Relating Creep Testing to Rutting of Asphalt Concrete Mixes

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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 mixtures made with 0, 30, 60, 85, and 100 percent 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. Cores with 4- and 6-in. diameters were drilled from rutted primary and Interstate pavements and from Interstate pavements with design changes intended to resist rutting. The top 2½ in. 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 4- and 6-in.-diameter cores. Creep resistance factors of 4- and 6-in.-diameter cores also correlated well. There is a poor correlation between the resilient modulus and the creep resistance factor. The rut depth per million 18,000-lb equivalent single-axle loadings for these pavements did not correlate well with either the resilient modulus or the creep resistance factor.

Over the years, hot-mix asphalt (HMA) 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 in which 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 to pavement performance. These variables include the aggregate (type, porosity, gradation, and hardness), the crushing (jaw, cone, and hammer), and 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.

A three-part study of creep and resilient modulus testing of HMA is being conducted. Part 1 (*1*), reported in January 1990, was a laboratory study of HMA mixtures made with 0, 30, 60, 85, and 100 percent crushed gravel, crushed limestone, and crushed quartzite combined with uncrushed sand and gravel. These aggregate combinations were used with 4, 5, and 6 percent asphalt cement (AC). Marshall specimens 2½ in. high by 4 in. 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 percentage of crushed particles and the perceived resistance to rutting.

The objective of Part 2, reported here, 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

Cores with 4- and 6-in. diameters were drilled from two groups of pavement. One group was primary and Interstate pavements on which 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 percent crushed particles and compaction to an increased percent of laboratory density to reduce the potential for rutting. The descriptions of the sections are presented in Table 1.

TESTING EQUIPMENT

Road Rater

The Iowa Department of Transportation (DOT) measures pavement deflections with a Foundation Mechanics, Inc., Model 400 Road Rater. The standard test procedure for AC uses a peak-to-peak force of 1,185 lb from approximately 400 to 1,600 lb at a frequency of 25 Hz.

Resilient Modulus Apparatus

Resilient modulus testing was performed using a Retsina Mark VI resilient modulus nondestructive testing device, purchased in 1988 from the Retsina Co., Oakland, California. The Ret-

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TABLE 1 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
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

sina device was selected from among numerous resilient modulus testing systems because of its low cost, simplicity, and ease of operation. As described in ASTM D4123, for a cylindrical specimen, diametral loading results in a horizontal deformation that is related to resilient modulus by the following formula:

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

where

M = resilient modulus (psi),
P = vertical load (lb),
ν = Poisson's ratio,
t = specimen thickness (in.), and
d = horizontal deformation (in.).

The device operates by applying a load pulse (0- to 1,000-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 by both a printer and a digital display.

Creep Test Device

The creep test device used 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 can deliver pressure of from 0 to 120 psi to the load units. The load units have a 12.4 to 1 force/pressure conversion ratio and a maximum output of 1,500 lb 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 load unit ram. 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 1,500 lb can be applied. Dial gauges readable to 0.001 in. 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 placed 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 4-ft gauge at the location where the 4- and 6-in.-diameter cores were to be taken. The Road Rater deflection was determined just before coring. Only the accelerometer reading located on the pavement at the center of the loading plate is reported here. The 10- and 1-mil scales were used to determine the deflections in mils at the springtime ambient temperature. Pavement temperatures at the time of testing were recorded.

Drilling and Preparation of Test Specimens

Three 4-in.-diameter cores and three 6-in.-diameter cores were drilled using diamond core bits cooled with water. The cores were stored at 70°F in the laboratory until normal laboratory testing operations decreased enough that personnel were available. Often, the top surface of the core was not perpendicular to the axis of the core. Approximately ⅛ in. of the top of both the 4- and 6-in.-diameter cores was sawed off to obtain a surface perpendicular to the axis of the core. A 2½-in.-thick slice was then cut off of the top of both the 4- and 6-in.-diameter cores. The thickness of the test specimen has a definite effect on the change in height and failure in the creep test. The initial testing was conducted using 2½-in.-thick Marshall specimens. The 2½-in.-thick slice was selected to make the drilled cores relate to the laboratory-compacted Marshall specimens. An Iowa DOT standard thickness of 2½ in. has been established for resilient modulus and creep testing. Most of the tested material was surface course, but the surface course was often only 2 in. thick. Thus, ½ to ¾ in. of binder layer was included to yield a 2½-in.-thick specimen.

