Field Performance of Large-Stone Hot Mix Asphalt on a Kentucky Coal Haul Road

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The results of a 3-year pavement performance monitoring program with a primary focus on rutting are summarized. Pavement coring was conducted to determine the magnitude and cause of rutting in individual pavement layers. A pavement trench was excavated for further examination of pavement layers. Field data indicate that rutting was concentrated in steep uphill grade locations where heavy coal trucks travel at very slow speeds. Data from pavement cores and a pavement trench indicate that rutting in the large-stone mix may have been caused by insufficient direct stone-on-stone contact, which made the mixture susceptible to permanent deformation. Observations of the pavement trench at the location where the rutting was greatest (1.8 in.) revealed no definite shear pattern within the cross section of the large-stone base layer. However, laboratory measurements indicated a significant reduction in the air voids content of the top 4 in. of the pavement after 2 years of exposure to coal haul traffic loads. This significant reduction in air voids coupled with a lack of sufficient stone-on-stone contact contributed to the plastic behavior of the material. Pavement elevation data indicate that there has been an overall settlement of the roadway. The settlement may be attributed to consolidation of the subgrade and densification of the drainage blankets caused by upward migration of fines from the dense-graded aggregate into the open-graded No. 57 layer and overall consolidation and penetration of particles along the interface between the two layers.

Rutting of hot mix asphalt concrete (HMAC) has become such a costly problem for many highway agencies that many have considered excluding HMAC from heavy traffic design applications. Kentucky was faced with the same challenge during the 1987–1988 period. A cooperative effort between several government and private organizations led to a recommendation that promoted the use of a large-stone mix designated Kentucky Class K. This recommendation was later implemented through the construction of a new heavy-duty pavement, 12 in. of large-stone bituminous base layer (see Figure 1). The project was located on a major coal haul corridor for eastern Kentucky, US-23–Louisa Bypass, Lawrence County. This corridor carried approximately 4 million equivalent single-axle loads (ESALs) in 1990. Some special features were included in this project, such as drainage layers with the following design thicknesses: 4 in. of dense-graded aggregate (DGA) on top of the subgrade and 4 in. of an untreated open-graded No. 57 coarse aggregate, plus pavement edge drains. Subgrade CBR was 9 percent, and it was not stabilized. The pavement surface was a nominally 1-in. conventional HMAC, modified with polymer over half of the project. The performance of the polymer-modified surface wearing course is outside the scope of this paper. However, preliminary results indicate that both the control and polymer-modified surface course sections are performing well without any signs of major distress. The Kentucky DOH engineers would generally agree that overall rutting resistance of the large-stone Class K base has been better than that of conventional Class I base under similar conditions; nevertheless, some rutting did occur on this project, and a forensic analysis of possible causes is presented.

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This paper constitutes a progress report as part of an ongoing effort devoted to long-term performance monitoring of large-stone mixtures. Kentucky is considered a leader in the field of experimentation with large-stone mixtures, which has been possible through a close cooperative effort between the Kentucky Transportation Cabinet, the University of Kentucky, and the asphalt industry in Kentucky. The data presented herein were gathered with limited financial support and are based on limited portions of the Louisa Bypass project, which focused only on conditions of incipient rutting failure. However, the data will be expanded in the near future to incorporate the entire project.

PAVEMENT PERFORMANCE DATA

Performance of the Louisa Bypass project has been monitored for the past 2 years, and monitoring will continue for the next 3 years through cooperative support by the Kentucky Transportation Cabinet and Federal Highway Administration. Whereas general roadway condition surveys are essential, the primary focus of this long-term performance-monitoring activity has been the field evaluation of the large-stone, Kentucky Class K, base layer.

