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RELATING CREEP TESTING TO RUTTING OF ASPHALT CONCRETE MIXES

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Highway Research Advisory Board
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Highway Division
Iowa Department of Transportation

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DISCLAIMER

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ABSTRACT

The Iowa Department of Transportation began creep and resilient modulus testing of asphalt concrete mixtures in 1989. Part 1 of this research reported in January 1990 was a laboratory study of hot mix asphalt (HMA) mixtures made with 0, 30, 60, 85 and 100% crushed gravel, crushed limestone and crushed quartzite combined with uncrushed sand and gravel. Creep test results from Marshall specimens related well to the percent of crushed particles and the perceived resistance to rutting.

The objective of this research, part 2, was to determine if there was a meaningful correlation between pavement rut depth and the resilient modulus or the creep resistance factor. Four and six inch diameter cores were drilled from rutted primary and interstate pavements and interstate pavements with design changes intended to resist rutting. The top 2 1/2 inches of each core, most of which was surface course, was used for creep and resilient modulus testing.

There is a good correlation between the resilient modulus of four and six inch diameter cores. Creep resistance factors of four and six inch diameter cores also correlated well. There is a poor correlation between resilient modulus and the creep resistance factor. The rut depth per million 18,000 pound equivalent single axle loadings (ESAL) for these pavements did not correlate well with either the resilient modulus or the creep resistance factor.

INTRODUCTION

Over the years, hot mix asphalt pavements have given outstanding performance. Experience has shown that HMA can be used on roadways carrying high volumes of heavy truck traffic without a problem of rutting. Unfortunately, there are still instances where objectionable rutting occurs. Improved test methods are needed to better evaluate the rutting potential of HMA mixes.

Researchers have identified numerous variables in asphalt concrete pavement design and construction having varying degrees of importance in regard to pavement performance. These variables include the aggregate (type, porosity, gradation and hardness), the crushing (jaw, cone and hammer), the asphalt cement (content, grade and quality), the mixing (drum or pugmill and temperature) and the laydown and compaction to mention just a few. This large number of variations is one reason for the difficulty in developing a test that will relate HMA mix design to pavement performance. There are factors and conditions apart from the HMA mixture that affect the depth of rutting and the length of time before objectionable rutting occurs. Air temperature, heat of the sun and truck loadings are the most important of the non-asphalt related factors. Some pavements have provided a number of years of good performance without rutting until being subjected to a prolonged period of unusually high temperature (for Iowa above 100°F). High temperature has contributed to substantial rutting in a short period of time. Hills and areas of starting and stopping are also factors that contribute to rutting problems.

This is part 2 of a three part study of creep and resilient modulus testing of HMA. Part 1 reported in January 1990 (1) was a laboratory study of HMA mixtures made with 0, 30, 60, 85 and 100% crushed gravel, crushed limestone and crushed quartzite combined with uncrushed sand and gravel. These aggregate combinations were used with 4, 5 and 6% asphalt cement (AC). Marshall specimens 2 1/2 inches high by 4 inches in diameter were made using 75 blow compaction. Laboratory testing of these specimens included creep and resilient modulus testing. A creep resistance factor developed in part 1 seemed to relate well to the percent of crushed particles and the perceived resistance to rutting.

OBJECTIVE

The objective of part 2 was to determine if there was a meaningful correlation between pavement rut depth and the resilient modulus or the creep resistance factor.

SELECTION OF PAVEMENT SECTIONS

Four and six inch diameter cores were drilled from two groups of pavement. One group was primary and interstate pavements where substantial rutting had been measured. The other group was interstate pavements constructed since 1984 with mix designs based on 75 blow Marshall compaction and specifications requiring more than 70% crushed particles and compaction to an increased percent of laboratory density to reduce the potential for rutting. The descriptions of the sections are given in Table 1.

TESTING EQUIPMENT

Road Rater

The Iowa DOT measures pavement deflections with a Foundation Mechanics, Inc. Model 400 Road Rater. The standard test procedure for asphalt concrete uses a peak-to-peak force of 1185 pounds from approximately 400 pounds to 1600 pounds at a frequency of 25 Hertz.

Resilient Modulus Apparatus

The resilient modulus testing for this study was performed using a Retsina Mark VI Resilient Modulus Non-Destructive Testing Device, purchased in 1988 from the Retsina Co., Oakland, California. The Retsina Device was selected among numerous resilient modulus testing systems due to its low cost, simplicity, and ease of operation. As described in ASTM D-4123, for a cylindrical specimen, diametral loading results in a horizontal deformation which is related to resilient modulus by the formula:

$$M = \frac{P(\nu+0.2734)}{t(d)}$$

where: M = resilient modulus, psi

P = vertical load, pounds

ν = poissons ratio

t = specimen thickness, inches

d = horizontal deformation, inches

The device operates by applying a load pulse (0 to 1000 lb range) diametrically through the specimen. Load duration (0.05 or 0.10 sec.) and frequency (0.33, 0.5, or 1.0 hz) are controlled by the operator. Horizontal deformations are sensed by transducers mounted on a yoke connected to the specimen. The number of cycles to be used in a test can be set by the operator. Results are calculated by a microprocessor and are presented both by printer and digital display.

Creep Test Device

The creep test device used in this study was fabricated by Iowa DOT Materials Laboratory Machine Shop and Instrumentation personnel. The device consists of three pneumatically actuated load units mounted on a load frame, and is capable of simultaneously testing three samples. An air regulator with digital display is capable of delivering pressure from

0 to 120 psi to the load units. The load units have 12.4 to 1 force/pressure conversion ratio and a maximum output of 1500 lbs. in the linear range. A compression load cell was used to calibrate the load units and develop the force/pressure conversion ratios. A brass load plate is centered on the frame directly under each of the load unit rams. A specimen is centered on the load plate and another load plate is placed on top of the specimen. The specimen and top load plate are aligned directly beneath a load unit ram through which a vertical force of from 0 to 1500 lbs. can be applied. Dial gauges readable to 0.001 inch are mounted to the load unit rams, and vertical deformation of the specimen as a function of time, is determined. The lower load frame and test specimens are contained in an insulated tank containing a temperature controlled water bath. The operational range of the water bath is from 25°F to 140°F.

TEST PROCEDURES

Rut Depth and Road Rater Testing

The rut depths were measured beneath a four foot gauge at the location where the 4 and 6 inch diameter cores were to be taken. The Road Rater deflection was determined just prior to coring. Only the accelerometer reading located on the pavement at the center of the loading plate is reported in this report. The 10 mil and 1 mil scales were used to determine the deflections in mils at the springtime ambient temperature. Pavement temperatures at time of testing were recorded.

