Field Evaluation of Sulfur-Extended Asphalt Pavements

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Twenty-six sulfur-extended asphalt (SEA) paving projects, constructed between 1975 and 1982 in 18 states, were surveyed to measure the incidence and severity of major, visible types of pavement distress. Present condition indices were calculated for each of the SEA pavements and for each pavement in a control group of closely matched, conventional asphalt concrete pavements. Analysis of the evaluation results indicates that the presence of 20 to 40 percent by weight of sulfur in the paving binder had no deleterious effect on the overall performance of SEA pavement but yielded not significant improvement compared with the control group. Within the limits of the analysis, the measured types of distress and their severity were not significantly affected by variation in the sulfur content of the paving binder.

The term "sulfur-extended asphalt" (SEA), applied to a paving binder, paving mixture, or pavement, denotes the replacement of a significant portion of the conventionally used asphalt with elemental sulfur. Typically, 20 to 40 percent by weight of the asphalt is replaced with sulfur.

The initial development of SEA technology was carried out in the early 1970s by several Canadian petroleum companies that had accumulated millions of tons of elemental sulfur recovered from sour natural gas. Interest in the United States in the SEA technology was spurred by the 1974 and 1979 disruptions of the petroleum market. Public and private agencies saw SEA as a possible means of conserving petroleum stocks through a reduction in asphalt usage in highway construction. At the time, elemental sulfur was considerably less expensive than asphalt cement; thus a savings in construction costs was also anticipated.

Laboratory research on SEA-aggregate mixtures [see, for example, Saylak and Conger *(1)* and the references therein] had indicated that significant benefits might be realized from the use of SEA paving mixes. Of particular interest was the possibility of employing a softer grade of asphalt than would normally be used in a particular situation in conjunction with the sulfur. At high ambient temperatures the sulfur was expected to stiffen the binder sufficiently to resist deformation, but at low temperatures the asphalt properties, which reduce the probability of thermal cracking, would predominate.

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Interest in the potential cost savings and engineering benefits of SEA binders led to the construction of more than 75 SEA pavement projects in the United States between 1975 and 1985. These projects involved new construction as well as overlays on existing pavements. A variety of methods of blending sulfur and asphalt were employed *(1, 2)*. Usually liquid (molten) sulfur was used, but some later projects investigated the introduction of the sulfur in solid, prilled form. SEA projects were built in every U.S. climatic zone and on all types of highway facility, from farm-to-market roads to Interstate highways.

In the 1980s the price of sulfur on the world market rose sharply, and surplus supplies were drawn down. The economic incentive for SEA use disappeared, and there was little information available on improved pavement performance to encourage the use of SEA.

Recently, increased attention has been paid to the use of modifiers to enhance the performance of asphalt paving mixes. As a potential asphalt modifier, sulfur is unique in that it has been extensively tested in pavement construction and is relatively inexpensive (as a modifier or additive, not as an extender). A comprehensive evaluation of existing SEA pavement performance, which would serve as a basis for estimating the effects of lesser amounts of sulfur added to paving mixtures as a modifier, is lacking. Although many of the SEA projects have received some degree of postconstruction evaluation, there has been no organized study of the overall performance of SEA pavements in the United States.

In 1985 the FHWA organized a task force to conduct a comprehensive SEA field evaluation study. The study objectives were to compare the field performance of a representative group of SEA pavements with that of a control group of conventional asphalt concrete (AC) pavements and determine what differences in performance and durability existed between the two groups. This paper is a summary of the important results and conclusion of that study. For a complete account of the experimental procedures, results, and analyses, the reader is referred to the full FHWA report *(2)*.

PROJECT SELECTION

Available information on the 75 SEA projects in the United States, including construction reports, postconstruction evaluations, and similar material, was reviewed to identify a representative set of projects for detailed evaluation by the task force.

The following factors were considered in the selection of the SEA projects:

1. Geographic location and climatic zone;
2. Ratio of sulfur to asphalt in the binder [expressed as S/A where S is the percentage by weight of sulfur and A is the percentage by weight of asphalt (e.g., 30/70, 20/80)];
3. Existence of a satisfactory AC control pavement for comparison;
4. Variety of uses (base course, surface course, overlay, etc.);
5. Variety of sulfur/asphalt blending methods;
6. Sulfur form; and
7. Project age at time of evaluation.