Background on Mixture Properties

Kentucky Class K was selected through a cooperative effort between state agencies and the asphalt industry in Kentucky to address the severe rutting problem in some coal haul regions of Kentucky. The gradation of this mixture is shown in Figure 2. On the basis of previous work (*1*), mixture properties such as Marshall stability (Table 1), resilient modulus, and creep were shown to be superior to those of the conventional mixtures. This was true for both laboratory-

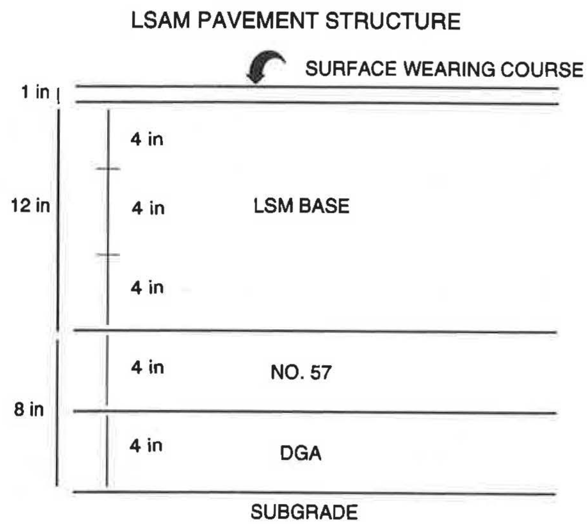

FIGURE 1 Pavement cross section, US-23–Louisa Bypass.

manufactured specimens and actual pavement cores (*1*,*2*). However, shortly after construction, a concern was raised on the basis of observations of the pavement cores that the degree of stone-on-stone contact of the large-stone base layer was not as high as initial expectations. It was critical to determine whether the Kentucky Class K gradation had a sufficient concentration of large particles to serve as a strong skeleton for distribution of extremely high magnitude and frequency of stresses, which are commonly encountered on Kentucky coal haul roads. The following sections describe the rutting and other performance characteristics that were observed on this road and an analysis of possible causes of rutting.

Analysis of Pavement Rutting Data

Measurable rutting was isolated in locations where trucks travel at relatively slow speeds (10 to 20 mph) along the northbound driving lane on steep uphill grades. The greatest amount of rutting after 2 years of service occurred at Milepost 17.46. It

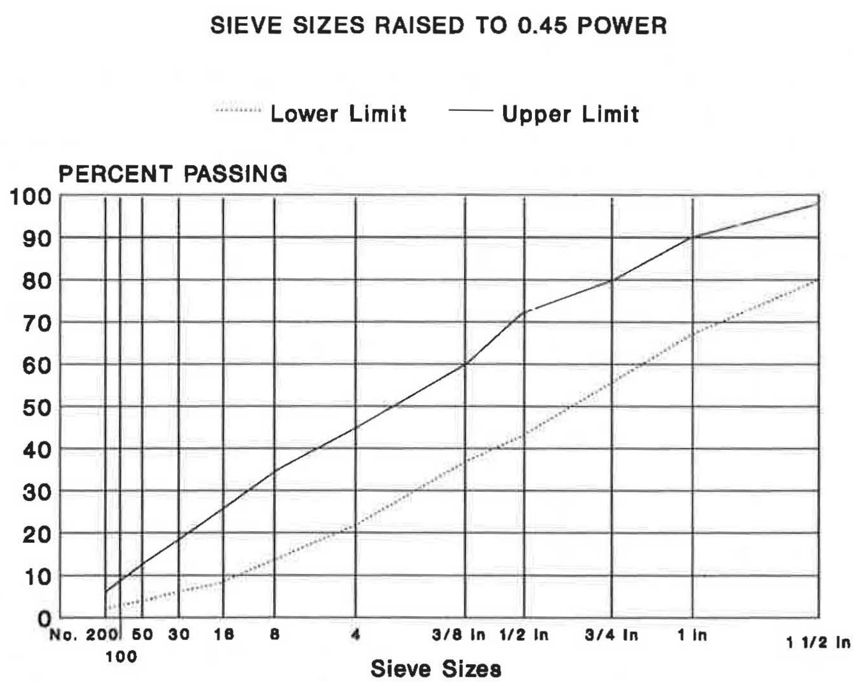

FIGURE 2 Gradation distribution for Kentucky large-stone Class K.