Drilling and Preparation of Test Specimens

Three four-inch and three six-inch diameter cores were drilled using a diamond core bit cooled with water. The cores were stored at 70°F in the laboratory until normal laboratory testing operations decreased enough that personnel were available. Quite often, the top surface of the core was not perpendicular to the axis of the core. Approximately 1/8 inch of the top of both the 4 and 6 inch diameter cores was sawed off to obtain a surface perpendicular to the axis of the core. A 2 1/2 inch thick slice was then cut off of the top of both the 4 and 6 inch diameter cores. The thickness of the test specimen will have a definite effect on the change in height and/or failure in the creep test. The initial testing was conducted using 2 1/2 inch thick Marshall specimens. In an effort to make the drilled cores relate to the laboratory compacted Marshall specimens, the 2 1/2 inch thick slice was selected. An Iowa DOT standard thickness of 2 1/2 inches has been established for resilient modulus and creep testing. Most of the tested material was surface course, but quite often the surface course was only 2 inches thick so 1/2 to 3/4 inch of binder layer was included to yield a 2 1/2 inch thick specimen.

<u>Resilient Modulus Testing</u>

Testing temperature for resilient modulus was targeted at 77±2°F. The only temperature control utilized was the ambient air temperature of the lab itself. At this time, the Iowa DOT does not have the capability for testing resilient modulus at elevated temperatures. The temperature of the specimen was determined by sandwiching a thermocouple wire between two specimens. If the indicated temperature was not 77±2°F, the test was not performed.

After confirming the temperature was within the desired range, a template was used to mark three 60° divisions on the diameter of the specimen. Specimen thickness was determined to .01 inch using a height comparator. Each specimen was placed in the frame and tested with the transducers directly opposite each other. After an individual test was completed, the specimen was reoriented by rotating 60° and the test was repeated. Each specimen was again rotated 60°, resulting in a total of three tests per specimen each at an orientation of 60° from the other two.

Each test consisted of twenty load cycles of 0.10 sec. and a frequency of 0.33 hz. Prior to this study, it was determined that preconditioning by subjecting the sample to a number of the cyclic loads had no effect on the outcome, consequently, the practice of preconditioning as recommended in ASTM D-4123 was not utilized. The three sets of twenty cycles were each repeated at loads of 50 and 75 pounds.

This same testing pattern was performed on each of the three four-inch and three six-inch diameter cores. All results for a set of three cores were then averaged to yield a single resilient modulus value. Final results were expressed in terms of thousands of pounds per square inch (Ksi).

Since the resilient modulus test is considered non-destructive at low loadings and moderate temperatures (the key factor being low horizontal deformation and accumulated deformation), when resilient modulus testing was completed, the same cores were then used for the creep test procedure.

Creep Test Procedure

After the cores were sawed to obtain the 2 1/2 inch slice, the flat faces were polished by laying them on a belt sander using #50 grit paper. This was done to remove surface irregularities that would result in uneven, internal stress distribution, and to allow the surface to be made as frictionless as possible. Surface friction reduction was further enhanced by the application of a mixture of #2 graphite flakes and water/temperature resistant silicon gel lubricant to the polished core faces.

Sets of three cores of the same diameter from the same site were tested simultaneously. Testing temperature was 104°F, and the specimens were conditioned in 104°F water for 1/2 hour prior to testing.

The specimens were then subjected to a preload of 40 psi contact pressure for 2 minutes using a 4 inch diameter load plate prior to testing. In order to achieve contact pressures of 200 psi during testing, a 3 inch diameter top load plate was used instead of a 4 inch diameter plate. After preloading, which was intended to properly seat the specimen, load plates and ram, and compress any final minute surface protrusions, the specimens were removed from the apparatus and their height measured to the nearest 0.0001 inch using a height comparator. The samples were then placed back in the apparatus; dial gauges were adjusted to read 0.500 inch; and the creep loads were applied.

Contact pressure was increased from 0 to 40 psi in step loads of 8 psi applied for 1 minute each. After 40 psi was reached, the dial gauges were read at ten minute intervals until 1 hour had passed. At this time, 8 psi step loads of one minute duration were again applied until a contact pressure of 80 psi was attained. Dial gauge readings were again taken at ten minute intervals for one hour. This entire sequence was repeated until the final step of 200 psi for 1 hour was achieved, or specimen failure occurred. Specimen failure is indicated by a rapid increase in height reduction or change in height of more than 0.05 inch. Total elapsed time (min.), the applied pressure at the time of failure and the measured reduction in height just prior to failure were recorded. If failure did not occur, total reduction in height at the end of the test (325 minutes) was used to calculate the creep resistance factor (CRF). The CRF was developed by the Iowa DOT to provide a single quantitative number value to creep test results. The reasoning in developing the CRF was that a mixture that failed prior to the 200 psi loading at 325 minutes was less resistant to permanent deformation than one that would withstand the 200 psi loading with limited deformation. Secondly, if two mixtures did not fail prior to the 200 psi loading, the amount of change in height was related to the resistance to deformation and the mixture with the least change should result in the higher single quantitative CRF. The formula for the CRF is:

$$CRF = \frac{t}{325}\,[100-c(1000)]$$

where: CRF is Creep Resistance Factor

t is time in minutes at failure , 0.05 inch height change, or 325 if failure did not occur.

c is change in height in inches or 0.05 inch if failure occurred.

For example, if failure did not occur, but total change in height was 0.037 inch, then

$$CRF = \frac{325}{325}\,[100-(0.037)(1000)]$$

$$= 63$$

In another example, if failure occurred at 265 minutes, then

$$CRF = \frac{265}{325} [100-(0.050)(1000)]$$

$$= 41$$

DISCUSSION

The data is given in Table 2A and 2B. The percent AC was determined from tank stick measurements during construction. The percent of crushed particles was based on the intended percentages of the various aggregates. Construction report pavement histories provided average field voids and average percent of laboratory Marshall density.

Most of the 18,000 pound ESAL were obtained from the pavement management computer records. When the ESAL were not available from the pavement management program, the current annual ESAL were used to estimate the accumulated ESAL.

On the interstate pavements, Iowa has used a program of removing the rutted driving lane and leaving the nonrutted passing lane. Five of the sites selected for drilling were the old and new HMA where the driving lane had been replaced. In those cases, the rut depth and the ESAL reported for the passing lane were those of the rutted driving lane just prior to its removal and replacement.

Interstate pavements constructed prior to 1984 were based on 50 blow Marshall compaction and the 4 inch diameter cores included in this research yielded an average creep resistance factor of 30 and an average resilient modulus of 1170. With 75 blow compaction on interstate projects constructed in 1984 and later the average creep resistance factor was 33 and the average resilient modulus was 763.

