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Analysis and Repair of Water-Damaged Bituminous Pavement

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An investigation of several bituminous concrete pavements on the Interstate system that experienced failures suspected to have been caused by stripping is reported. On two of the pavements, the degree of deterioration and potential serviceability was determined from the indirect tensile strength of cores and Dynaflect test results. Recommendations based on the investigation have resulted in repairs that are believed to be best suited to each situation. An emulsion mix design was developed for stripped bituminous concrete removed from a project with the expectation that it could be used as a surface mix on a highway with a low volume of traffic; however, because of risks involving performance, it was recommended for use as a base course. Resurfacing on a project that had experienced stripping failure is being monitored, and its performance is being evaluated.

Stripping, which is the separation of the asphalt coating from the surface of the aggregate in flexible pavements, has resulted in considerable damage to several Virginia pavements in recent years. The deterioration that has resulted from the stripping has varied in severity from minor cracking to almost complete disintegration of the pavement. In 1978, stripping was suspected to be causing deterioration on several Interstate pavements, and an investigation was undertaken to determine the condition of several sections of distressed pavement and to recommend rehabilitative measures.

Although stripping problems in bituminous pavements have been encountered for many years, little attention has been given to selecting the most appropriate rehabilitative measures for particular situations. Usually, a resurfacing is applied as a temporary solution to the problem and no attempt is made to optimize the service life of the pavement. The initial step in deciding on the best type of repair for a given situation should be to determine the cause of failure, the degree of damage, and the strength of the overall pavement structure. The type of repair and rehabilitation selected should prevent further deterioration, where necessary, and strengthen the pavement structure so that it will provide satisfactory service. Other important factors that must be considered are limitations on the funds that are available and such construction-related restraints as the need to maintain the flow of traffic and the occurrence of minimum bridge clearances that limit the thickness of resurfacings. In Virginia, limitations on maintenance funds are becoming severe because of the reduction in tax revenue occasioned by reduced consumption of gasoline and inflation.