TABLE 1 DESIGN PARAMETERS FOR CLASS K BASE, US-23–LOUISA BYPASS

Parameter	Louisa Bypass	Criteria
Stability, lb.	5,300	3,000 (min)
Flow, 0.01 in.	16	28 (max)
Air Voids, %	3.6	3.5 - 5.5
VMA, %	13.1	11.5 (min)
Retained Tensile Strength, %	Pass	70

was 1.8 and 1.2 in. under the right and left wheelpaths, respectively. Figure 3 shows a reconstructed view of the pavement cross section at Milepost 17.46 on the basis of data from pavement cores.

The following sections present an analysis of data based on a pavement trench (Figure 4) and pavement cores at Milepost 17.46, where the greatest amount of rutting on this project was developed. All statistical comparisons were conducted using an analysis of variance technique and a least significant difference procedure when needed (*3*) at 95 percent level of significance (i.e., alpha error = 5 percent). In the analysis of pavement cores, the assumption was made that quality control measures during the construction of this project, as reported by Williams (*4,5*), produced a uniform quality mixture (in terms of mixture air voids and density) within each lane and within each lift at any given milepost. That is, it was reasonable to assume that before traffic was allowed on this roadway, there were no significant differences in large-stone HMAC air voids and densities at locations corresponding to future under- and between-the-traffic wheelpaths for any given milepost within each lane and within each lift. Examination of the postconstruction data, and specifically the relative coefficient of variability for the air voids and the density of each lift, as a measure of data dispersion, revealed that this assumption was reasonable. The quantitative justification for this assumption is presented in Table 2. It was possible to show that the three 4-in. lifts of the large-stone asphaltic base had significantly different air voids before traffic, with the top and middle lifts having the highest air voids and the bottom layer having the lowest (F value = 19.79 > $F_{0.05,2,33}$ = 3.29) (Table 3). Lower air voids in the bottom lift could be attributed to the following: (*a*) higher asphalt content (4.1 percent in the bottom lift as opposed to 3.7 percent in the middle and top lifts), which was used as a means for reducing the potential for stripping in the bottom lift, and (*b*) some partial compaction during compaction of the middle and top lifts.

It is believed that the process that has led to rutting on this project is not very different from the one known for conventional hot mix asphalt (HMA). The evidence clearly indicates that there has been a significant reduction in the air voids content of large-stone HMA after 2 years of exposure to heavy truck traffic. It is believed that rutting of HMA is typically a two-stage process. First, traffic-induced densification often reduces the air void content to a critically low level, which is different for different mixtures. Second, in the absence of a strong aggregate interlock, the critically densified mix deforms plastically under load. In the case of the Class K base, this means that the concentration of stone-on-stone contact was not great enough and, therefore, some modification of the gradation may be warranted.

The data from the pavement trench did not indicate any distinguishable shear planes within the large-stone base layer. The fact that shear planes were not visually detectable in the trenched cross section does not diminish the possibility of shear deformations. If oblong-shaped aggregate particles are present in the mix, they often align themselves along the direction of shear flow patterns. The large-stone aggregate in this project did not include a large percentage of oblong particles; hence, the existence of shear flow patterns was not visually verifiable.

The following sections describe significant changes that were observed within each asphaltic sublayer.

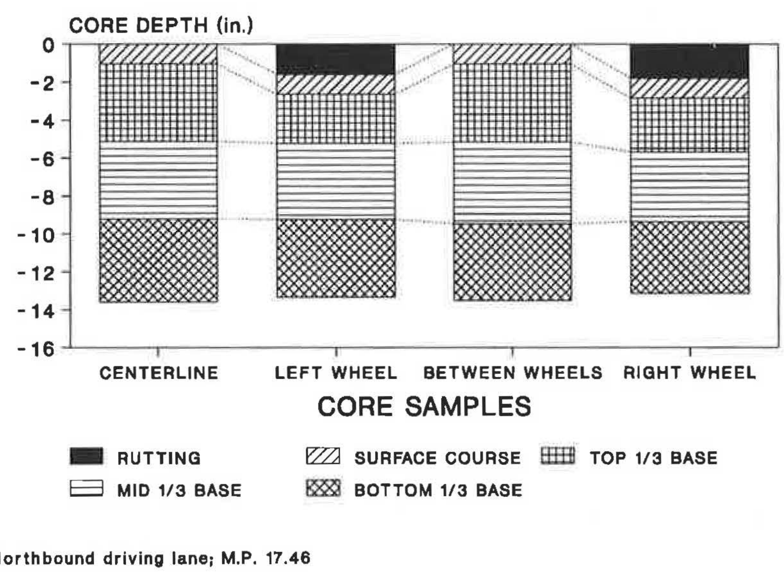

FIGURE 3 Reconstructed view of the pavement cross section based on pavement core data, US-23–Louisa Bypass.