For the correlations with creep resistance factors and resilient modulus, site 15 with very low annual ESAL resulted in data points that were substantially separated from all other data points. The site 15 data were excluded from all correlations with rut depths per million ESAL.

A good correlation (r^2=0.89) between resilient modulus of 4 inch and 6 inch diameter cores (Figure 1) was obtained. This would demonstrate that the test is consistent and that it consistently evaluates the same properties. There was also relatively small variation between three cores of the same set.

Poor correlations were obtained between resilient modulus and rut depth per million ESAL. Resilient modulus of the 4 inch diameter cores (Figure 2) gave a correlation coefficient r^2 of 0.15 with rut depth per million ESAL. There was some relationship, but apparently other factors had a significant effect. A correlation of the resilient modulus of 4 inch diameter cores with rut depth per log of ESAL yielded a correlation coefficient r^2 of 0.06, which was even worse than using rut depth per million ESAL.

The correlation with the resilient modulus of 6 inch diameter cores (Figure 3) was very similar with a correlation coefficient r^2 of 0.17.

There was very little correlation between the creep resistance factor and the resilient modulus of 4 inch diameter cores (Figure 4) with a correlation coefficient r^2 of 0.11.

The correlation of the creep resistance factor of 4 inch and 6 inch diameter cores (Figure 5) gave a correlation coefficient r^2 of 0.81. The creep resistance factor of the 6 inch diameter cores was about 10% greater than those for the 4 inch diameter cores. Based on the good correlation and only 10% difference, it appears that 4 inch diameter cores were adequate for creep testing. There was some concern that there would be substantial difference of results between the 4 inch diameter cores and the 6 inch diameter cores due to shearing in the 4 inch diameter cores. The shear angle should vary with the amount of crushed particles in a mixture and be relatively vertical with a high percentage of crushed particles. With only 10% difference between the 4 inch and 6 inch diameter cores, it would seem that shearing was of minimal contribution.

In part 1 of this research, the creep resistance factor related very well to the percent of crushed particles in a HMA mixture. Unfortunately, it did not correlate well with the rut depth per million ESAL (Figure 6 & 7) with a correlation coefficient r^2 of 0.21 for 4 inch and an r^2 of 0.18 for the 6 inch. A correlation of the creep resistance factor of 4 inch diameter cores with rut depth per log of ESAL yielded an r^2 of 0.06. There were apparently a number of other factors such as aging of the asphalt cement that had a substantial effect on the results. The creep resistance factor may predominately evaluate the aggregate "skeleton". In this part 2 research, the correlation with the resilient modulus and the creep resistance factor were similar, but neither exhibited a meaningful correlation with rut depth.

The Road Rater deflection data was obtained at pavement temperatures ranging from 40°F to 88°F. Through a nomagraph the deflection readings given in Table 2A and 2B have been corrected to readings for 80°F. There was an interest in correlation of Road Rater deflections with rut depths and resilient modulus. The correlation of rut depth with Road Rater deflections yielded an $r^2 = 0.00$. There was absolutely no relationship. The correlation of Road Rater deflection with resilient modulus of 4 inch diameter cores yielded an $r^2 = 0.00$ which again shows absolutely no relationship. It would appear that our current rutting is not related to base failure and is, therefore, not related to the structural values from the Road Rater.

FUTURE RESEARCH-PART THREE

Part 3 of this research is currently in progress. The objective of part 3 is to determine the relationship of creep and resilient modulus for (1) Marshall specimens from laboratory mixing for mix design (2) Marshall specimens from construction plant mixing and (3) cores drilled from the HMA pavement. Five 1990 projects have been selected ranging from an 85% crushed particle interstate mix to a Type B mix (requiring at least 30% crushed particles) for a low traffic volume roadway. During construction of each project, a box sample of HMA mix was taken from a truck delivering mix to the paver. Three Marshall specimens were made in the laboratory for resilient modulus and creep testing.

For each project, three four-inch diameter cores were drilled from the compacted asphalt pavement at the location where the mix represented by the box sample was used. After trimming to obtain a plane perpendicular to the axis of the core, the top 2 1/2 inches was cut off for resilient modulus and creep testing. Resilient modulus and creep resistance factor data are not yet available.

CONCLUSIONS

This research supports the following conclusions in regard to creep and resilient modulus testing of HMA:

1. Results of both the resilient modulus and creep testing are relatively repeatable with small variation for cores from a particular HMA pavement.

2. There is a good correlation between the resilient modulus of 4 inch and 6 inch diameter cores.

3. Creep resistance factors of 4 and 6 inch diameter cores correlated very well.

4. For the HMA pavements selected for this research, there is a poor correlation between rut depth per million ESAL and either resilient modulus or creep resistance factors.

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TABLE TITLES

1. Description of Coring Locations

2. HMA Mix and Testing Data

Table 1A Description of Coring Locations

Site	County	Project #	Date of Construction	Highway	MP	Lane
1	Adair	IR-80-2(114)73--12-01	1987	I-80 EB	81.40	Dr
2	Adair	IR-80-2(107)86--12-01	1986	I-80 EB	95.45	Dr
3	Adair	IR-80-2(91)86--12-01	1982	I-80 EB	95.45	Pass
4	Cass	I-IR-80-1(131)42--14-78	1981	I-80 EB	52.2	Dr
5	Cass	I-IR-80-1(131)42--14-78	1981	I-80 WB	55.0	Pass
6	Cass	IR-80-1(161)56-12-15	1986	I-80 EB	59.7	Dr
7	Cass	I-EACIR-80-1(127)54--0E-15	1979-1980	I-80 EB	59.7	Pass
8	Cass	IR-80-1(161)56--12-15	1986	I-80 WB	59.9	Dr
9	Cherokee	EACF-3-2(5)--20-18	1979-1980	IA 3	44.25	WB
10	Cherokee	EACF-3-2(5)--20-18	1979-1980	IA 3	54	EB
11	Cherokee	FN-59-7(16)--21-18	1973	US 59	150.7	SB
12	Cherokee	FN-59-7(16)--21-18	1973	US 59	154	SB
13	Dallas	IR-80-3(52)99--12-25	1987	I-80 EB	109.65	Dr
14	Dickinson	F-71-9(9)--20-30	1978	US 71	231	SB
15	Harrison	FN-44-1(2)--21-43	1978-79	IA 44	1.5	WB
16	Harrison	IR-29-4(33)72--12-43	1987	I-29 SB	87.45	Dr
17	Harrison	EACIR-29-5(42)78--0C-43	1982	I-29 SB	87.45	Pass
18	Osceola	FR-60-4(20)--26-72	1986	IA 60	50.8	NB
19	Osceola	FR-60-4(20)--26-72	1986	IA 60	50.8	NB
20	Osceola	FR-60-4(20)--26-72	1986	IA 60	50.8	SB
21	Plymouth	EACF-75-1(36)--2K-97	1983	US 75 SB	5	Dr
22	Plymouth	FN-75-2(24)--21-75	1985	US 75 NB	5	Dr
23	Pocahontas	FN-4-4(1)--21-76	1970	IA 4	76+	NB
24	Pocahontas	FN-4-4(10)--21-76	1976	IA 4	93+	NB
25	Pottawattamie	EACIR-80-1(138)5--06-78	1983	I-80 WB	6	Dr
26	Pottawattamie	IR-80-1(146)0-12-78	1984	I-80 WB	11.00	Dr
27	Pottawattamie	EACIR-80-1(138)5--06-78	1983	I-80 EB	11.00	Dr
28	Pottawattamie	IR-80-1(146)0-12-78	1984	I-80 WB	18.00	Dr
29	Pottawattamie	EACIR-80-1(138)5--06-78	1983	I-80 EB	18.00	Dr
30	Sac	FN-175-4(4)--21-81	1986	IA 175	68.00	WB
31	Sac	FN-175-4(4)--21-81	1986	IA 175	68.1	EB

