Asphalt Concrete Mixtures as Related to Pavement Rutting: Case Studies

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The objective of this paper is to document case studies of pavements that have rutted prematurely. The investigation of the nature and cause of the rutting includes study data from cores, beams across the lane widths, mix designs, nondestructive testing, and traffic data. Three projects are presented in this documentation, two of which rutted prematurely and one of which is identified as rutting-resistant. The rutting in the first project was caused by overcompaction in construction, which was the result of mix design, quality control, and inadequate construction standards. Premature and long-term rutting were both shown in the second project. The rutting was found in all layers of the asphalt, and rutting continued after each corrective action. This problem resulted from a combination of mix and structural designs. The third project used a 4-in.-thick stone-filled binder and surface over a 6-in.-thick, regular dense-graded asphalt base. The stone-filled mixtures are generally higher in initial air-void content and can be compacted to a higher percent of laboratory density in construction. They do not seem to be sensitive to asphalt content and are in that respect not subject to additional compaction under traffic. The void-in-mineral-aggregate curve is usually very flat and shows little change with the asphalt content.

The data presented in this paper are based on projects in three states: Interstate 55 in East Arkansas; the Turner Turnpike near Oklahoma City, Oklahoma; and U.S. 54 in Kingman, Kansas, approximately 35 mi west of Wichita. The Arkansas and Oklahoma projects involved case studies of pavement rutting utilizing data from laboratory testing of field cores or trench sections and nondestructive deflection measurements. The Kansas project involved the use of a stone-filled mix design for both binder and surface courses.

Historically, the term *permanent deformation* was used to describe any distortion of the pavement surface, including shoving and pushing due to mix instability (*1*). Today, however, this term is used for longitudinal depressions, or ruts, that form in the wheelpaths because of "consolidation and/or lateral movement in one or more of the component pavement layers due to repeated, transient load applications" (*2*). Because rutting appears only as a change in the transverse surface profile, it was often erroneously blamed on surface instability. Investigations at the AASHO Road Test, however, revealed that permanent deformation occurred in all layers of the pavement system.

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Generally, for properly designed and constructed asphalt pavements, the rut depth on the inside wheelpath (IWP) will be greater than the rut depth on the outside wheelpath (OWP) because the pavement makes the greatest response to its load at the IWP. Greater rut depth in the OWP would indicate instability in any or all of the component layers of the pavement system. On the other hand, nondestructive deflection measurements are usually greater in the OWP. If the wheelpath deflections are equal, the rut depths, similarly, should be equal.

I-55 IN EAST ARKANSAS

Construction Background

In 1976, a 9.8-mi section of the original 10-in.-thick portland cement concrete pavement was undersealed and overlaid. The 10-in. overlay design consisted of the following layers: approximately 3½ in. of crack relief; 3½ in. of binder (or more, as required) for leveling; 2½ in. of surface; and an open-graded friction course.

Based on a 50-blow Marshall design, the mix properties were as shown in Table 1.

During construction of the overlay, traffic was routed onto the parallel frontage roads, which had been previously overlaid with 3½ in. of the same mix that was to be used on the main lanes. Although the frontage roads rutted shortly thereafter, no adjustments were made to the mix design for the main lanes. As construction was completed and safety precautions were met, traffic was rerouted to the main lanes in early September. Although the entire 9.8-mi overlay had not yet been completed, rutting was observed within 30 days on those sections opened to traffic. An observation point to monitor the rutting was established in the vicinity of a truck weigh station, where the rut depth in early October measured approximately ½ in. From October to early December, the rut depth increased an additional 1/16 in., resulting in a maximum rut of 9/16 in.