FIGURE 4 Pavement trench at Milepost 17.46, US-23–Louisa Bypass.

Surface Wearing Course

A 1-in.-thick, dense-graded conventional surface wearing course having a construction variability of ⅛ to ¼ in. throughout the project was used to provide a smooth riding surface. An examination of the pavement trench where rutting was maximum indicated that the surface wearing course was by and large stable, and no measurable amount of rutting was detected in that layer. The 1-in. surface layer conformed to the rutting contour of the large-stone base layer. Data will be expanded to include the long-term performance of the polymer-modified wearing course.

Top Lift of Large-Stone Mixture

The top 4 in. of the large-stone base showed significant changes in the air voids content after 2 years of service. Along the right wheelpath, where the rutting was highest, the air voids

TABLE 2 CONSTRUCTION VARIABILITY IN THE NORTHBOUND LANE US-23–LOUISA BYPASS

		Top Lift		Middle Lift		Bottom Lift	
		Air Voids (%)	Density (pcf)	Air Voids (%)	Density (pcf)	Air Voids (%)	Density (pcf)
MP 15.07	Mean	6.0	147.8	5.2	149.1	4.1	151.2
	Standard Deviation	0.9	1.4	1.3	2.1	1.3	2.1
	Relative Coefficient of Variation	7.5%	0.4%	12.5%	0.7%	15.9%	0.7%
MP 17.46	Mean	6.1	147.7	4.6	150.0	2.2	154.1
	Standard Deviation	0.4	0.5	0.3	0.5	0.2	0.3
	Relative Coefficient of Variation	3.3%	0.2%	3.3%	0.2%	4.5%	0.1%
MP 17.73	Mean	5.2	149.2	4.5	150.2	2.8	153.2
	Standard Deviation	0.5	0.6	0.7	1.1	1.2	1.8
	Relative Coefficient of Variation	4.8%	0.2%	7.8%	0.4%	21.4%	0.6%

TABLE 3 POSTCONSTRUCTION DATA ANALYSIS FOR THE NORTHBOUND DRIVING LANE, US-23–LOUISA BYPASS

	Top Lift		Middle Lift		Bottom Lift	
	Air Voids (%)	Density (pcf)	Air Voids (%)	Density (pcf)	Air Voids (%)	Density (pcf)
MP 15.07	7.4 5.8 5.6 5.4	145.7 148.3 148.4 148.8	4.6 4.2 4.8 7.1	150.1 150.6 149.6 146.0	5.1 3.2 2.7 5.4	149.6 152.6 153.4 149.1
	Mean: 6.0^A	Mean: 147.8^B	Mean: 5.2^A	Mean: 149.1^B	Mean: 4.1^C	Mean: 151.2^D
MP 17.46	6.0 5.7 6.5 6.3	147.9 148.3 147.1 147.4	4.2 4.7 4.8 4.8	150.8 149.7 149.8 149.8	2.5 2.1 2.2 2.1	153.7 154.3 154.2 154.3
	Mean: 6.1^A	Mean: 147.7^B	Mean: 4.6^A	Mean: 150.0^B	Mean: 2.2^C	Mean: 154.1^D
MP 17.73	5.9 5.1 4.9 4.9	148.4 149.3 149.6 149.6	4.0 5.2 3.7 5.0	150.9 149.1 151.4 149.4	2.4 2.0 2.2 4.5	153.8 154.4 154.1 150.5
	Mean: 5.2^A	Mean: 149.2^B	Mean: 4.5^A	Mean: 150.2^B	Mean: 2.8^C	Mean: 153.2^D

