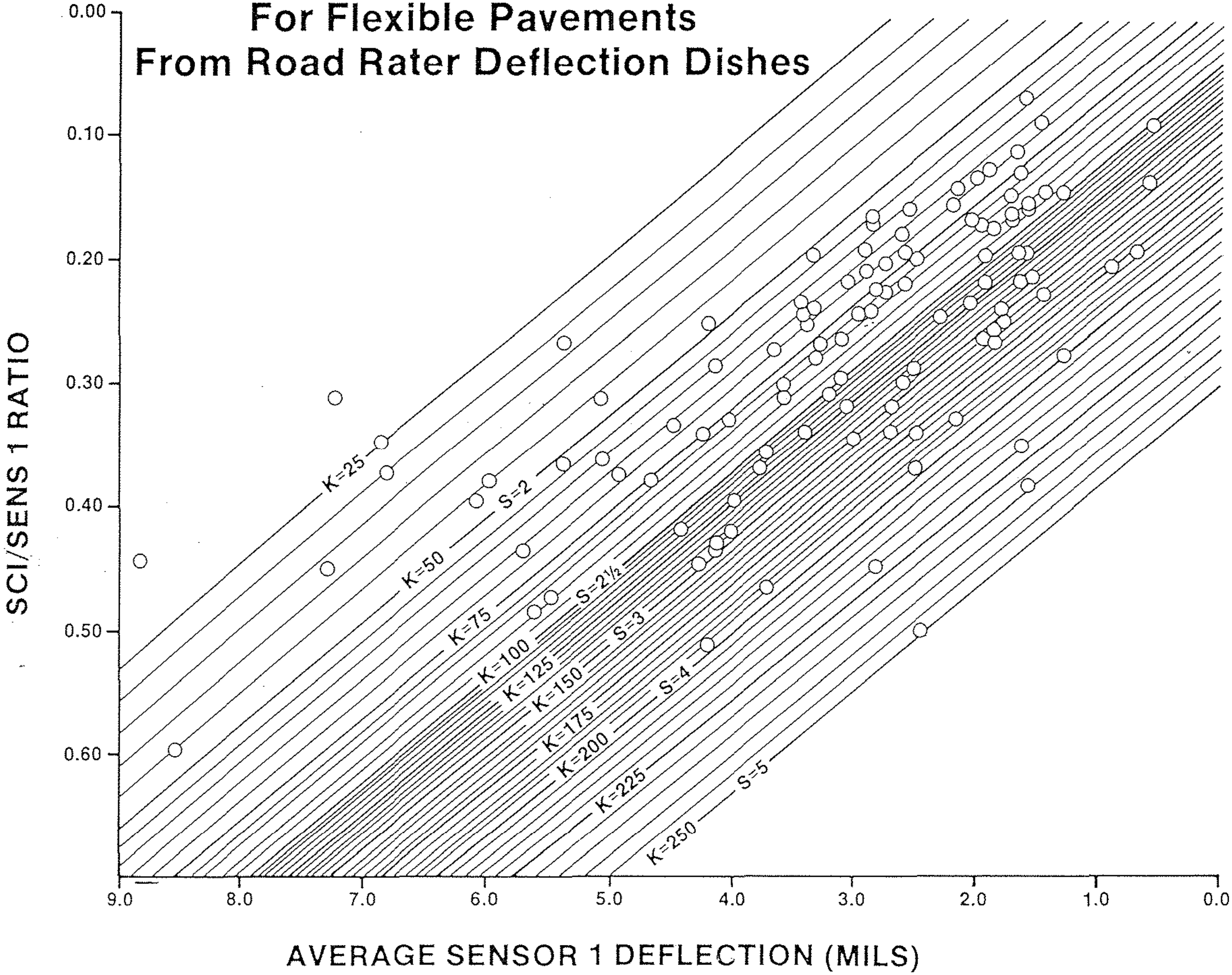


FIGURE 10
ROAD RATER STRUCTURAL RATING
VERSUS
PAVEMENT TEMPERATURE
FOR RIGID PAVEMENTS