Investigation

In December 1976, the Asphalt Institute was asked to help determine the cause of the rutting. Five 6-in. cores were cut through the full depth of the overlay from the outside lane, one each in the IWP and OWP, and three outside the wheelpaths. In addition to the cores, a beam section spanning the

TABLE 1 MIXTURE PROPERTIES OF I-55

PROPERTY	SURFACE	BINDER
Unit Wt (lb/ft^3)	147.8	148.4
Air Voids (%)	4.2	4.0
Stability (lb)	1425	1000
Flow (0.01 in)	12	11
VMA[1]	16.2	13.5
G_{mm}	2.469	2.477
AC (% by wt of mix)	5.3	4.3

(1) VMA back calculated using G_{mm} and G_{se}

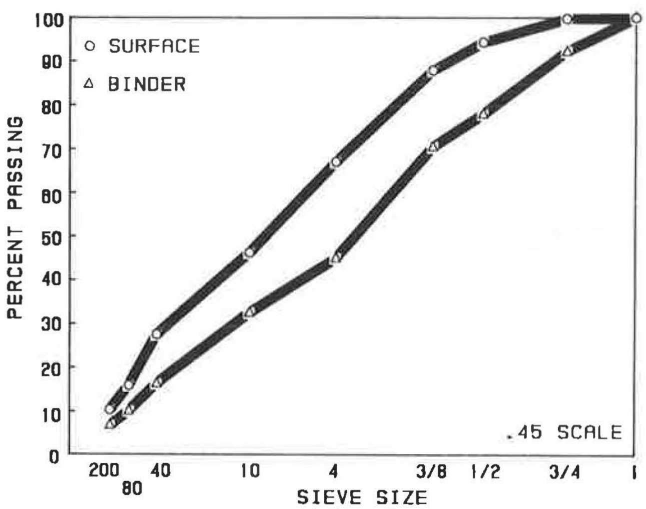

FIGURE 1 Gradation of extracted aggregate (I-55).

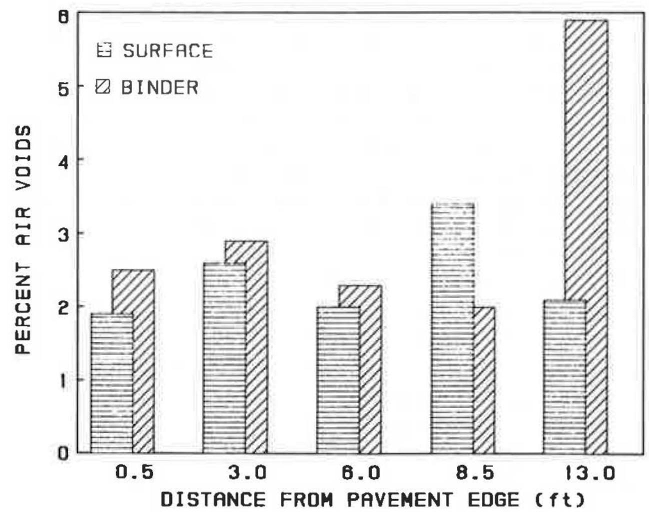

FIGURE 2 Variation in air voids (I-55).

wheelpaths was cut from the traffic lane. The crack-relief layer, consisting of 3-in. top-size aggregate, could not be removed intact, yielding a beam thickness of approximately 5.5 in. From the beam section, eight additional cores were cut from both distressed and nondistressed areas. The cores were trimmed to Marshall size specimens (4-in. diameter and 2.5-in. height) where feasible and used in Marshall and Hveem testing as well as for extraction and recovery tests.

Shown in Figures 1 and 2 and Tables 2 to 4 are average core properties and test results.

Traffic

Traffic counts indicated consistently heavy use by trucks: approximately 189 equivalent single-axle loads with 21 percent truck traffic, as projected in the overlay design.

Nondestructive Testing

Although deflection measurements were made with both the Dynaflect and the Falling Weight Deflectometer devices, only the Dynaflect data are presented here. The data set included deflection measurements at 32 locations in each lane. Average deflections for both north- and southbound lanes were essentially the same: the northbound lane had a mean of 0.46 mil for the inside lane and 0.45 mil for the outside lane, whereas both of the southbound lanes had a mean deflection of 0.47 mil. The coefficients of variation were less than 10 percent. Using computer software that accompanied the Dynaflect device, the average moduli for the dense- and open-graded layers were calculated to be 455,500 and 112,500 psi, respectively.