Legend for comparisons by columns and rows (A,B,C,D)	
Significantly Different at 95%	Superscripts are different
Not Significantly Different at 95%	Superscripts are the same

were significantly reduced; the mean changed from 6.1 to 3.0 percent (Table 4). The reduction in air voids was statistically highly significant (F value = 188.26 >> $F_{0.05,1,5}$ = 6.61). The between-the-wheels cores indicated a significant reduction in the air voids content (F value = 70.69 >> $F_{0.05,1,5}$ = 6.61) but was not as highly significant as the previously indicated change in the right wheelpath. The significant reduction in the air voids content effectively indicates an in-service compaction due to traffic. In fact, within the top lift after 2 years of service, air voids were much lower under the right wheelpath than between the wheels (F value = 24.02 >> $F_{0.05,1,4}$ = 7.71). This behavior may be attributed to the high magnitude of compressive stresses and especially shear stresses within this zone.

Middle Lift of Large-Stone Mixture

After 2 years of service, the middle 4 in. of the large-stone base showed no significant change in the air voids under the right wheel path (F value = 0.05 < $F_{0.05,1,5}$ = 6.61). The between-the-wheels data indicated a significant reduction in the air voids for this layer (F value = 30.74 > $F_{0.05,1,5}$ = 6.61). This trend is inconclusive at this point, and more data are needed to verify this observation.

Bottom Lift of Large-Stone Mixture

The bottom lift showed a significant increase in the air voids content after 2 years of service. The trend was consistent for both under the right wheel (F value = 399.5 >> $F_{0.05,1,5}$ = 6.61) and between the wheels (F value = 15.2 > $F_{0.05,1,5}$ = 6.61). This observation is inconclusive, but the movement of the subbase layers (DGA and No. 57) may have provided an opportunity for an effective decompaction of the bottom base layer. At this point, further studies are needed before definite conclusions can be made. For example, an analysis of asphalt content of cores obtained from the bottom lift may shed some light on the possible cause (stripping, etc.).

Analysis of the Pavement Drainage Blanket

A two-layer drainage blanket was included in this project as a means of facilitating subsurface pavement drainage. A DGA layer was placed directly on top of the subgrade (4-in. design thickness). The top surface of the DGA layer was treated with a light emulsion prime coating (SS-1h) before placement of the No. 57 subbase (4-in. design thickness). Gradation distributions for the DGA and No. 57 are shown in Figure 5. After 2 years of service, the pavement was trenched at a location where rutting was more severe. The analysis of the trench revealed that the initial nominally 8-in., two-layer drainage blanket was approximately 6.75 in. in thickness. Further evidence was sought to characterize this phenomenon. It was noted that the postconstruction visual distinction between the two layers has been diminished, and the emulsion prime coating was ineffective in this regard. Roadway elevation data indicated an overall pavement settlement (Figure 6). As a follow-up to this observation, the filter criteria as reported by the U.S. Bureau of Reclamation (*6*) were checked for the theoretical gradations (defined as the midpoints within the specification limits) for both DGA and No. 57 drainage layers as a possible reason for the penetration of particles at the interface. It was discovered that the filter criteria were either marginally satisfied or not satisfied at all. This information is summarized in Table 5 (numbers shown in brackets refer to the filter characteristics of the pavement drainage blanket). As a follow-up, actual DGA and No. 57 samples were taken from the pavement trench location in accordance with the details shown in Figure 7. The data indicated that