Twenty-six SEA projects located in 18 states were identified for evaluation by the task force. The location and age at the time of evaluation of each of these projects are given in Table 1.

TABLE 1 SUMMARY OF SEA PROJECT

State	Review Section Number	Location	Age (Years)[a]	Freezing Index
AZ	850401	Glendale Ave., Phoenix	5.2	0
CA	850601	I-15, West of Baker	3.2	0
CA	860601	Lincoln Ave., Anaheim	4.3	0
CA	860602	Lincoln Ave., Anaheim	4.3	0
DE	851001	US 13 in Greenwood	6.4	0
FL	861201	Southwest 16th Ave. in Gainesville	6.9	0
FL	861202	I-75 North of Gainesville	5.4	0
GA	861301	Bainbridge Bypass (US 27 & US 84)	4.6	0
ID	851601	State Route 14, East of Golden	4.0	500
LA	862201	State Route 22, near Darrow	6.0/7.2[b]	0
ME	852301	I-95, 30 miles so. of Bangor	4.1	1000
ME	852302	I-95, 90 miles no. of Bangor	6.2	2000
MN	862701	Trunk Highway 63, no. of Rochester	7.0	1700
MS	862801	State Route 15, so. of Phila.	4.4	0
NV	853201	US 93-95, no. of Boulder City	8.9	0
NV	853202	US 50 Alternate, near Fernley	5.3	200
NM	853501	US 62/180, near Carlsbad	3.7	0
ND	853801	US 2-82, west of Minot	5.2	2500
PA	854201	Emmaus Ave., near Allentown	4.4	250
TX	854801	I-10, near Fort Stockton	4.2	0
TX	854802	MH153 in College Station	7.4	0
TX	854803	Loop 495, north of Nacogdoches	5.2	0
TX	854804	US 59, near Lufkin	3.2	0
WA	855301	US 2, west of Pullman	6.2	200
WI	865501	State Highway 29, west of Tilleda	3.6	1500
WY	865601	State Route 225, west of Cheyenne	3.7	1250

[a]Age of pavement at time of evaluation.

[b]Ages varied for two design sections.

In general, each SEA project that was evaluated is composed of one or more SEA pavements and one or more contiguous AC pavements built simultaneously with and to the same specifications as the SEA pavement or pavements. The AC pavements are designated as controls for comparative purposes. The evaluation discussed here is a "snapshot" of the condition of matched pairs of SEA and AC pavements during late 1985 and early 1986. The types and severity of pavement distress that occur in the SEA pavements may be compared directly with those found in the AC pavements, and the overall condition of the SEA pavements may be contrasted with the condition of those in the AC control group.

An essential feature of this effort is the strict reliance in each SEA project on comparison of pairs of SEA and AC pavements, constructed contemporaneously with virtually identical mix designs and structural sections; this allows factors other than the presence or absence of sulfur to be filtered out of the analysis. Of necessity, the analysis considers only in a peripheral way the effects of such factors as age and climate on pavement performance; possible variability in construction quality and material properties is assumed to be small and reasonable within each SEA project.

EXPERIMENTAL PROCEDURES

A standardized method for identifying and measuring different types of pavement distress was required to assure the validity of the evaluation results. The method needed to be comprehensive, sensitive to differences in distress level from project to project and within a given project, and objective. Objectivity is especially important because measurements made on different pavements by different evaluation teams are directly compared.

The distress evaluation methodology contained in the Highway Pavement Distress Identification Manual for Highway Condition *(3)* was chosen because of its widespread use and because it describes types of distress along with their primary causes. Levels of severity are also defined; measurement criteria are given; and typical photographs of each type of distress and level of severity are provided.

In addition, a method was needed to derive a pavement condition rating from the discrete distress measurements obtained during the evaluation. This rating would allow comparison of the overall condition of the pavements reviewed. The method developed by Carpenter et al. *(4)* was used to determine a present condition index (*PCI*) for each pavement surveyed. The *PCI* is determined through a comprehensive evaluation of visible pavement distress.