Because the core properties, test results, and measured deflections for both lanes were nearly identical, it seems rea-

TABLE 2 CORE PROPERTIES OF I-55

PROPERTY	SURFACE	BINDER
Unit wt (lb/ft^3)	150.1	151.6
Air Voids (%)	2.6	2.4
VMA (%)	14.4	12.7

TABLE 3 GRADATION OF EXTRACTED AGGREGATE FROM I-55

	PERCENT PASSING	
SIEVE SIZE	SURFACE	BINDER
1 in	100.0	100.0
3/4	99.8	92.3
1/2	94.3	77.9
3/8	87.9	70.5
No 4	67.1	45.0
10	46.3	32.6
40	7.4	16.3
80	15.8	9.9
200	10.2	6.7
Filler/AC	1.9	1.5

TABLE 4 PROPERTIES OF RECOVERED ASPHALT FROM I-55

PROPERTY	SURFACE	BINDER
Asphalt Content	5.4	4.8
(% by wt of mix)		
Viscosity		
@ 140 ^{0}F (poise)	2181	3370
@ 275 ^{0}F (cSt)	499	570
Penetration		
(77 ^{0}F, 5 s, 100 g)	79	54

sonable to conclude that the underlying layers were relatively stable and that the primary source of the structural weakness was associated with the surface and binder courses. Condition surveys indicated a plastic and horizontal movement of the upper pavement layers toward the outside edge. This was further shown by snowplows clipping the friction course at the outer pavement edge and on each side of the wheelpaths.

Summary of Study

Data from the mix designs and condition surveys point to the surface course as the primary source of rutting, with some contribution from the binder course. The design asphalt content of the surface course, 5.3 percent, was above (to the right of) the minimum void in mineral aggregate (VMA), suggesting that the mix would be susceptible to plastic flow. Furthermore, densities of the field cores from both surface and binder courses were greater than 102 percent of the laboratory-compacted density, indicating that the mix had been overcompacted. Average void contents for the surface and binder cores were 2.6 percent and 2.4 percent, respectively—well below the 4.0 percent specified in the mix design. The void content was slightly higher in some rutted areas, indicating that traffic had actually decompacted the mat. The VMA values from the field cores appeared to be adequate (14.4 percent for the surface and 12.7 percent for the binder), but both were lower than the values calculated at the design asphalt content. Although the gradation of the extracted aggregate did not reveal any particular problem, the filler-to-asphalt ratios for the surface and binder of 1.9 and 1.4, respectively, both exceeded the generally accepted upper limit of 1.2 recommended by the FHWA in Technical Advisory 5040.24, *Asphalt Concrete Mix Design and Field Control.*

From the beam cores, the average Hveem stabilometer values were 12 for the surface and 27 for the binder. Although the average Marshall stability values of 1,335 lb (surface) and 1,550 lb (binder) were acceptable based on existing criteria, the flow values of 15 (surface) and 20 (binder) were high.

To summarize, the apparent causes of the pavement rutting were selection of the design asphalt content above the minimum VMA and high filler-to-asphalt ratios for both the surface and binder courses, which led to overcompaction of the mat.

Corrective Action

Before this project was accepted in October 1978, the Arkansas Highway and Transportation Department required the contractor to place an additional open-graded friction course on the rutted area. This removed the appearance of all rutting at the time. In December 1982, the rut depth was measured at ½-in. on the IWP. In 1985, approximately 1.5 in. was milled off the surface and overlaid with a mixture based on a 75-blow Marshall, as outlined in the Asphalt Institute's MS-2, *Mix Design Methods for Asphalt Concrete*. As of this writing, the pavement is performing satisfactorily without any measurable rutting.