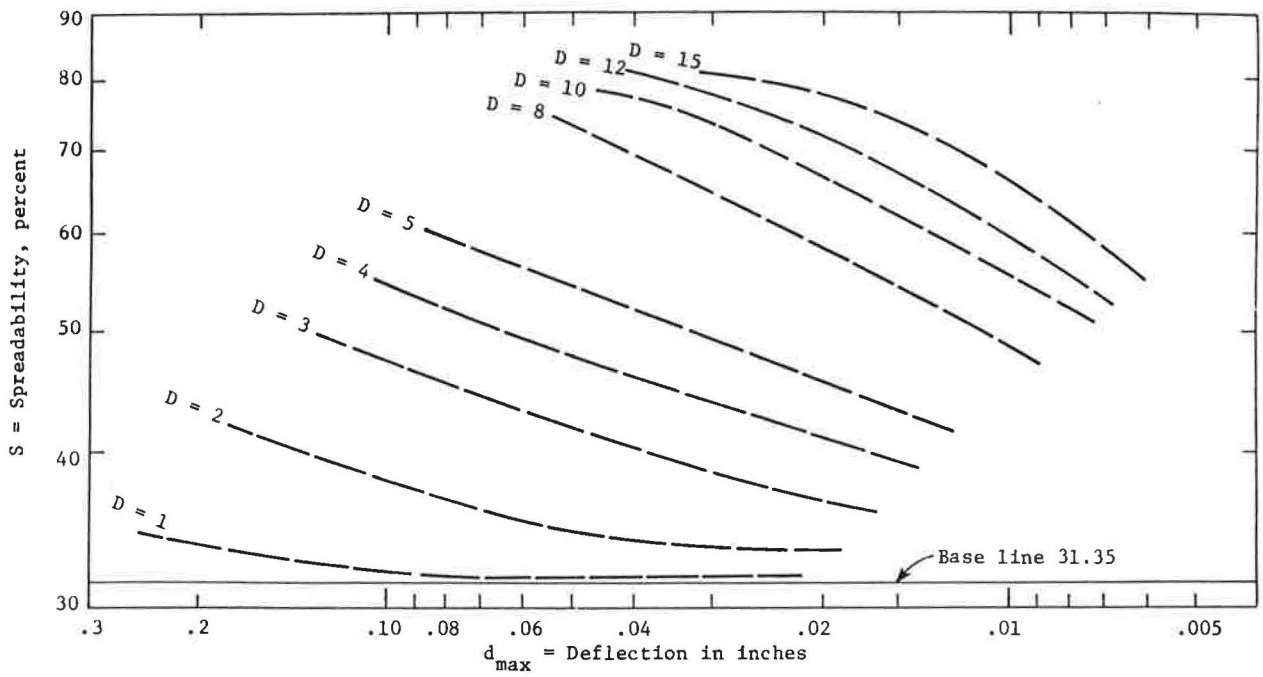
TESTS USED

In the investigation reported here, a testing program was designed to determine the strength of the overall pavement structure and that of the asphaltic concrete courses under dry and wet conditions. Because pavements usually develop more distress under wet than under dry conditions, the wet strength was considered to be important.

Several sections of Interstate roads were investigated. The most extensive testing was conducted on sections of I-64 and I-85. In 1979, 34 and 30 cores were removed from I-64 and I-85, respectively. The cores were subjected to indirect tensile tests, as described later, to gain an indication of the overall strength and the loss in strength caused by moisture. In addition, a visual determination of stripping was made.

Viscosity and penetration measurements were made according to ASTM D2170 and ASTM D5, respectively,

Figure 1. Chart used in determining thickness equivalency.



on asphalt cement recovered from cores by use of the Abson recovery procedure (ASTM D1856).

The strengths of the pavement structures were computed from the results of Dynaflect measurements. The results of these measurements were also used to predict the remaining service life of the pavement.

Pavement strengths were determined in terms of thickness equivalencies, which represent equivalent thicknesses of full-depth bituminous concrete. The maximum deflection, the shape of the deflection basin (spreadability), and the general evaluation chart shown in Figure 1 (1) were used to compute the thickness equivalencies. In this calculation, the maximum deflection is defined as the equivalent Benkelman beam deflection and the spreadability is defined as

$$S = [(d_{max} + d_1 + d_2 + d_3 + d_4)/5d_{max}] \times 100 \quad (1)$$

where d_{max} is the deflection under the center of the applied load and d_1, d_2, d_3, and d_4 are the deflections at 1, 2, 3, and 4 ft from the center of the applied load.

PAVEMENTS INVESTIGATED

The pavement sections investigated had exhibited various degrees of distress in the spring of 1978. Preliminary observations at that time revealed stripping damage; however, no extensive examinations of the pavements were made prior to the investigation reported here.

I-64 in Goochland County

A section of I-64 approximately 10.5 miles long in Goochland County showed initial distress in the form of cracks. Later, potholes developed. A trench cut across the westbound traffic lane in the spring of 1978 revealed stripping throughout the full depth of the asphaltic concrete. The cracks were sealed prior to the application of a slurry-seal treatment in the summer of 1978; however, potholes continued to appear in the spring of 1979.

The pavement structure on this section consists of 6.0 in of stabilized soil cement, 8.0 in of no. 21-A crushed subbase material, 7.5 in of B-3 bituminous concrete base, 1.2 in of I-2 bituminous concrete, and 0.9 in of S-5 bituminous concrete surface. The design ranges for the 21-A dense-graded aggregate and the bituminous concrete mixture, respectively, were as follows (percentage by weight passing square mesh sieves) (2):

Sieve Size	Percent Passing
2 in	100
1 in	94-100
0.375 in	63-72
No. 10	32-41
No. 40	16-24
No. 200	8-12

	Percent Passing by Mix Type		
Sieve Size	S-5	I-2	B-3
1.5 in			100
1 in		100	
0.75 in			73-85
0.5 in	100		
0.375 in		63-77	
No. 4	53-67	43-57	38-48
NO. 8			28-35
No. 30	19-27		
No. 50		6-14	
No. 200	4-8	2-6	2-6

The aggregate was from a quarry used only for the construction of the Interstate pavement. Although it had a high mica content, it passed all Virginia specifications for quality and soundness.

In June 1979, cores were taken and Dynaflect tests were performed approximately every 1 mile in the eastbound traffic lane (EBTL) and westbound traffic lane (WBTL) and every 2 miles in the passing lanes (PLs). Usually, three Dynaflect tests were performed within 150 ft of the area cored.

Analysis of Cores

After they were separated into individual layers,

Table 1. Indirect tensile strengths for cores from I-64.