The following procedure was employed to evaluate each SEA project and determine specific distress factors and the *PCI* for each SEA and AC pavement section in the project. A team composed of two or three task force members drove over the entire SEA project length at a low rate of speed. The project was observed to determine if any portion or portions deviated significantly from the general observed condition. Planned survey locations were adjusted as necessary to obtain a representative survey of the overall project condition. Selected sections of the projects (or ideally the entire project when its length permitted) were then surveyed on foot by the evaluation team. All visible pavement distress was categorized, measured, and classified by level of severity. For example, lineal feet of transverse cracking were measured with a tape measure and classified by crack width to determine feet of cracking at low, medium, and high levels of severity.

Distress data in the form of total lineal feet of cracking, total square feet of rutting, and so forth were converted mathematically to deduct values for each type of distress and level of severity present in the pavement section. The values represent the relative effect of the specific type of distress and its severity and density on the structural or operation condition of the pavement, or both. The *PCI* for the pavement section was in turn calculated from the individual deduct values. The *PCI* represents the overall rating of the structural integrity and operational condition of the pavement.

In practice, the *PCI* for a pavement section is calculated by the equation

$$PCI = 100 - CDV$$

where *CDV* is the total corrected deduct value; the *CDV* represents an adjustment of the total individual deduct values for the pavement to account for the observation that the overall impact of several types of distress on pavement condition is less than the linear sum of the deduct values.

Each of the 26 SEA projects evaluated has been assigned in Table 1 a unique review section number that codes the project location and its review chronology. Each SEA project contains one or more SEA pavements and one or more AC control pavements. In many cases SEA projects were constructed with a variety of pavement sections with varying sulfur contents, structural sections, asphalt cement grades, and so forth. Each review section was further divided into design sections. The design sections of the least complicated projects differ only in the sulfur content of the paving binder. On other projects, additional design sections were needed to account for differences in typical structural section within the project or the use of several AC grades.

In general, the entire length of the SEA and AC control pavements in each SEA project was surveyed and the distress measured. Some projects, such as in Idaho (review section 851601), were many miles in length; in such cases each design section was divided into samples that differed only in station location within the project. Each sample represents at least 0.1 mi of pavement; the samples for evaluation were chosen by using a random number table.

Ideally, each review section should be divisible into pairs of design sections that differ only in the presence or absence of sulfur in the paving binder. This is generally the case; however, for a few projects this pairing could not be completely achieved because of the circumstances of the original project design; this required comparison of a single AC control section with two or more SEA sections that had varying sulfur/asphalt ratios.

The data requirements for each SEA project were organized in a three-tier arrangement that approximated the division of each SEA project into a review section, design sections, and samples. Tier 1 contains overall project data, Tier 2 data on the design sections, and Tier 3 the field distress survey results for the design sections or samples. The large volume of data, including both historical records and distress survey results, was entered into a computer data base developed for the study. A hard copy of the full data base is available elsewhere *(2)*.

RESULTS OF PROJECT EVALUATION

Tables 2–4 give mean values of the *PCI* and the combined cracking and rutting distress values measured for each SEA project. The means are calculated over all design sections in the project with equal sulfur content. Comparisons of the mean *PCI*-values and the cracking and rutting deduct values over all of the SEA and AC design sections are presented graphically in Figures 1 and 2.

In reviewing these results, it should be recalled that a pavement free of any significant visible distress will have a *PCI* of 100. A distress deduct value of zero indicates that the type of distress is not present in the pavement sample surveyed. Thus, Figure 1 shows that both the SEA and the AC pavements surveyed, considered as a group, are in quite satisfactory condition. Combined cracking (i.e., the total of the transverse, longitudinal, and joint reflective cracking found in a pavement) is the predominant type of distress in both the SEA and the AC pavement groups with rutting a distant second. Alligator cracking is also found in the SEA pavements to a much greater degree than in the AC control pavements, but its incidence is small in both types of pavement. Other types of distress occur to a minor degree in both pavement groups. A full enumeration of all types of distress and deduct values found for each SEA project is available elsewhere *(2)*.