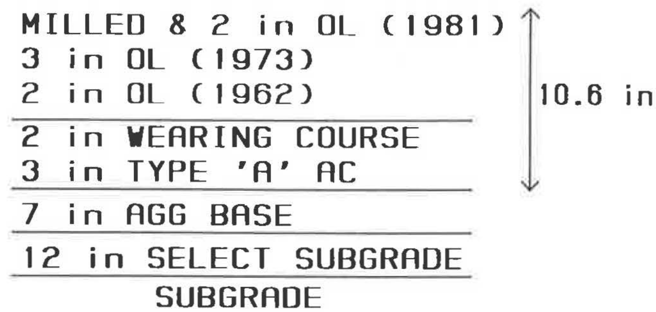

FIGURE 3 Turnpike pavement structure.

TURNER TURNPIKE IN OKLAHOMA

Construction History (*3*)

Opened to traffic in 1953, the 90-mi Turner Turnpike connects Oklahoma City and Tulsa. The original structure as shown in Figure 3 consisted of approximately 12 in. of select subgrade, 7 in. of stabilized aggregate base, and 5 in. of asphalt concrete.

According to maintenance records, surface irregularities were observed as early as 1959. Condition surveys noted fatigue and shrinkage cracking and localized structural failures. A 23-mi section was overlaid with a nominal thickness of 2 in. in 1962 and 3 in. in 1973. In 1981, all four lanes were milled to various depths and overlaid with approximately 2 in. of asphalt concrete (55 percent virgin and 45 percent reclaimed material). Shortly after completion, rutting was observed in the outside lane of the westbound lanes (WBL). The project consultant concluded that this was due to Texas Gyratory Hveem stabilities below the recommended minimum of 40. As a result, a 12-mi section of the WBL was milled and replaced prior to final acceptance of the project. This section, however, rutted shortly thereafter. Because the rutting appeared to be confined primarily to the WBL, trench sections were cut across the lane at Mileposts 1.6 and 11.5. Visual observation of the component layers provided conflicting data. At Milepost 1.6 the rutting appeared to be confined to the top layer, whereas at Milepost 11.5, rutting had occurred in all layers.

A brief review of the road's traffic history might prove useful before turning to the investigation of the causes of the rutting and remedial measures taken. In only 7 yr of operation, the turnpike had carried the traffic expected for the first 12 yr. The total traffic volume in 1980 was more than twice that originally predicted, with truck traffic nearly three times the original prediction.

Field Investigation

Based on the conflicting data from the trench sections, a comprehensive program of materials sampling and testing of the 23-mi west end section of the turnpike was undertaken. Using Dynaflect, Austin Research Engineers measured pavement deflections every 0.2 mi in the wheelpath (OWP on the outside lane and IWP on the inside lane) for a total of 500 data points. Standard Testing and Engineering Company of Oklahoma City extracted 65 full-depth cores at 16 different locations (see Figure 4 for core location relative to wheel-

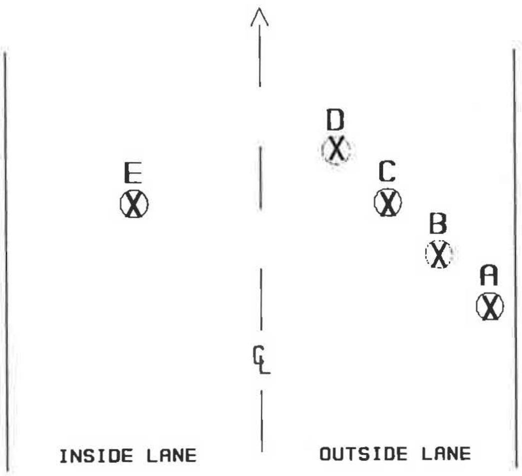

FIGURE 4 Core locations (Turner Turnpike).

path). Laboratory evaluation of the cores included such tests as density/voids analysis, extraction and gradation of the aggregate for the asphalt-bound layers, California bearing ratio, Atterberg limits, and gradation for the base and subgrade.

The results of the density/voids analysis and extraction are shown in Tables 5 and 6. These same results are shown graphically in Figures 5 and 6. Based on the consolidation of the mixture, as shown in Figures 5 and 6, it was concluded that rutting was evident in all the layers.