Table 1B Description of Coring Locations

Site	County	Project #	Date of Construction	Highway	MP	Lane
32	Sioux		1983	IA 10	28.25	EB
33	Warren	FI-35-2(93)43--29-91	1969	I-35 SB	52.0	Pass
34	Warren	IR-35-2(192)42--12-91	1986	I-35 SB	52.0	Dr
35	Warren	FI-35-2(95)57--29-91	1969	I-35 NB	61.9	Pass
36	Warren	IR-35-2(192)42--12-91	1986	I-35 NB	61.9	Dr
37	Woodbury	FR-12-1(8)--26-97 AC 13	1984	IA 12 WB	2	Dr
38	Woodbury	FR-12-1(8)--26-97 No AC 13	1984	IA 12 WB	2	Dr
39	Woodbury	IR-29-6(82)123--12-97	1986	I-29 SB	138.20	Dr
40	Woodbury	INP-29-8(12)151--15-97	1971	I-29 SB	146.2	Pass
41	Woodbury	IR-29-6(85)126--12-97	1988	I-29 SB	149.45	Dr

Table 2A HMA Mix and Testing Data

Site	AC %	% Cr. Part.	Marshall Comp. Blows	Lab Voids %	Field Voids %	Avg. Field Dens. %	Creep Resis. Factor 4"	Creep Resis. Factor 6"	Resilient Modulus Ksi 4"	Resilient Modulus Ksi 6"	ESAL	Rut Depth Inches	Rut Depth Per Million ESAL Inches	Road Rater Defl. Mils
1	5.8	85.0	75	4.5	7.9	96.0	32	30	1505	1375	1,542,389	0.05	0.05	1.3
2	5.2	70.0	75	4.8	8.2	96.5	30	36	1290	1030	2,172,285	0.25	0.10	0.8
3	5.0	45%RAP	50		6.6		21	20	980	537	3,400,000	0.60	0.20	0.9
4	5.2	70.0	50	3.6	7.7	96.8	12	12	1570	1255	3,687,311	0.55	0.15	0.9
5	5.2	70.0	50	3.6	7.7	96.8	20	19	1035	995	3,687,311	0.10	0.05	0.9
6	4.7	70.0	75	3.1	5.7	97.3	37	43	1385	1270	2,108,253	0.10	0.05	0.9
7	5.1	70.0	50	3.3	7.1	96.35	53	68	1425	1600	5,000,000	0.50	0.10	0.8
8	4.7	70.0	75	3.1	5.7	97.3	41	38	735	820	2,108,253	0.05	0.00	1.1
9	6.2	5.0	50	2.9	6.7	95.2	18	22	510	410	269,841	0.65	2.40	2.0
10	6.2	5.0	50	2.9	6.7	95.2	21	16	870	525	266,532	0.40	1.50	3.4
11	6.5	30.0	50	4.2	8.8	95.1	10	21	195	155	436,329	0.30	0.70	2.5
12	6.5	30.0	50	4.2	8.8	95.1	13	14	620	530	158,766	0.40	2.50	2.0
13	4.9	85.0	75	1.8	6.8	94.9	31	36	670	640	699,056	0.05	0.05	1.4
14	5.5	30.0	50	4.5	9.2	95.4	21	21	810	620	448,462	0.10	0.20	2.6
15	6.5	50.0	50	4.6	7.5	95.9	42	49	675	550	43,418	0.20	4.60	2.1
16	5.0	85.0	75	5.1	6.6	98.4	29	20	480	380	700,000	0.10	0.15	2.1
17	5.8	70.0	50	4.5	6.9	96.3	11	15	1250	1160	1,800,000	0.60	0.35	1.9
18	5.9	70.0	50	3.6	6.1	96.9	14	20	315	260	197,278	0.25	1.25	1.5
19	5.9	70.0	50	3.6	6.1	96.9	16	15	270	200	197,278	0.10	0.50	1.7
20	5.9	70.0	50	3.6	6.1	96.9	25	22	415	330	197,278	0.15	0.75	1.7
21			50				22	30	795	745	1,600,000	0.30	0.20	2.1
22	5.1	70.0	50	3.8	7.3	96.7	37	37	291	210	1,010,820	0.40	0.40	1.8
23	5.5	70.0	50	5.8			31	42	1125	1040	600,000	0.30	0.50	2.3
24	7.0	30.0	50	9.0	12.5	96.0	37	35	1285	1025	70,000	0.10	1.45	5.9
25	4.9	70.0	50	5.0	8.0	96.8	31	37	975	855	6,500,000	0.05	0.00	1.2
26	4.7	70.0	75	4.9	7.4	97.4	22	31	NA	1330	5,200,000	0.05	0.00	1.5
27	4.9	70.0	50	5.0	8.0	96.8	10	10	835	665	6,500,000	0.45	0.05	1.3
28	4.7	70.0	75	4.9	7.4	97.4	25	27	375	455	5,100,000	0.05	0.00	1.2
29	4.9	70.0	50	5.0	8.0	96.8	34	40	725	550	6,300,000	0.10	0.00	0.8
30			50				9	16	199	164	91,006	0.25	2.75	1.1
31			50				9	10	238	191	91,006	0.20	2.20	1.1