A sulfur/asphalt ratio of 30/70 is found in 21 of the 26 SEA

TABLE 2 MEAN *PCI* SUMMARY

State Code/ Review Section Number		Mean Present Condition Index for Each Sulfur/Asphalt Ratio Represented					
		0/100	20/80	25/75	30/70	35/65	40/60
AZ	850401	95.0			98.0		
CA	850601	100.0	100.0				100.0
DE	851001	90.0			83.5		
ID	851601	96.6			100.0		
ME	852301	87.0	92.0		84.0		
ME	852302	88.0			82.0		
NV	853201	85.0			88.5		
NV	853202	87.0		89.5			
NM	853501	94.0			100.0		
ND	853801	83.5		80.0	83.0		
PA	854201	95.5			90.0		
TX	854801	100.0			100.0		
TX	854802	57.0			80.0		
TX	854803	85.0				80.0	
TX	854804	82.0			82.0		
WA	855301	90.0			89.0		85.0
CA	860601	97.0			93.0		
CA	860602	100.0			100.0		
FL	861201	96.0			97.0		
FL	861202	90.0			74.0		52.0
GA	861301	86.7			90.4		
LA	862201	90.0			90.0		87.0
MN	862701	65.5					79.0
MS	862801	100.0			100.0		100.0
WI	865501	71.0			85.3		
WY	865601	82.0	84.0				
Mean		88.2	92.0	84.8	90.0	80.0	83.8

TABLE 3 MEAN COMBINED CRACKING DEDUCT VALUE SUMMARY

State Code/ Review Section Number		Mean Combined Cracking Deduct Value for Each Sulfur/Asphalt Ratio Represented					
		0/100	20/80	25/75	30/70	35/65	40/60
AZ	850401	10.0			0.0		
CA	850601	0.0	0.0				0.0
DE	851001	29.0			51.5		
ID	851601	0.0			0.0		
ME	852301	47.0	28.0		44.0		
ME	852302	8.0			1.7		
NV	853201	43.0			18.0		
NV	853202	33.7		10.5			
NM	853501	6.0			0.0		
ND	853801	8.5		8.0	4.0		
PA	854201	0.0			6.0		
TX	854801	0.0			0.0		
TX	854802	58.0			24.0		
TX	854803	24.0				13.0	
TX	854804	35.0			34.0		
WA	855301	30.0			21.0		24.0
CA	860601	3.0			2.0		
CA	860602	0.0			0.0		
FL	861201	2.5			3.0		
FL	861202	10.0			39.0		0.0
GA	861301	16.3			10.2		
LA	862201	5.0			5.0		20.0
MN	862701	55.0					61.0
MS	862801	0.0			0.0		0.0
WI	865501	13.0			22.3		
WY	865601	44.0	35.5				
Mean		18.5	21.2	9.2	13.6	13.0	17.5

Note: Sum of the individual deduct values measured for transverse cracking, longitudinal cracking and joint reflective cracking.

projects. Examination of the data in Tables 3 and 4 fails to uncover any remarkable trends in the observed occurrence of combined cracking and rutting distress with variation in sulfur/asphalt ratio from 20/80 to 40/60.

Laboratory testing of SEA mixtures has indicated that increased sulfur content in the binder is reflected in increased binder stiffness, all other factors being equal. This trend might be expected to be translated into increased pavement cracking and decreased rutting with increasing sulfur content. The data presented here fail to substantiate these expected trends in the pavements surveyed during this study. Indeed, the data in Tables 2–4 and Figures 1 and 2 suggest that performance of the SEA pavements surveyed was comparable to that of the AC control group regardless of the sulfur content of the binder. This observation will be tested more rigorously in the next section.