TABLE 4 STATISTICAL COMPARISONS FOR THE NORTHBOUND DRIVING LANE, US-23–LOUISA BYPASS

	Time: 0 yrs. BW, RW		Time: 2 yrs. BW		Time: 2 yrs. RW	
	Air Voids (%)	Density (pcf)	Air Voids (%)	Density (pcf)	Air Voids (%)	Density (pcf)
Top Lift	6.0 5.7 6.5 6.3	147.9 148.3 147.1 147.4	3.7 4.0 4.3	151.5 151.1 150.6	2.9 2.8 3.2	152.8 152.9 152.3
	Mean: 6.1^{A}	Mean: 147.7^{I}	Mean: 4.0^{B}	Mean: 151.1^{J}	Mean: 3.0^{C}	Mean: 152.7^{K}
Middle Lift	4.2 4.7 4.8 4.8	150.8 149.7 149.8 149.8	3.7 3.7 3.5	151.4 151.4 151.8	4.1 4.9 4.7	150.8 149.6 149.8
	Mean: 4.6^{A}	Mean: 150.0^{I}	Mean: 3.6^{B}	Mean: 151.5^{J}	Mean: 4.6^{A}	Mean: 151.1^{I}
Bottom Lift	2.5 2.1 2.2 2.1	153.7 154.3 154.2 154.3	3.9 5.4 3.4	151.4 149.1 152.3	5.3 5.4 5.0	149.3 149.1 149.7
	Mean: 2.2^{D}	Mean: 154.1^{L}	Mean: 4.2^{B}	Mean: 150.9^{J}	Mean: 5.2^{B}	Mean: 149.4^{J}

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Significantly Different at 95%	Superscripts are different
Not Significantly Different at 95%	Superscripts are the same

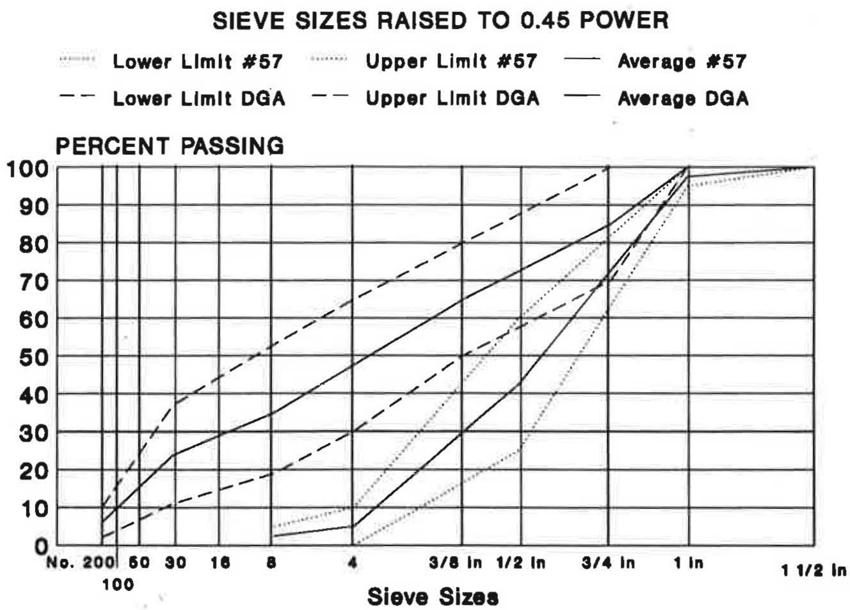

FIGURE 5 Gradation distributions for DGA and No. 57 aggregate.

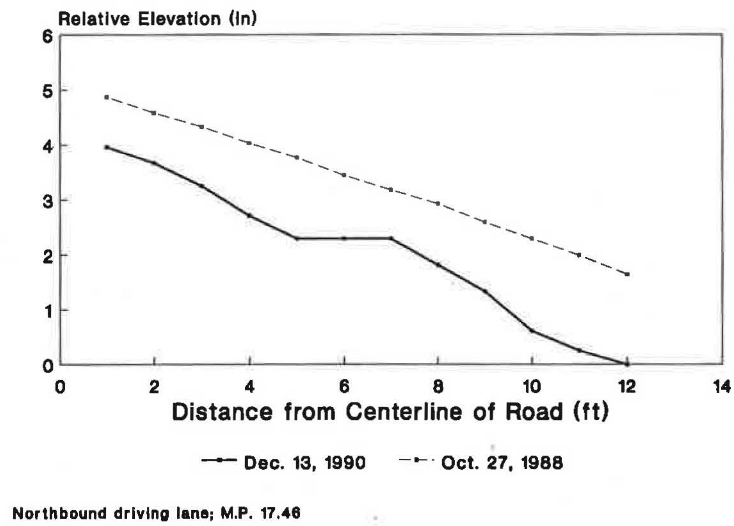

FIGURE 6 Roadway elevation data, US-23–Louisa Bypass.