Resilient Modulus Testing

The testing temperature for resilient modulus was targeted at 77° ± 2°F. The only temperature control used was the ambient air temperature of the laboratory itself. At this time, Iowa DOT does not have the capability to test 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 that 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 0.01 in. 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 it 60 degrees. The test was then repeated. Each specimen was again rotated 60 degrees, resulting in a total of three tests per specimen, each at an orientation of 60 degrees from the other two.

Each test consisted of 20 load cycles of 0.10 sec and a frequency of 0.33 Hz. It had been previously determined that preconditioning by subjecting the sample to a number of cyclic loads had no effect on the outcome; consequently, the practice of preconditioning as recommended in ASTM D4123 was not used. The three sets of 20 cycles were each repeated at loads of 50 and 75 lb.

This same testing pattern was performed on each of the three 4-in.-diameter and three 6-in.-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 thousands of pounds per square inch (ksi).

Because the resilient modulus test is considered nondestructive at low loadings and moderate temperatures (the key factor being low horizontal deformation and accumulated deformation), the same cores were used for the creep test procedures.

Creep Test Procedure

After the cores were sawed to obtain the 2½-in. slice, the flat faces were polished by laying them on a belt sander using #50 grit paper. The sanding 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 applying a mixture of #2 graphite flakes and water- and 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. The testing temperature was 104°F, and the specimens were conditioned in 104°F water for ½ hr before testing.

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

Contact pressure was increased from 0 to 40 psi in step loads of 8 psi applied for 1 min each. After 40 psi was reached, the dial gauges were read at 10-min intervals until 1 hr had passed. At this time, 8-psi step loads of 1-min duration were again applied until a contact pressure of 80 psi was attained. Dial gauge readings were again taken at 10-min intervals for 1 hour. This entire sequence was repeated until the final step of 200 psi for 1 hr 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 in. The total elapsed time, the applied pressure at the time of failure, and the measured reduction in height just before failure were recorded. If failure did not occur, total reduction in height at the end of the test (325 min) was used to calculate the creep resistance factor (CRF). The CRF was developed by Iowa DOT to provide a single quantitative number value for creep test results. The reasoning in developing the CRF was that a mixture that failed before the 200-psi loading at 325 min was less resistant to permanent deformation than one that would withstand the 200-psi loading with limited deformation. In addition, if two mixtures did not fail before 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 as follows:

$$\mathrm{CRF} = \frac{t}{325}\,(100 - 1{,}000c)$$

where

CRF = creep resistance factor,
t = time in minutes at failure (0.05-in. height change), or 325 min if failure did not occur; and
c = change in height in inches, or 0.05 in. if failure occurred.

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

$$\mathrm{CRF} = \frac{325}{325}\,[100 - (1{,}000)(0.037)]$$
$$= 63$$

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

$$\mathrm{CRF} = \frac{265}{325}\,[100 - (1{,}000)(0.050)]$$
$$= 41$$

DISCUSSION OF RESULTS

The data are presented in Table 2. 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.

TABLE 2 HMA MIX AND TESTING DATA

Site	AC %	% Cr. Part.	Marshall Comp. Blows	Lab Voids %	Field Voids %	Avg. Field Dens. %	Creep Resis. Factor		Resilient Modulus Ksi		ESAL	Rut Depth Inches	Rut Depth Per Million ESAL Inches	Road Rater Defl. Mils
							4"	6"	4"	6"				
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
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

Most of the 18,000-lb ESALs were obtained from pavement management computer records. When the ESALs were not available from those records, the current annual ESALs were used to estimate the accumulated ESALs.

On 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 on which the driving lane had been replaced. In those cases, the rut depth and ESALs reported for the passing lane were those of the rutted driving lane just before its removal and replacement.

Interstate pavements constructed before 1984 were based on 50-blow Marshall compaction, and the 4-in.-diameter cores included in this research yielded an average CRF of 30 and an average resilient modulus of 1,170. With 75-blow compaction on Interstate projects constructed in 1984 and later, the average CRF was 33 and the average resilient modulus was 763.

For correlations with the CRF and resilient modulus, Site 15, with very low annual ESALs, 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 ESALs.

A good correlation ($r^2 = 0.89$) between the resilient modulus of 4- and 6-in.-diameter cores (see Figure 1) was obtained. This finding demonstrates 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 ESALs. Resilient modulus of the 4-in.-diameter cores (see Figure 2) yielded a coefficient of determination (r^2) value of 0.15 with rut depth per million ESALs. There was some relationship, but apparently other factors had a significant effect. A correlation of the resilient modulus of 4-in.-diameter cores with rut depth per log of ESALs yielded an r^2 value of 0.06, which was even worse than using rut depth per million ESALs.