ANALYSIS OF RESULTS

Statistical methods of analysis were employed to test the significance of observed differences in performance factors (*PCI*

TABLE 4 MEAN RUTTING DEDUCT VALUE SUMMARY

State Code/ Review Section Number		Mean Rutting Deduct Value for Each Sulfur/Asphalt Ratio Represented					
		0/100	20/80	25/75	30/70	35/65	40/60
AZ	850401	0.0			0.0		
CA	850601	0.0	0.0				0.0
DE	851001	0.0			0.0		
ID	851601	3.2			0.0		
ME	852301	0.0	0.0		0.0		
ME	852302	11.0			26.3		
NV	853201	6.0			6.0		
NV	853202	0.0		0.0			
NM	853501	0.0			0.0		
ND	853801	12.0		19.0	14.0		
PA	854201	2.5			1.0		
TX	854801	0.0			0.0		
TX	854802	31.0			9.0		
TX	854803	0.0				0.0	
TX	854804	0.0			0.0		
WA	855301	0.0			0.0		0.0
CA	860601	0.0			0.0		
CA	860602	0.0			0.0		
FL	861201	1.5			0.0		
FL	861202	0.0			0.0		0.0
GA	861301	0.0			0.0		
LA	862201	0.0			0.0		0.0
MN	862701	0.0					0.0
MS	862801	0.0			0.0		0.0
WI	865501	31.5			7.0		
WY	865601	15.0	0.0				
Mean		4.4	0.0	9.5	3.0	0.0	0.0

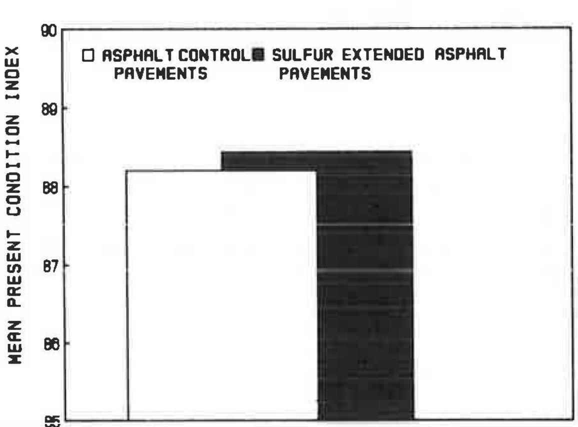

FIGURE 1 Comparison of the *PCI* for SEA and AC pavement sections.

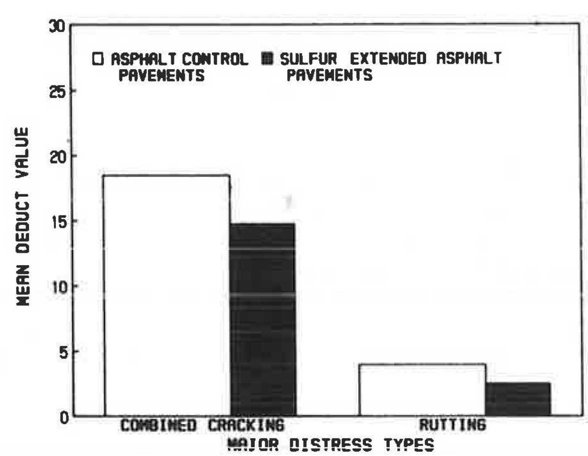

FIGURE 2 Comparison of mean distress deduct values for SEA and AC pavement sections.

and distress deduct values) between the SEA and AC pavement groups. That every SEA pavement may be matched with a control AC pavement that is presumed to be identical to it except for the sulfur content of the binder aided the analyses. Random, variable effects of construction quality, traffic volume, age, and so forth and the precision of the evaluation procedure are also minimized by provision of the AC control group. The analysis may therefore be concentrated on the main item of interest, the effect of sulfur on the performance and durability of the pavements.

The Student's *t*-test was employed to estimate the significance of the observed differences among the SEA and AC pavement groups. This test is described in detail in any textbook of statistical methods (*5*, p. 194 ff). The analysis is predicated on testing a null hypothesis; in this case, the null hypothesis states that observed differences between the SEA and the AC pavement groups are not statistically significant. The magnitude of the *t*-statistic allows acceptance or rejection of the null hypothesis at a desired level of significance.