Table 2B HMA Mix and Testing Data

Site	AC %	% Cr. Part.	Marshall Comp. Blows	Lab Voids %	Field Voids %	Avg. Field Dens. %	Creep Resis. Factor 4"	Creep Resis. Factor 6"	Resilient Modulus Ksi 4"	Resilient Modulus Ksi 6"	ESAL	Rut Depth Inches	Rut Depth Per Million ESAL Inches	Road Rater Defl. Mils
32							13	18	250	285	378,956	0.30	0.80	1.5
33	5.3	70.0	50		9.3	94.8	39	60	1450	1250	3,864,486	0.60	0.15	1.2
34	5.0	70.0	75	5.4	7.3	97.8	58	66	450	280	950,000	0.10	0.10	1.6
35	5.3	70.0	50		9.4	94.9	37	37	1910	1435	4,021,889	0.60	0.15	0.9
36	5.0	70.0	75	5.4	7.3	97.8	39	29	740	668	1,000,000	0.05	0.05	1.5
37	4.7	80.0	75	5.0	7.2	97.6	31	31	455	464	430,000	0.10	0.25	1.0
38	4.7	80.0	75	5.0	7.2	97.6	45	52	700	590	430,000	0.15	0.35	0.8
39	6.5	70.0	75	4.9	6.2	98.4	17	26	375	345	331,807	0.10	0.30	1.0
40	6.1		50	4.1	8.8	95.0	61	53	1110	520	6,800,000	0.30	0.05	0.8
41	5.6		75	3.7	6.4	97.4	31	23	690	565	414,407	0.35	0.85	1.0