TABLE 5 GRADATION REQUIREMENTS FOR FILTER MATERIALS (*6*)

Filter Material Characteristics	R_{15}	R_{50}
Uniform grain size filters, C_u = 3 to 4 [3]	-	5 to 10
Graded filters, subrounded particles	12 to 40	12 to 58
Graded filters, angular particles	6 to 18 [16]	9 to 30 [2]

$$R_{15} = \frac{D_{15} \text{ of filter material}}{D_{15} \text{ of material to be protected}}$$

$$R_{50} = \frac{D_{50} \text{ of filter material}}{D_{50} \text{ of material to be protected}}$$

NOTE 1. Maximum size of the filter material should be less than 76 mm (3 in.). Use the minus No. 4 fraction of the base material for setting filter limits when the gravel content (plus No. 4) is more than 10%, and the fines (minus No. 200) are more than 10%. Filters must not have more than 5% minus No. 200 particles to prevent excessive movement of fines in the filter and into drainage pipes. The grain size distribution curves of the filter and the base material should approximately parallel in the range of finer sizes.

NOTE 2. Numbers shown in brackets refer to the filter characteristics of the pavement drainage blanket.

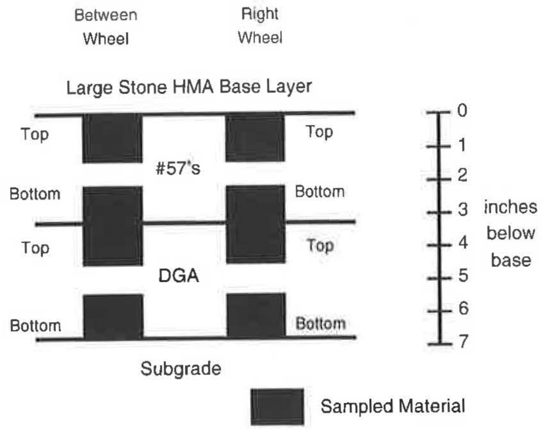

FIGURE 7 Sampling locations for DGA and No. 57 subbase material.

there has been some intrusion of small particles into the No. 57 layer, pushing parts of the gradation distribution of the No. 57 materials outside of the specification limits (Figures 8 and 9). This phenomenon was more severe at the under-the-wheel location. Water-associated migration of DGA fines into the No. 57's is possible. Load-associated forcing of the No. 57's into the DGA may also cause the thinning. This seems plausible because of the gradation differences of the between-the-wheel and under-the-wheel samples. Obviously, more work is needed before the actual cause is determined.

CONCLUSIONS AND RECOMMENDATIONS

The information presented herein has been intended as a progress report on an ongoing effort in Kentucky to better understand design and construction of large-stone asphalt mixtures. The conclusions and recommendations are based on limited data focused on a specific problem. Several features were included in this experimental project, but the primary focus of this paper has been on the rutting performance of the large-stone asphalt base. In general, the Kentucky Class K large-stone asphalt base rates a mixed review. It has clearly improved the rutting performance compared with conventional asphalt pavements on coal haul roads. On the other hand, there are clear indications that the insufficient concentration of stone-on-stone contact has provided an opportunity for some traffic-induced densification followed by plastic deformation. The fact that shear planes were not visually detectable in the trenched cross section does not diminish the possibility of shear deformations. The large-stone aggregate in this project did not include a large percentage of oblong particles; hence, the existence of shear flow patterns was not visually verifiable. The changes in the air voids and density in the middle and bottom base layers were inconclusive and further data are needed before final conclusions are drawn. The placement of the No. 57 subbase layer directly over DGA warrants a review; adjustments are warranted to minimize the migration of fines. It is recommended that the long-term performance monitoring of this roadway continue. Adjustments in the Kentucky Class K gradations are recommended to ensure more stone-on-stone contact. This can be done by reducing the fine and midsize portions and increasing the relative content of larger aggregate.