Mix	Lane	Indirect Tensile Strength (lbf/in²) Dry	Vacuum Saturated	Dry Strength (%)
I-2	WBTL	90	57	63
	EBTL	67	32	48
	PL	134	120	90
B-3	WBTL	91	50	55
	EBTL	85	39	46
	PL	180	100	56

Table 2. Properties of recovered asphalt from I-64.

Mix	Penetration (mm)	Viscosity: Dynamic at 140°F (poises)	Kinematic at 275°F (cSt)
B-3	40	8800-11 400	740-940
I-2	21-23	49 000-66 000	1840-2120
S-5	17-24	29 000-73 000	1580-2550

Table 3. Thickness equivalency for I-64.

Lane	Thickness (in): Design	Needed for Current Traffic	Measured: Avg	Range
EBTL	14.7	14	6.5	5.0-7.5
WBTL	14.7	14	9.0	8.0-10.5
EBPL	14.7	11	8.0	6.5-8.5
WBPL	14.7	11	9.0	8.0-11.0

half of the cores taken were dried and the other half were vacuum saturated with water. The cores were tested in indirect tension at a vertical deformation rate of 2 in/min and a temperature of 72°F. The mix in the surface course was not tested in indirect tension because of insufficient thickness. Penetration and viscosity tests were performed on asphalt cement recovered from several cores to obtain an indication of the brittleness of the pavement.

Table 1 gives the indirect tensile strengths of the I-2 and B-3 layers. It should be noted that the strength of the layers from the EBTL was less than that of the layers from the WBTL, especially for the I-2 mix. The materials used in both lanes were from the same source, and the traffic counts were approximately equal in both directions; therefore, the difference in strengths does not appear to be related to these items. The strengths for the passing lanes were considerably greater than those for the traffic lanes, probably because of the higher traffic volume carried by the latter.

The reductions in the strengths of the asphaltic concrete from the traffic lanes ranged from 37 to 54 percent when the material was vacuum saturated. These results indicate a significant reduction of pavement strength in late winter and early spring, when the pavement is wet. These results agree with the pavement performance, since failures occur more frequently in the wet seasons of late winter and early spring than at other times.

The properties of asphalt recovered from the cores were determined and are given in Table 2. All of the results except those for the B-3 cores indicated severe oxidation. The penetration for the asphalt from the S-5 and I-2 mixes averaged approximately 20 mm, and the B-3 material gave a value of 40 mm.

Dynaflect Tests

The total pavement strength (thickness equivalency) was determined from the results of Dynaflect tests. Since the Dynaflect tests were performed in June 1979, the pavement should have been relatively dry. Table 3 gives the thickness equivalency values. The measured thickness equivalencies were from 5 to 7 in less than that needed for the current traffic volume, especially in the traffic lanes. These results can be interpreted to indicate that the pavement will not stand up under the current traffic volume for the design life and that there will be additional premature failures.

It was recommended that the structural strength be increased and the surface sealed to prevent the entrance of water because of the low strength of the overall pavement structure and of the asphaltic concrete when wet. Three of the worst sections were repaired by using a different method for each section: resurfacing with 1.4 in of hot mix, resurfacing with 1.4 in of hot mix and a fabric sealer, and resurfacing with 2.2 in of hot mix. The performance of these test sections will be evaluated to determine the most efficacious of the three methods. Recycling was not considered because of the poor performance of the original pavement.

I-85 in Brunswick County

Cracking occurred in varying degrees of severity along a 20-mile section of I-85 in Brunswick County. Cores taken from one of the most deteriorated areas revealed extensive stripping through the full depth of the asphaltic layers. In 1978, this area was repaired with a slurry-seal treatment that seemed to alleviate the deterioration.

The pavement structure on this section of I-85 consists of 6 in of soil cement, 6 in of cement-treated stone, and 9-10 in of asphaltic concrete. The granitic aggregate used in the mixes was supplied from both a permanent and a temporary quarry.

Tests were performed on five 2-mile sections spaced throughout the 20-mile length because of traffic-control restraints. Cores were obtained in both the traffic and passing lanes, and Dynaflect tests were performed near the core locations.

Analysis of Cores

Table 4 gives the dry and saturated indirect tensile strengths of the I-2 and B-3 layers. The strength of the layers in the saturated condition was only approximately 30-50 percent of the dry strength; therefore, the structural integrity of the pavement could be greatly reduced in the spring if water penetrated the pavement and drying conditions were poor.