Table 5 gives the results of the analysis of the observed

TABLE 5 *t*-TEST RESULTS: COMPARISON OF SEA AND AC PAVEMENT PERFORMANCE FACTORS

Performance Factor	n	t	Accept or reject null hypothesis[a] at $\alpha = 0.005$
Present Condition Index, all design sections	43	0.437	Accept
Rutting deduct value, all design sections	43	-1.336	Accept
Combined cracking deduct value, all design sections	43	-0.965	Accept
Present Condition Index, 30/70[b] design sections	29	0.959	Accept
Rutting deduct value, 30/70 design sections	29	-1.238	Accept
Combined cracking deduct value, 30/70 design sections	29	-0.632	Accept
Present Condition Index, 20/80 and 25/75 design sections	5	0.848	Accept
Rutting deduct value, 20/80 and 25/75 design sections	5	-0.444	Accept
Combined cracking deduct value, 20/80 and 25/75 design sections	5	-2.168	Accept
Present Condition Index, 35/65 and 40/60 design sections	9	-0.526	Accept
Rutting deduct value, 35/65 and 40/60 design sections	9	N.A.[c]	N.A.[c]
Combined cracking deduct value, 35/65 and 40/60 design sections	9	0.468	Accept

[a]The null hypothesis states that the observed difference between the two groups is not statistically significant.

[b]S/A = Sulfur to asphalt weight ratio, e.g. 30/70, 20/80, etc.

[c]N.A.: Not applicable. The rutting deduct values for all nine SEA and AC design sections were 0.0.

differences of *PCI*, combined cracking deduct value, and rutting deduct value between the SEA and the control AC groups at a level of significance of 0.005. Insofar as possible, data for unique pairs of SEA and AC design sections that differed only in sulfur content of the binder were compared; however, for a few projects, because of their original design, a single control AC design section was compared with more than one SEA design section. Also, for design sections with multiple samples, the mean parameter value for the samples was used in the analysis.

The results given in Table 5 indicate that the null hypothesis may not be rejected for the *PCI* or either distress deduct value. This indicates that no significant differences exist between the SEA and the control AC pavement groups within the limits of this analysis. In all respects, the analysis concludes that the two types of pavements have performed comparably.

Table 6 gives the results of an analysis of observed differences of *PCI* and distress deduct values among SEA pavements with sulfur/asphalt ratios of <30/70, 30/70, and >30/70. For all cases, the *t*-test indicates that the null hypothesis may not be rejected at a level of significance of 0.005. In all respects, the analysis concludes that the performance of the SEA pavement was not significantly influenced by the sulfur content of the paving binder (within the range of sulfur/ asphalt ratios in the SEA pavement group).

Table 7 gives the results of the determination of the correlation coefficient (r) for the pavement performance factors compared with pavement age and climatic exposure expressed as freezing index (*2*, Appendix 1) for both the SEA and the control AC pavement groups. The sample correlation coefficient (*5*, p. 321 ff) was used to estimate what percentage of variation ($100\ r^2$) in one set of observations may be accounted for by the variation in another set of observations. The calculated values of r and $100\ r^2$ are low, which implies a lack of evidence for causal relationships between age or freezing index and the *PCI* and distress deduct values measured for the pavements.

FINDINGS AND CONCLUSIONS

The statistical analysis carried out on the pavement evaluation data gathered in this study of 26 SEA projects built between

TABLE 6 *t*-TEST RESULTS: COMPARISON OF SEA PAVEMENTS WITH DIFFERENT SULFUR/ASPHALT RATIOS IN THE BINDER

Performance Factor	n	t	Accept or Reject null hypothesis[a] at $\alpha = 0.005$
Present Condition Index:			
30/70[b] vs. 20/80 and 25/75	32	0.103	Accept
30/70 vs. 35/65 and 40/60	36	1.685	Accept
20/80 and 25/75 vs. 35/65 and 40/60	12	0.851	Accept
Rutting Deduct Value:			
30/70 vs. 20/80 and 25/75	32	-0.393	Accept
30/70 vs. 35/65 and 40/60	36	-2.078	Accept
20/80 and 25/75 vs. 35/65 and 40/60	12	-0.473	Accept
Combined Cracking Deduct Value:			
30/70 vs. 20/80 and 25/75	32	0.265	Accept
30/70 vs. 35/65 and 40/60	36	1.570	Accept
20/80 and 25/75 vs. 35/65 and 40/60	12	1.388	Accept

[a]The null hypothesis states that the observed difference between the two groups is not statistically significant.