Layers 3 and 4, which represent the initial construction, indicate excessive deformation due to both consolidation and plastic movement. The 1962 overlay, represented by Layer 2, did not rut in the WBL but it did crack severely. The next corrective action (the 1981 overlay) showed evidence of rutting in both lanes. The most severe rutting was observed in the OWP of the westbound lane. Accordingly, 12 mi were milled and replaced with essentially the same mix utilizing virgin materials. The rest of the project began to rut shortly thereafter. A summary of rut-depth measurements following the 1981 construction is shown in Table 7.

Nondestructive Testing

Based on the Dynaflect data, the 23-mi section was divided into four statistically different sections, two each in the eastbound and westbound lanes. Table 8 shows that the subbase has a lower modulus than that of the subgrade. The asphalt concrete modulus is also low when compared with typical values for asphalt concrete moduli.

Summary of Study

As noted previously, permanent deformation was observed in all of the asphalt-bound layers. The data suggested that several factors led to this rutting. The initial failure could be attributed to structural design, as shown by the load-associated cracking and rutting in the wheelpaths. This structural failure was the result of a weak subbase that had a modulus lower than that of the subgrade. The rutting, which appeared to be greater in the OWP, provided additional confirmation of the instability of the underlying layers. Also, the pavement structure was inadequate for the actual load and volume of truck traffic. Unfortunately, rehabilitation efforts compounded the problem since the overlay mixes had low air voids and high filler-to-asphalt ratios. These types of mixes are typically susceptible to excessive permanent deformation.

In 1983, the surface was milled and replaced with approximately 2.5 in. of a dense-graded, high-stability mix (40+ Hveem) compacted to a minimum of 4 percent air voids. An open-graded friction course was placed as the final wearing course. According to turnpike officials, this corrective action has eliminated the deformation associated with the plastic mix, although the presence of the unstable subbase is still obvious, as evidenced by continued rutting in the OWP.

U.S. 54 IN KANSAS

Design and Construction

In an effort to prevent rutting and cracking, this project was redesigned by the contractor as part of the Kansas Department of Transportation (KDOT) Value Engineering program. The 19-mi project west of Kingman involved not only overlaying the existing pavement but also placing full-depth asphalt on the relocated sections. Although paving was not completed until November 1988, traffic was allowed on the completed sections of the binder (BM-7) and base (BM-2) in early 1987.

A 500-ft portion of a relocated section was identified to monitor the pavement performance. In cooperation with KDOT and the paving contractor, aggregate, asphalt cement, mix, and cores from this section were obtained by the Asphalt Institute for laboratory evaluation of the engineering properties of the mix. The laboratory-measured properties are being compared with those determined by nondestructive deflection measurements and condition surveys.

The full-depth asphalt section consists of 6 in. of dense-graded asphalt base (BM-2), 3 in. of stone-filled binder (BM-7), and 1⅛ in. of stone-filled surface (BM-1). Stone-filled mixes typically have aggregate gradations well below the maximum density line, as shown in Figure 7 (see also Table 9). This is accomplished by increasing the coarse aggregate fraction by as much as 15–25 percent.

The mix properties based on a 50-blow Marshall design are shown in Table 10.

Nondestructive Test

To compare engineering properties of this pavement system with those of the Arkansas and Oklahoma projects previously discussed, Dynaflect deflection data were used to back-calculate the elastic modulus of each layer. To obtain a representative measure of the modulus, deflections were recorded at 20 different locations in both wheelpaths and between the wheelpaths. The moduli were back-calculated to be 500,000, 350,000, and 200,000 psi for the surface, binder, and base, respectively. These values compare favorably with those of Interstate 55 and, considering the reduced volume of traffic projected for this primary road, it is unlikely that there will be significant permanent deformation.