FIGURE CAPTIONS

1. Graph of Resilient Modulus of 4 Inch vs 6 Inch Cores

2. Graph of Resilient Modulus of 4 Inch Cores vs Rut Depth per Million ESAL

3. Graph of Resilient Modulus of 6 Inch Cores vs Rut Depth per Million ESAL

4. Graph of Creep Resistance Factor vs Resilient Modulus for 4 Inch Cores

5. Graph of Creep Resistance Factor of 4 Inch vs 6 Inch Cores

6. Graph of Creep Resistance Factor of 4 Inch Cores vs Rut Depth per Million ESAL

7. Graph of Creep Resistance Factor of 6 Inch Cores vs Rut Depth per Million ESAL

FIGURE 1
RESILIENT MODULUS OF 4" VS. 6" CORES

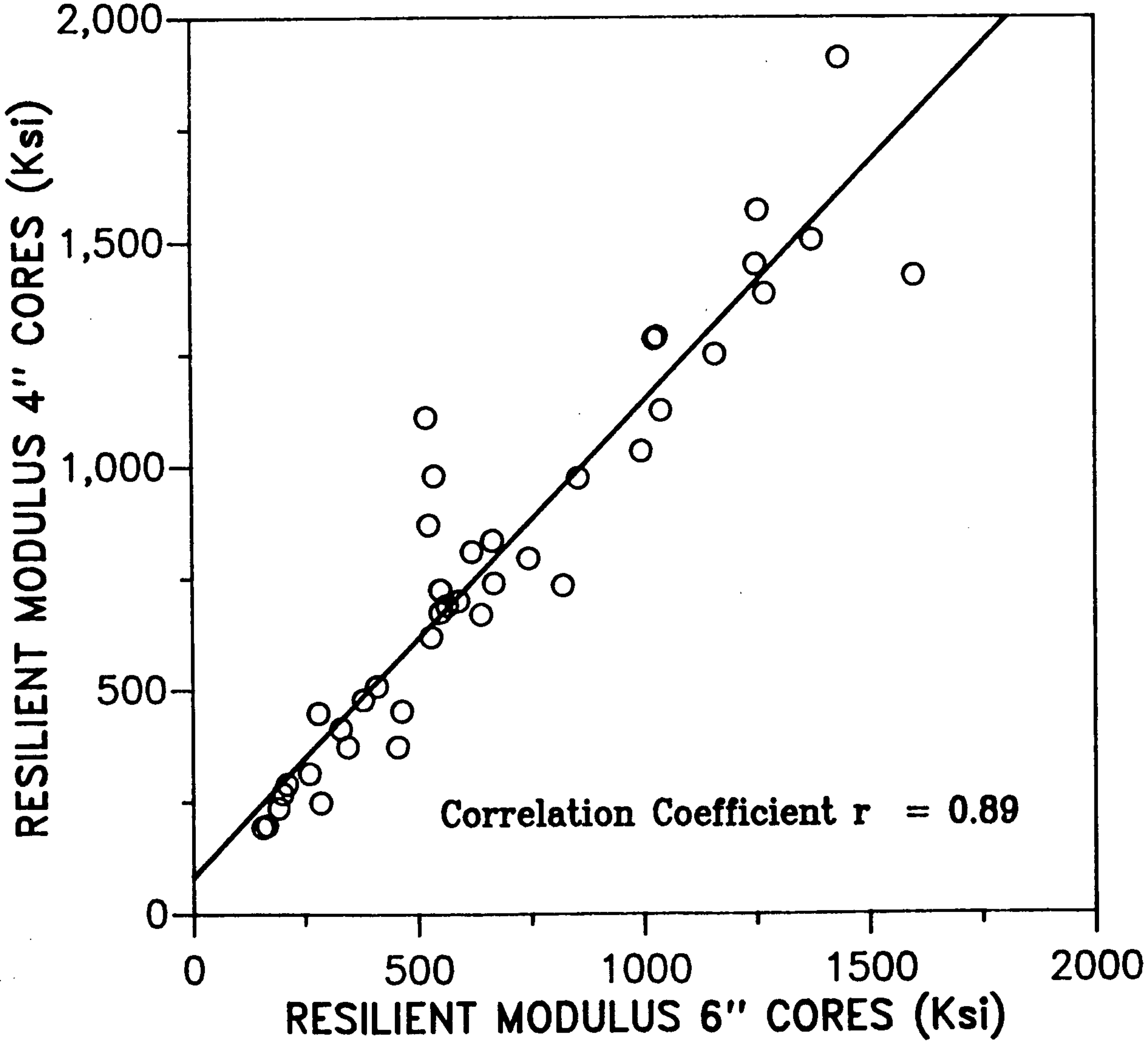

FIGURE 2
RESILIENT MODULUS 4" CORES VS. RUT DEPTH PER MILLION ESAL

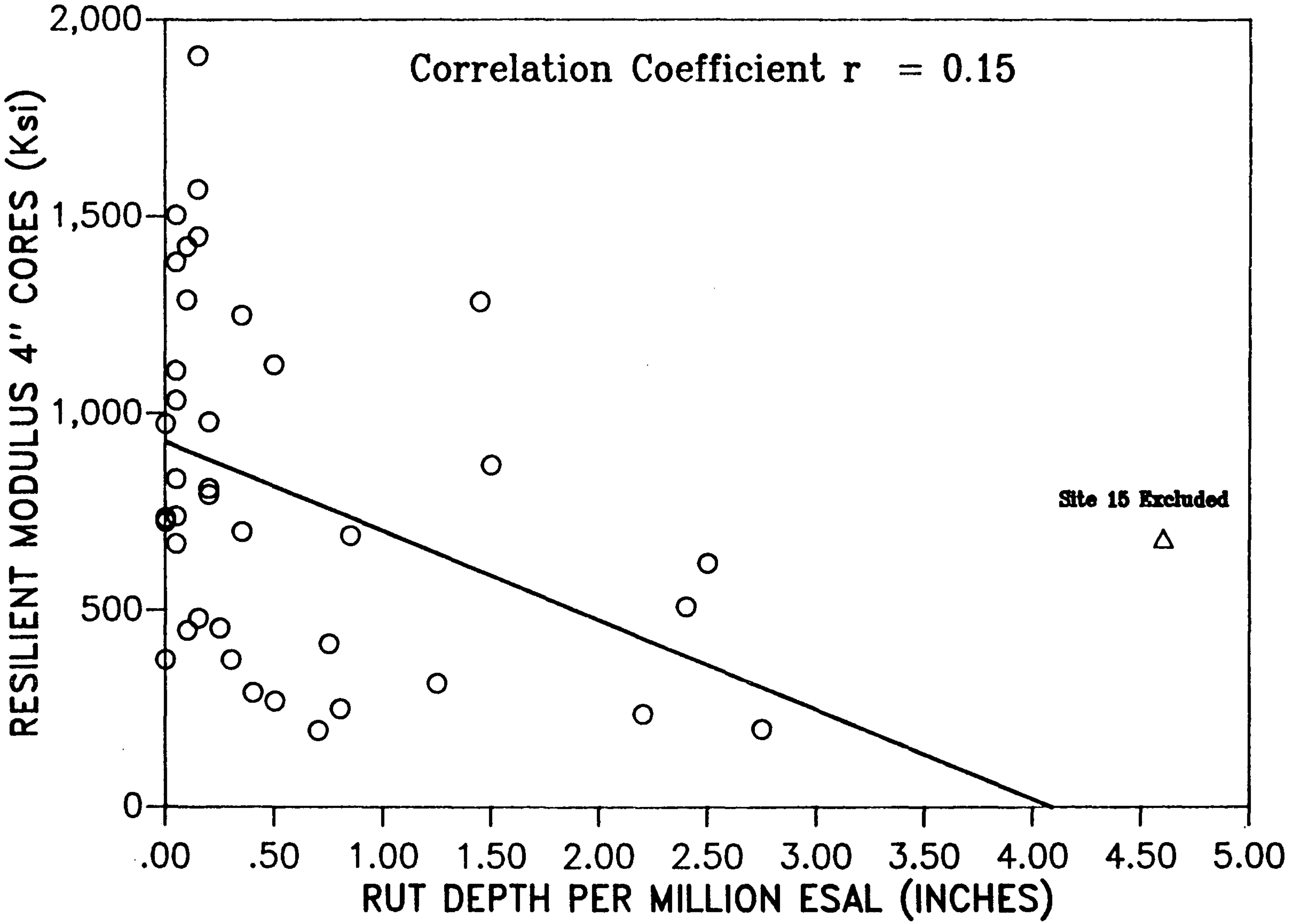

FIGURE 3
RESILIENT MODULUS 6" CORES VS. RUT DEPTH PER MILLION ESAL

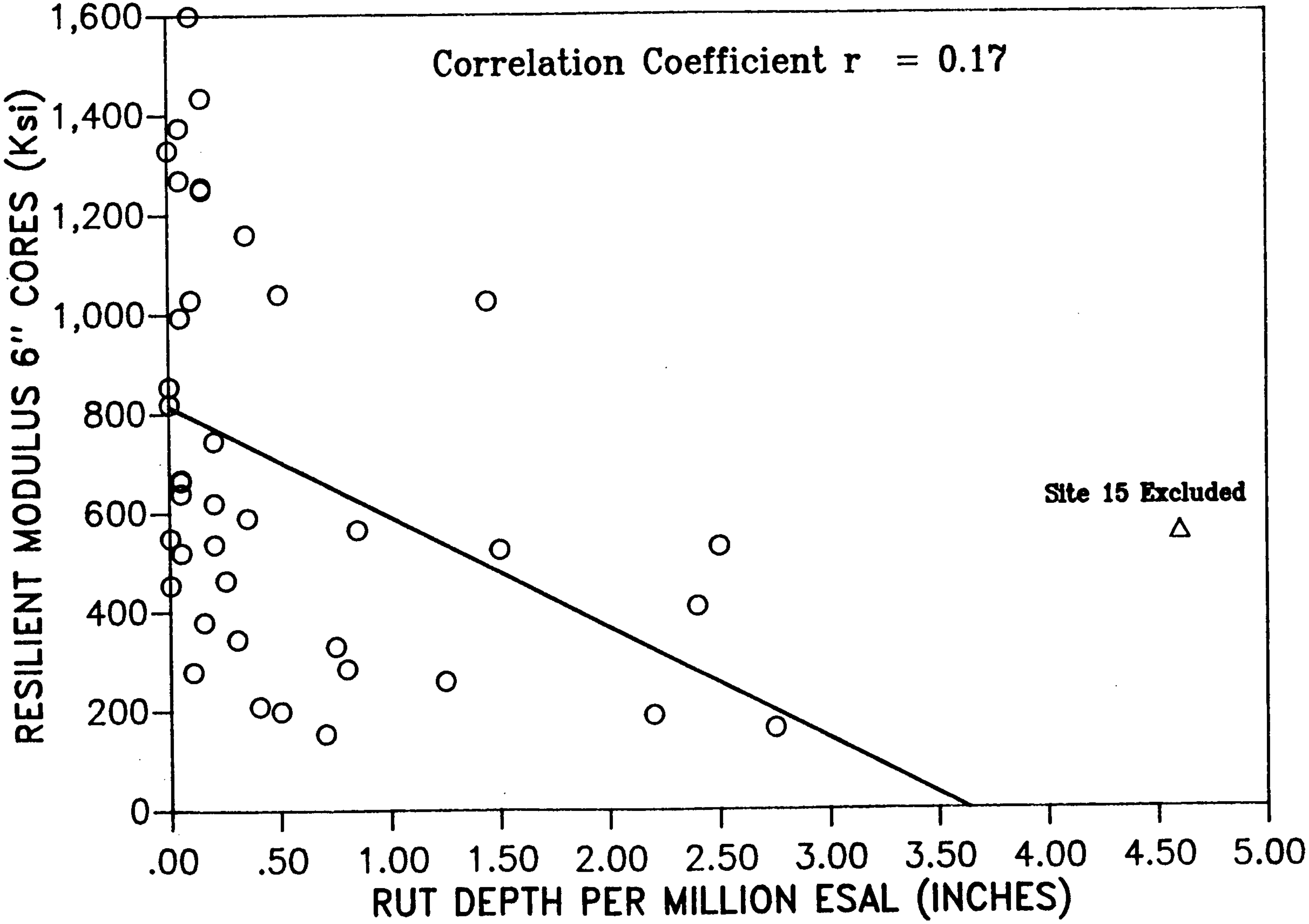