The correlation with the resilient modulus of 6-in.-diameter cores (see Figure 3) was similar, with an r^2 value of 0.17.

There was little correlation between the CRF and the resilient modulus of 4-in.-diameter cores (see Figure 4), with an r^2 of 0.11.

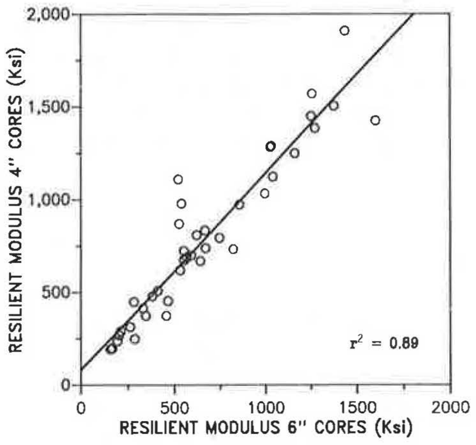

FIGURE 1 Resilient modulus of 4-in. versus 6-in. cores.

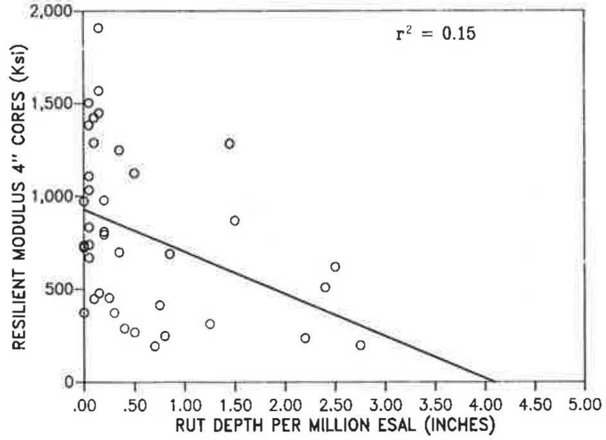

FIGURE 2 Resilient modulus of 4-in. cores versus rut depth per million ESALs (Site 15 excluded).

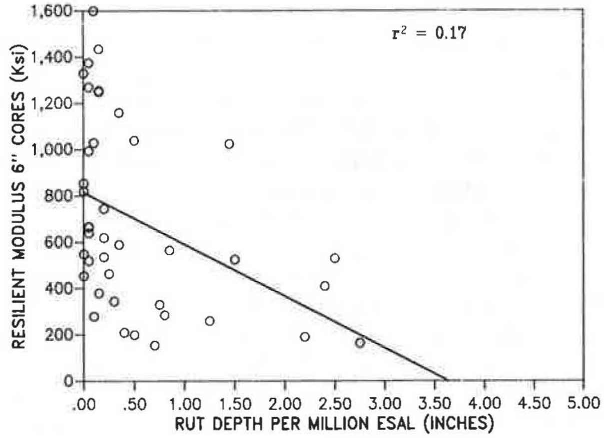

FIGURE 3 Resilient modulus of 6-in. cores versus rut depth per million ESALs (Site 15 excluded).

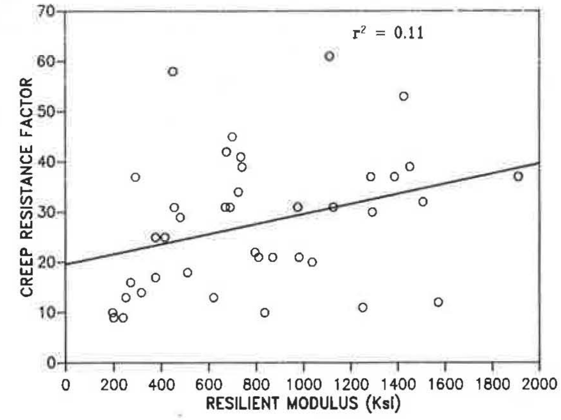

FIGURE 4 CRF versus resilient modulus for 4-in. cores.