The excellent performance of the slurry-sealed section probably can be attributed to the treatment preventing water from entering the pavement surface. The properties of the recovered asphalt, given in Table 5, indicate severe oxidation, especially for the I-2 and S-5 mixes. The asphalt is prone to cracking and failure because of brittleness.

Results of Dynaflect Tests

The thickness equivalencies for the sections tested are given in Table 6. The measured thickness equivalencies of sections 1-3 were approximately equal to that necessary for the current traffic load; those

Table 4. Indirect tensile strength for cores from I-85.

Mix	Section	Indirect Tensile Strength (lbf/in^2) Dry	Vacuum Saturated	Dry Strength (%)
I-2	1	86	34	40
	2	84	46	55
	3	85	34	40
	4	-	-	-
	5	93	27	29
B-3	1	62	33	53
	2	89	55	62
	3	77	32	42
	4	92	36	39
	5	81	44	54

Table 5. Properties of recovered asphalt from I-85.

Mix	Penetration (mm)	Viscosity: Dynamic at 140°F (poises)	Kinematic at 275°F (cSt)
B-3	20-45	5300-38 000	820-1280
I-2	19-21	40 000-50 000	1400-1570
S-5	15-21	70 000-84 000	1670-2180

Table 6. Thickness index for I-85.

Section	Thickness (in): Design	Needed for Current Traffic	Measured: Avg	Range
1	17.9	17.5	16	12-18
2	18.4	17.5	18	15-20
3	18.4	17.5	17	15-18
4	17.4	17.5	14	10-17
5	17.9	17.5	13	10-17

for sections 4 and 5 were slightly less.

Based on the Dynaflect results, which indicated that the present pavement strength is equal to or only slightly less than the design strength, it was not considered necessary to apply a hot-mix resurfacing. Since the strength of the asphaltic concrete was greatly reduced when saturated and the slurry seal that was applied to an adjacent section seemed to alleviate the deterioration, it was recommended that the pavement be sealed. A slurry seal was applied in July 1980 and should prevent or retard further deterioration.

I-81 in Washington and Smyth Counties

Several sections of asphaltic concrete pavements on I-81 were found to have developed severe cracking and potholes. The makeup of the pavements on these sections varied as follows: 10-12 in of select material with a minimum California Bearing Ratio of 30, 6 in of crushed stone, 7.5 in of H-3(1) bituminous base (currently B-3 designation), 1.2 in of H-2 intermediate mix (currently I-2 designation), and 0.7 in of I-3 surface mix (currently S-5 designation). All of the sections investigated were covered with approximately 1.5 in of maintenance resurfacing (S-5).

The pavement distress had appeared in the form of cracks and potholes in the spring of 1978. An inspection revealed that damage was confined to the original surface and overlay and that it had resulted from severe stripping in the original surface. The maintenance resurfacings that had been applied to these sections were of two types: an S-5 nonpolishing mix and a sprinkle mix (3). Tests revealed that the sprinkle mix was very permeable and allowed water to reach the original surface mix, which contained a quartzite aggregate that is not now allowed for use in Interstate pavements because of its stripping history.

When the stripping problem was determined to have originated in the original surface, it was decided to remove approximately 1.5-2.0 in of the asphaltic concrete by cold milling and to apply a new surface. Recycling the removed material for the new surface was not considered because of past poor performance, but it was considered for use at other locations nearby.

Approximately 27 miles of the surface were removed, and there was a considerable amount of material to be reused or disposed of. It was anticipated that the removed surface could be used as a base material or in an emulsion surface mix on a low-traffic-volume highway. After an emulsion mix design was examined in the laboratory, it was decided not to use the material in this manner because of performance risks but to use it as an aggregate base material.

Other Pavements

Another section of Interstate pavement was found to have a problem in a layer of asphaltic concrete containing an aggregate that, after construction, was banned from use in Interstate pavements because of its susceptibility to stripping. A 2.5-in maintenance resurfacing was applied to a limited area and is being observed to determine whether other areas can be treated similarly if the need arises. After one year, slight distress has been observed in several places; however, any conclusions at this time would be premature.

An additional section of Interstate pavement experienced considerable distress in late winter and early spring. The distress seemed to be confined to a maintenance resurfacing. An examination of cores removed from the pavement revealed an accumulation of water and lack of bond between the original surface and the maintenance resurfacing. A fabric sealer and resurfacing have been applied to some of the worst areas in an attempt to seal out the water and provide additional strength.