TABLE 5 AVERAGE PERCENT VOIDS AND VMA, TURNER TURNPIKE

	Core Location[1]				
	A	B	C	D	E
Eastbound Lanes					
Layer 1					
Voids (%)	1.3	.9	1.9	.9	2.0
VMA (%)	13.2	13.1	13.7	13.0	13.8
Layer 2					
Voids (%)	3.4	1.7	3.7	1.3	1.0
VMA (%)	16.8	15.2	16.9	13.7	14.3
Layer 3					
Voids (%)	4.2	2.1	3.9	2.2	3.8
VMA (%)	15.1	13.4	15.3	13.2	15.3
Layer 4					
Voids (%)	5.4	2.6	3.7	6.6	6.6
VMA (%)	16.4	13.9	14.7	14.5	17.8
Westbound Lanes					
Layer 1					
Voids (%)	2.3	1.6	2.6	2.1	3.0
VMA (%)	13.8	13.6	14.1	13.8	14.8
Layer 2					
Voids (%)	2.8	3.1	3.2	3.0	2.7
VMA (%)	15.8	15.7	16.2	15.8	15.6
Layer 3					
Voids (%)	3.0	1.1	2.4	1.8	4.5
VMA (%)	15.6	13.8	14.8	14.2	16.6
Layer 4					
Voids (%)	6.6	3.8	5.4	3.6	6.9
VMA (%)	18.2	16.0	17.2	16.7	18.5

(1) Locations relative to the wheelpaths are shown in Figure 4.

TABLE 6 AVERAGE GRADATION OF EXTRACTED AGGREGATE FROM TURNER TURNPIKE

	LAYER			
SIEVE SIZE	FIRST	SECOND	THIRD	FOURTH
1 1/2 in				100.0
1				99.7
3/4	100.0	100.0	100.0	98.4
1/2	92.6	99.1	98.1	92.4
3/8	85.4	91.7	89.2	86.1
No 4	65.3	64.0	67.3	66.9
10	48.5	45.9	47.2	48.6
40	26.9	29.5	30.3	31.1
80	16.0	18.4	17.6	18.5
200	8.7	7.5	5.6	6.1
AC (%)	4.7	5.5	5.3	5.0
Filler/AC	1.9	1.4	1.1	1.2

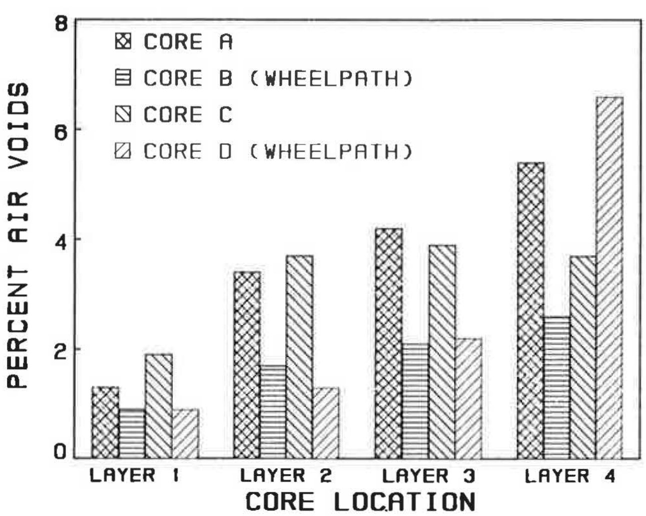

FIGURE 5 Eastbound lane voids (Turner Turnpike).

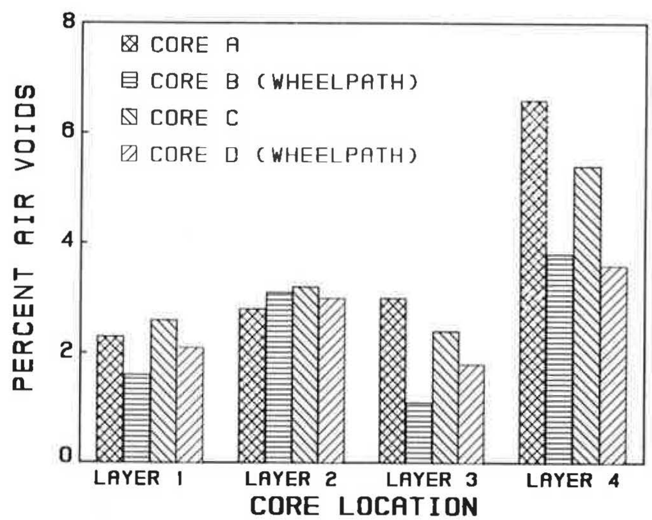

FIGURE 6 Westbound lane voids (Turner Turnpike).