[b]S/A = Sulfur to asphalt weight ratio in SEA binder, e.g., 30/70, 20/80, etc.

TABLE 7 CORRELATION AMONG PAVEMENT PERFORMANCE FACTORS, PAVEMENT AGE, AND FREEZING INDEX

For Correlation Between:	Correlation Coefficient, r	Percent Variation Explained, 100r
PCI (30/70[a]) and Age	0.439	19.3
PCI (20/80 and 25/75) and Age	0.576	33.2
PCI (35/65 and 40/60) and Age	-0.770	59.3
PCI (AC) and Age	-0.412	17.0
PCI (30/70) and Freezing Index	-0.357	12.8
PCI (20/80 and 25/75) and Freezing Index	-0.716	51.2
PCI (35/65 and 40/60) and Freezing Index	-0.112	1.3
PCI (AC) and Freezing Index	-0.404	16.3
Rutting Deduct Value and Freezing Index (all design sections:		
SEA	0.644	41.5
AC	0.477	22.8
Combined Cracking Deduct Value and Freezing Index (all design sections:		
SEA	0.181	3.3
AC.	0.714	51.0

[a]S/A = Sulfur to asphalt weight ratio in SEA binder, e.g., 30/70, 20/80, etc.

1977 and 1982 in 18 states indicates that the overall performance and susceptibility to distress of the SEA pavements are not significantly different than those of the closely matched, control AC pavement group. Furthermore, for the SEA pavements studied, the level of sulfur in the paving binder did not have a significant effect on pavement performance or measured levels of distress. Correlation of SEA and AC pavement *PCI* and distress deduct values with pavement age and freezing index was poor, which indicates a lack of important causal relationships.

The SEA projects evaluated here were generally built to study only the effect of the presence or absence of sulfur on pavement performance. Sulfur was substituted for from 20 to 40 percent of the asphalt in the mix; the binder content was adjusted to maintain equal binder volume in the mix; and in general the typical structural section of the pavement was unchanged. Rarely was the asphalt grade altered in the SEA binder to test the practical consequences of changes in binder consistency, temperature susceptibility, and stiffness noted in the laboratory on introduction of sulfur into asphalt.

It is noteworthy that, in the 26 SEA projects evaluated, the use of sulfur in substantial quantities in the paving binder appears to have had little, if any, deleterious effect on pavement condition and, by extension, pavement performance and durability. Only one SEA project (Florida, review section 861202) was found to be in poor condition, and this situation appeared to be the result of severe moisture damage to which the presence of sulfur was one of several contributory factors.

The results of this study imply that in most circumstances the use of sulfur as an extender in asphalt paving mixtures is innocuous and that SEA pavements should perform in a satisfactory manner if they are constructed to proper design and with adequate attention to detail. Given the 1987 cost of elemental sulfur compared with that of asphalt, the use of SEA is difficult to justify because no significant improvement in pavement performance attributable to the incorporation of sulfur was found.

The observation that SEA performance as measured in this study was not significantly affected by variation in the sulfur content of the binder within wide limits is surprising. On the basis of past research *(1)*, some significant if perhaps small effect would have been expected. The field results reported here may indicate that in practical terms the effects of variation in binder and mixture properties are masked by the inherent variability of the construction process.

The results of this study suggest two areas in which further research may be useful. First, because the use of sulfur as an asphalt extender did not have detrimental effects, investigation of the use of elemental sulfur as an additive for asphalt modification may be worthwhile, if only because elemental sulfur is relatively inexpensive compared with other proposed modifiers. Second, the entire SEA data set collected in this study *(2)* may be analyzed further to determine if factors such as traffic influenced SEA pavement performance at specific locations in a manner not discerned in the comparative analyses reported here.

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