FIGURE 4
CREEP RESISTANCE FACTOR VS. RESILIENT MODULUS FOR 4" CORES

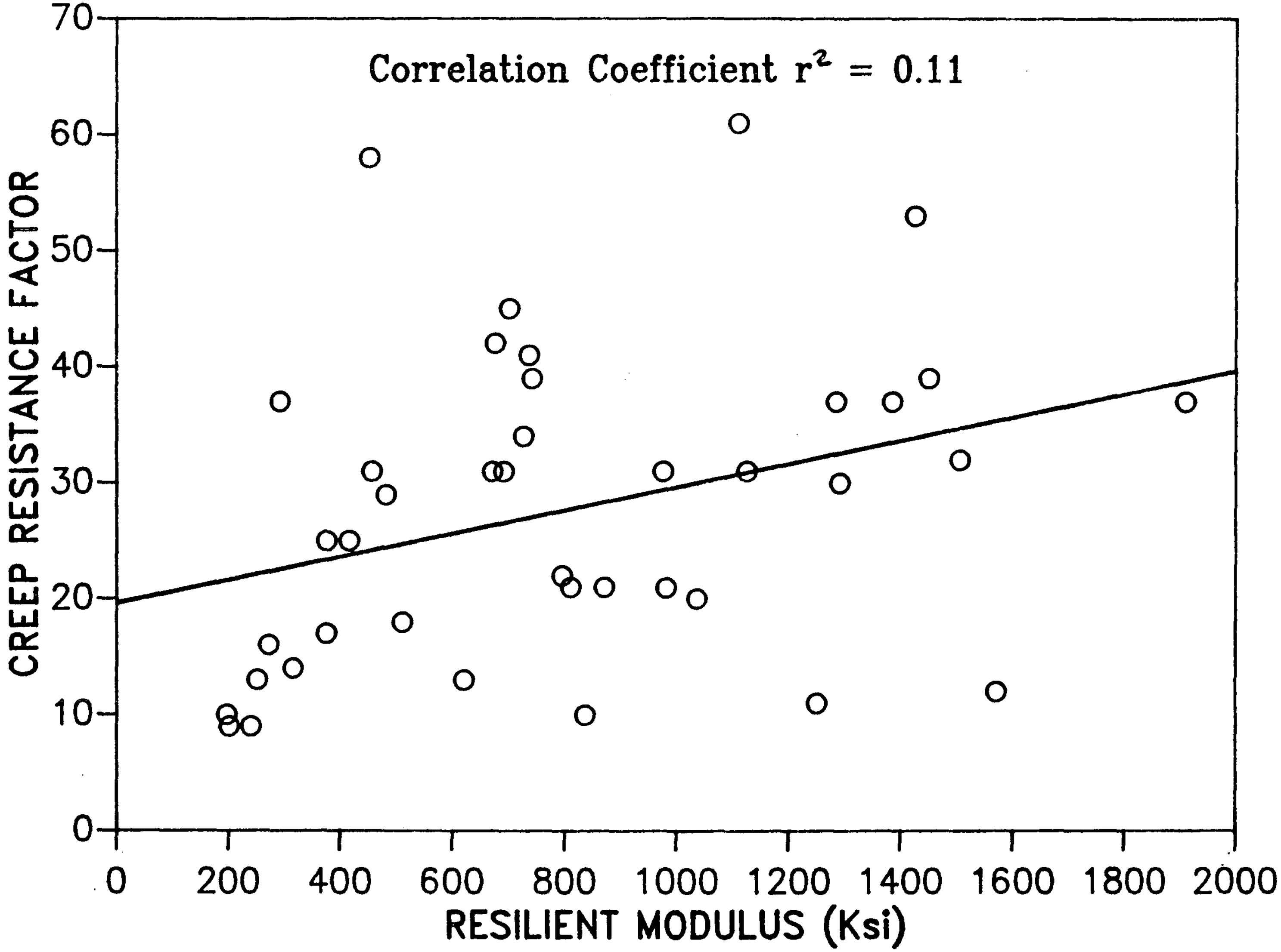

FIGURE 5
CREEP RESISTANCE FACTOR 4" VS. 6" CORES

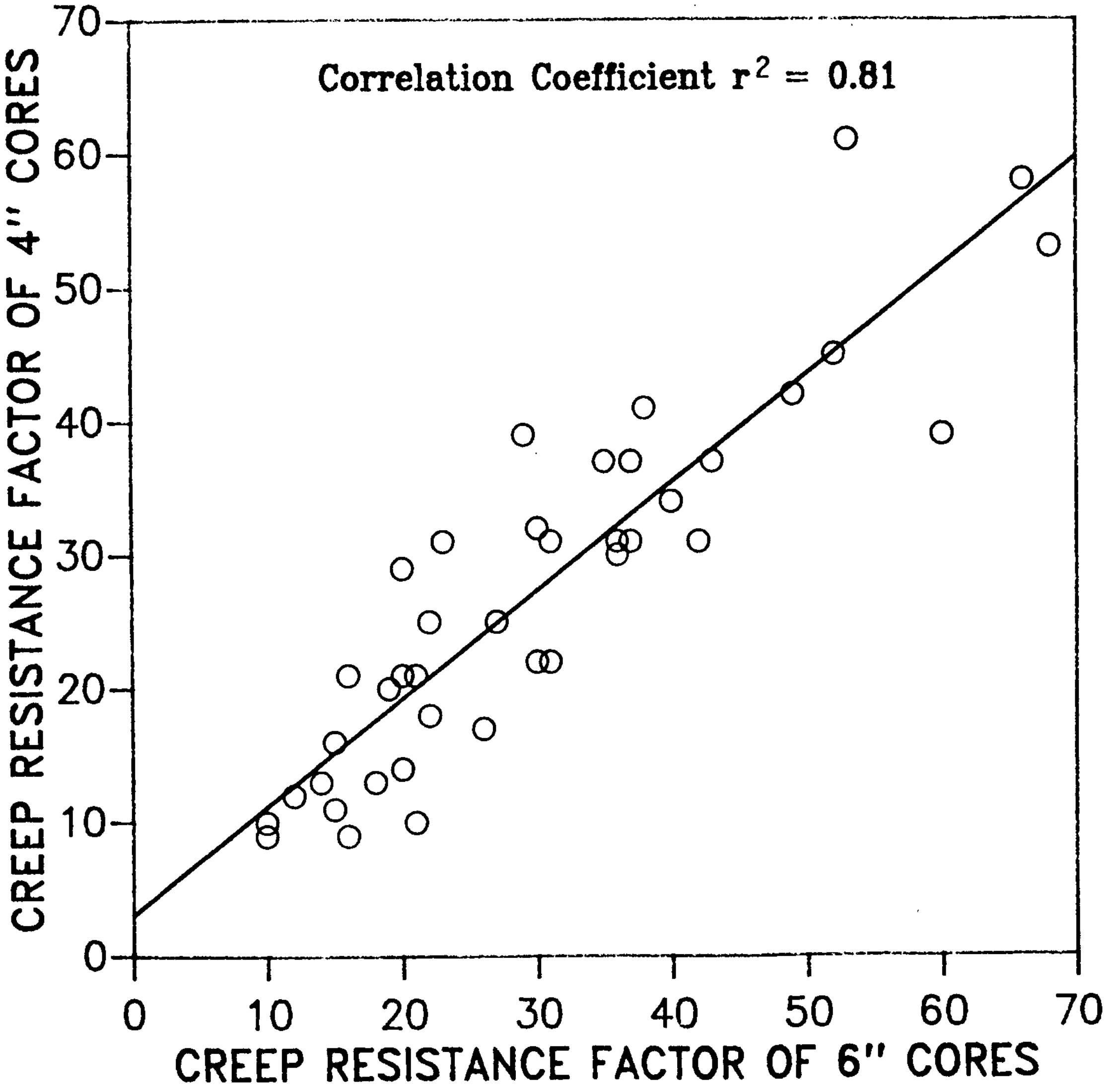

FIGURE 6
CREEP RESISTANCE FACTOR 4" CORES VS. RUT DEPTH PER MILLION ESAL

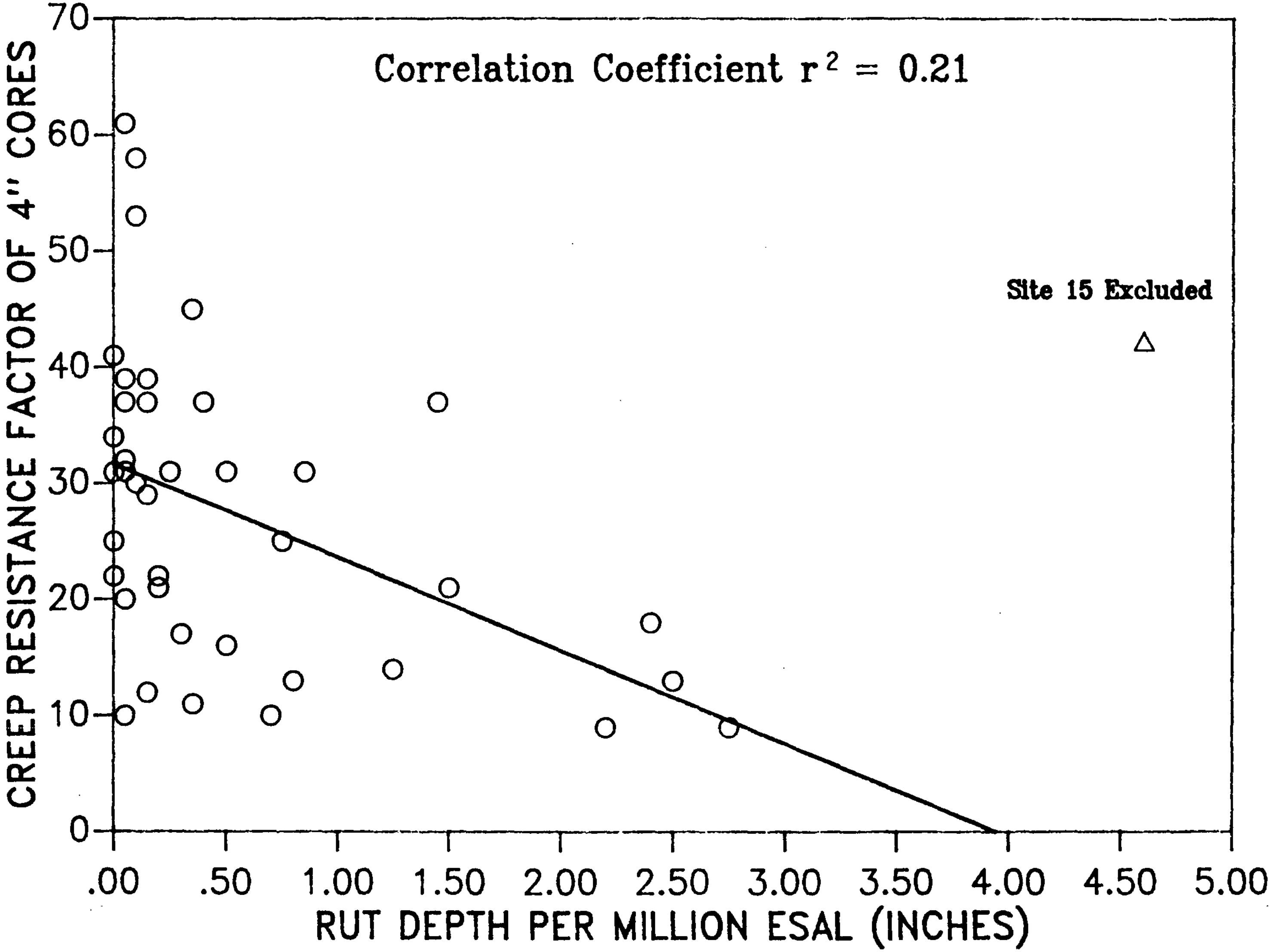

FIGURE 7
CREEP RESISTANCE FACTOR 6" CORES VS. RUT DEPTH PER MILLION ESAL