TABLE 7 RUT-DEPTH OF OUTER WHEELPATH ON TURNER TURNPIKE

	Eastbound Lane	Westbound Lane
Mean (in)	0.51	0.36
Std Dev	0.16	0.27
CV (%)	31.4	75.0

TABLE 8 ELASTIC MODULI BASED ON DYNAFLECT DATA FOR TURNER TURNPIKE

		ELASTIC MODULUS (psi)			
		AC	Base	Subbase	Subgrade
MILE POST					
EBL	2.00 - 18.65	170,000	35,000	18,000	25,500
	18.65 - 26.00	150,000	55,000	18,000	18,800
AVERAGE MODULUS		160,000	45,000	18,000	21,500
WBL	2.00 - 19.35	130,000	35,000	15,000	22,000
	19.35 - 26.00	100,000	45,000	15,000	18,900
AVERAGE MODULUS		115,000	40,000	15,000	20,450

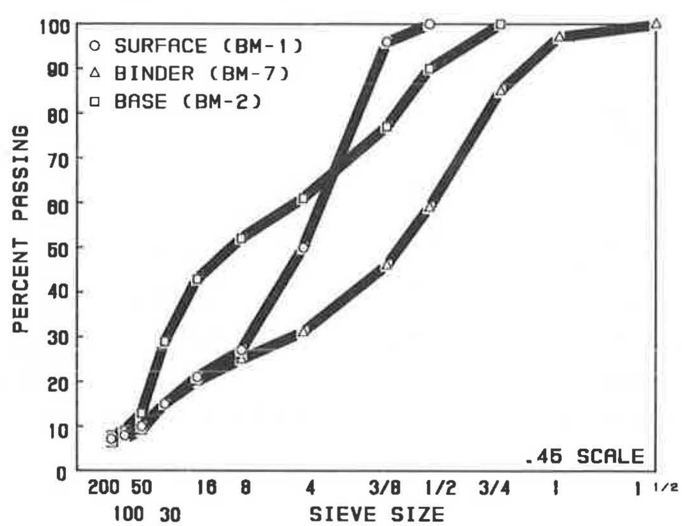

FIGURE 7 Aggregate gradations (Kansas U.S. 54).

TABLE 9 JOB MIX FORMULA FOR KANSAS U.S. 54

	Percent Passing		
SIEVE SIZE	SURFACE	BINDER	BASE
1 in		97	100
3/4		85	100
1/2	100	59	90
3/8	96	46	77
No 4	50	31	61
8	27	25	52
16	21	20	43
30	15	15	29
50	10	9	13
100	8	7	9
200	7	6	8
AC (%)	5.5	4.5	5.3
Filler/AC	1.3	1.3	1.5

TABLE 10 MIX PROPERTIES FOR KANSAS U.S. 54

PROPERTY	SURFACE	BINDER	BASE
Unit wt (lb/ft^3)	144.0	143.6	146.6
Air Voids (%)	5.4	6.9	3.2
VMA[1] (%)	14.0	13.8	13.0
VFWA[2] (%)	61.4	50.5	75.3
G_{mm}	2.436	2.464	2.430
Stability (lb)	2140	2100	1473
Flow (.01 in)	12	14	10

Summary of Study

Although portions of the project were opened to traffic for almost a full year before the surface course was placed, there was no evidence of measurable rutting. In the absence of intermediate fines and with the addition of coarse material, it is likely that the stone-filled mixes will be less sensitive to asphalt content and less susceptible to additional consolidation. Additional condition surveys and deflection measurements are planned to further document the effectiveness of the stone-filled mixes in minimizing permanent deformation.

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