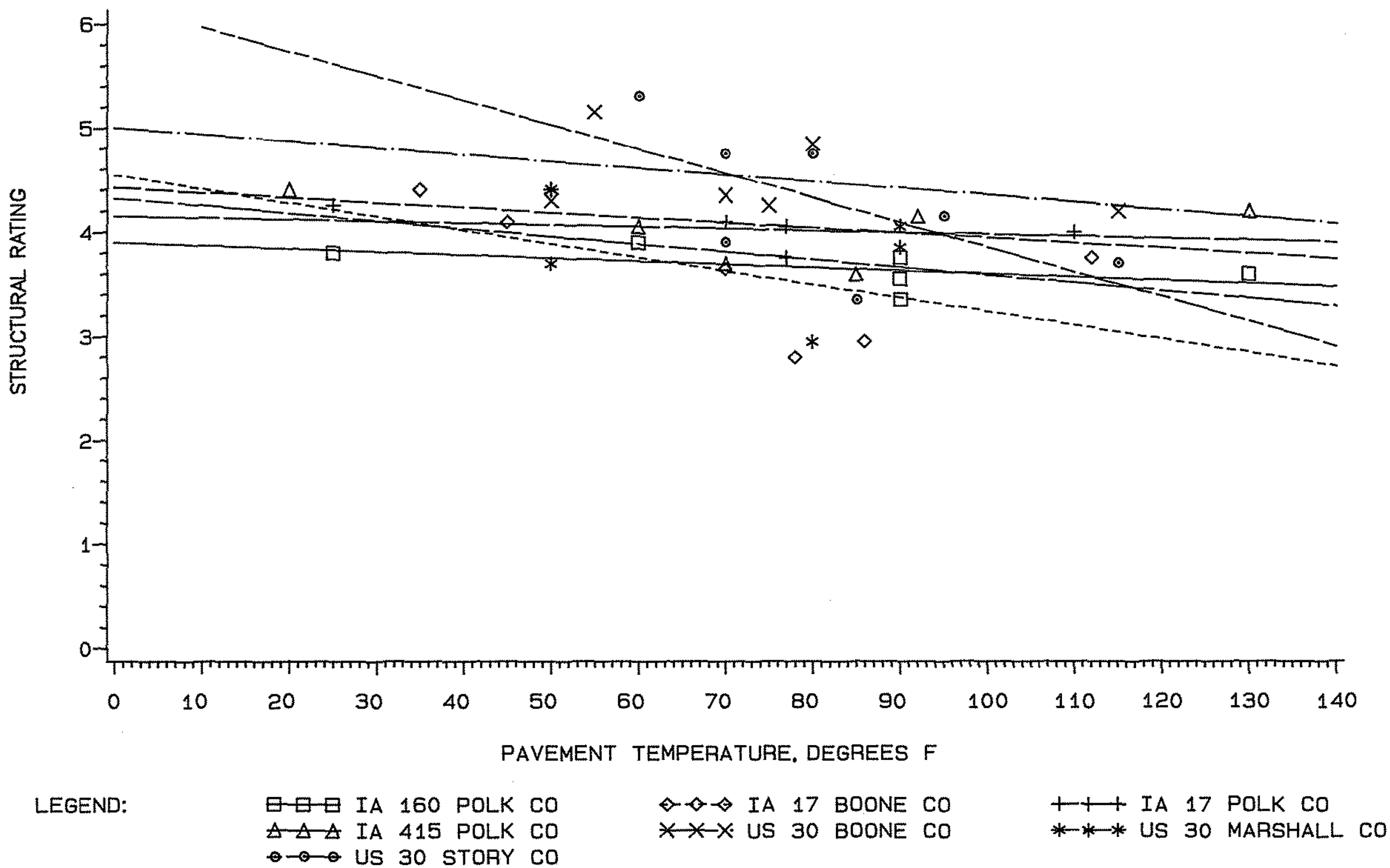


FIGURE 11

ROAD RATER STRUCTURAL RATING VERSUS PAVEMENT TEMPERATURE FOR COMPOSITE PAVEMENTS