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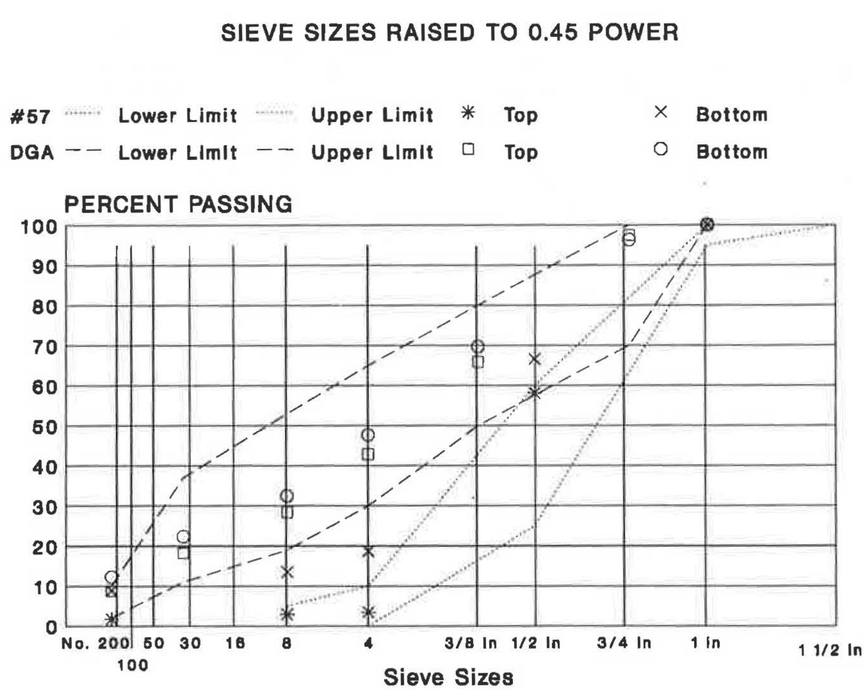

FIGURE 8 Gradation distributions for under-the-right-wheel samples.

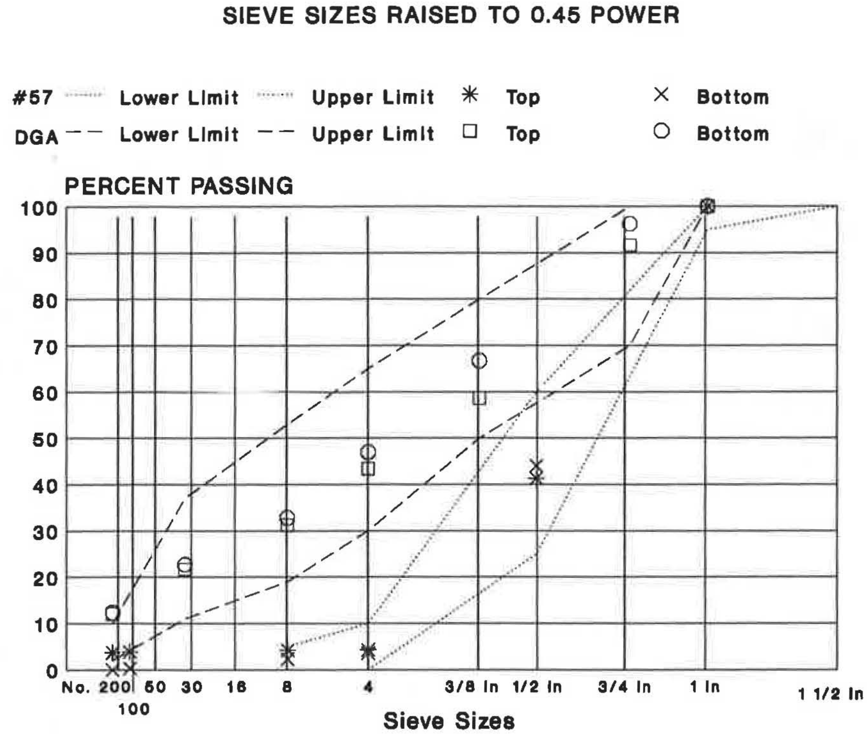

FIGURE 9 Gradation distributions for between-the-wheels samples.

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