SUMMARY

The importance of a thorough investigation before major pavement repairs are made is emphasized by the results of the investigation described in this paper. Although the pavement failures investigated had resulted from water damage, the individual cases required different rehabilitative measures. The popular repair technique of applying a hot-mix resurfacing would have been unwise in several of these cases because it would not have sealed out water or it would have been unnecessary from the standpoint of strengthening the pavement structure.

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Rational Approach to Design of Bituminous Stockpile Patching Mixtures

PRITHVI S. KANDHAL AND DALE B. MELLOTT

Although a considerable amount of maintenance expenditure is spent on bituminous patching, the performance of conventional cold stockpile patching materials has been generally unsatisfactory. No concerted effort has been made to design these mixtures on a rational basis. The challenges of designing these mixtures are reviewed, and some new concepts vital for the survival of these mixtures in the adverse environment of potholes are presented. These concepts among others include the use of finer and predominantly one-sized gradation for the aggregate and the maximum dust content (minus 200 fraction) of two percent in the mixture. A formulation based on these concepts has been developed and used in the field during the past three years. The data obtained from the field and laboratory evaluation of the suggested formulation are reported. Laboratory test data indicate the effect of dust content on the workability of these mixtures. Attempts were made to quantify the workability of the mixtures by using a cement concrete penetrometer. However, the results were inconsistent and merely show a trend of higher penetrometer readings for mixtures with poor workability.

After severe winters, potholes are certain to appear. Several estimates of the extent of the pothole problem have been attempted. According to a CBS Evening News broadcast of February 21, 1978, in 1977 there were an estimated 160 million potholes produced in nearly 4 million miles of roads and streets in the United States, which cost nearly $1 billion to repair. The most comprehensive damage estimates so far come from The Roads Information Program (TRIP), whose researchers estimated in a February 28, 1979, news release that 93 million potholes dotted roads around the country in 1979. According to TRIP, 5 million tons of asphalt mix, costing $256 million, was required just to fill the craters.

Pennsylvania's 72 418 km (45 000 miles) of state-administered highways constitutes the fourth largest such system in the United States. A value engineering study (1) conducted by the Pennsylvania Department of Transportation (PennDOT) for the Federal Highway Administration (FHWA) during the 1975-1976 fiscal year indicated that this vast network required a maintenance expenditure of $145 million, of which $25.8 million or 17.8 percent was required for bituminous patching. The cost for bituminous patching material alone was $5.7 million, or 22.1 percent of the total patching allotment. The remaining 77.9 percent covered the costs for equipment and labor. This study indicated that PennDOT should be providing a more permanent patch and reducing the number of repeat trips to the same area. To realize this goal, the need for using proper patching techniques cannot be overemphasized. O'Brien (2) has reported the annual costs per ton of patching material in place for five different patching techniques, taking into consideration the life of the patch. The annual cost per ton of the material was determined to be $307.68 when it was simply dumped in the pothole in one lift and hit with a shovel versus $61.41 when it was placed properly (proper placement includes shaping the area, removing loose debris, applying a tack coat, shoveling in the material, leveling with a lute, and compacting with a pug roller).

Many proprietary patching products have been promoted by various manufacturers. These mixtures are usually tailor-made with one stone type under strictly controlled conditions and supplied in 55-gal drums. The cost of such materials ranges from $100 to $500/ton, which makes their use prohibitive from the economic standpoint.

There is a need to develop a stockpile patching mixture that is economical, capable of withstanding some abuse in placement, and reasonably durable. It may be more cost effective to design mixtures for better durability. Information assembled from numerous sources, including a large number of highway and transportation departments (3), indicates the lack of a rational design procedure.

CHALLENGES OF MIX DESIGN

It is difficult to design stockpile patching mixtures because the properties required in stockpiling and handling and after the material is placed in the pothole are contradictory. Some of these contradictory requirements are as follows:

1. Aggregate gradation--For good mixture workability, an open gradation is desired. After the mix is placed, however, a denser gradation is needed to improve durability.
2. Aggregate shape--To obtain good workability, angular aggregate shape should be avoided. However, once the mix is in place, a high degree of angularity is desirable for better stability.
3. Binder viscosity--Lower binder viscosity is