The correlation of the CRF of 4- and 6-in.-diameter cores (see Figure 5) gave an r^2 of 0.81. The CRF of the 6-in.-diameter cores was about 10 percent greater than that for the 4-in.-diameter cores. On the basis of the good correlation and only 10 percent difference, it appears that 4-in.-diameter cores were adequate for creep testing. There was some concern that

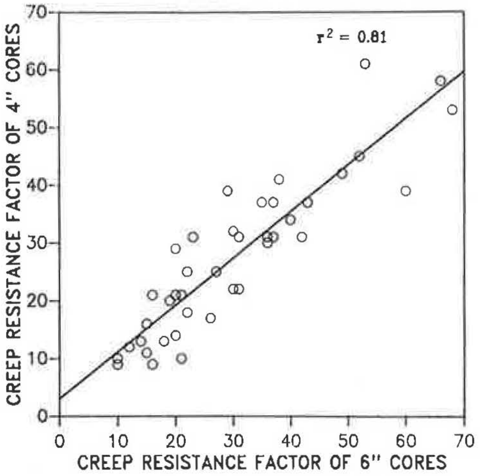

FIGURE 5 CRF of 4-in. versus 6.-in. cores.

there would be substantial difference of results between the 4- and 6-in.-diameter cores due to shearing in the 4-in.-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 percent difference between the 4- and 6-in.-diameter cores, it would seem that shearing was of minimal contribution.

In Part 1 of this research, the CRF related very well to the percent of crushed particles in an HMA mixture. Unfortunately, it did not correlate well with the rut depth per million ESALs (see Figures 6 and 7), with an r^2 of 0.21 for the 4-in. diameter and an r^2 of 0.18 for the 6-in. diameter. A correlation of the CRF of 4-in.-diameter cores with rut depth per log of ESALs 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 CRF may predominately evaluate the aggregate skeleton. In Part 2, the correlation with the resilient modulus and the CRF was similar, but neither exhibited a meaningful correlation with rut depth.

The Road Rater deflection data were obtained at pavement temperatures ranging from 40°F to 88°F. Through a nomogram the deflection readings given in Table 2 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 of 0.00—absolutely no relationship. The correlation of Road Rater deflection with the resilient modulus of 4-in.-diameter cores also yielded an r^2 of 0.00. It would appear that the current rutting is not related to base failure and is, therefore, not related to the structural values from the Road Rater.

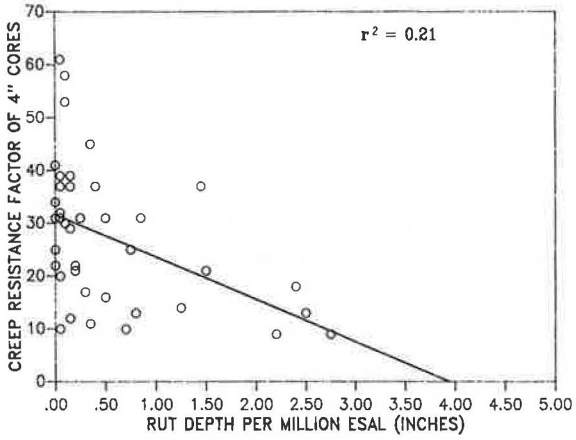

FIGURE 6 CRF of 4-in. cores versus rut depth per million ESALs (Site 15 excluded).

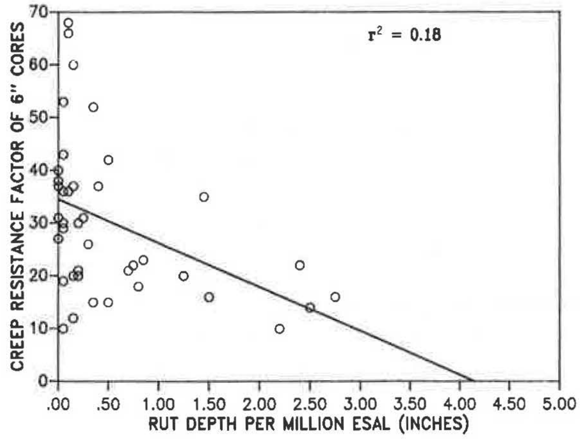

FIGURE 7 CRF of 6-in. cores versus rut depth per million ESALs (Site 15 excluded).

FUTURE RESEARCH

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 (a) Marshall specimens from laboratory mixing for mix design, (b) Marshall specimens from construction plant mixing, and (c) cores drilled from the HMA pavement. Five 1990 projects were selected, ranging from an 85 percent crushed particle Interstate mix to a Type B mix (requiring at least 30 percent 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 4-in.-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 2½ in. 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 for 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- and 6-in.-diameter cores.
3. CRFs of 4- and 6-in.-diameter cores correlated very well.
4. For the HMA pavements selected, there is a poor correlation between rut depth per million ESALs and either resilient modulus or CRFs.

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