Research Report
UKTRP-83-15

CRUSHED ROCK BASES

by

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in cooperation with the

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and the
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16. Abstract Prepared in cooperation with the US Department of Transportation, Federal Highway Administration

Gradations containing high, medium, and low percentages of fines were evaluated by laboratory tests and by behavioral responses in situ. Significant differences in strength parameters were not found. Differences in densities were not significant.

17. Key Words Dense-Graded Aggregate Road Rater In Situ Moduli Resonant Column Moduli CBR, Triaxial Shear	18. Distribution Statement

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INTRODUCTION

Roman roads contained layers of broken stone or gravel over compacted soil. An abiding question has been: Do the larger sizes or the smaller sizes serve better on the bottom? Tresagruet, Telford, and MacAdam systems evolved. The so-called waterbound macadam base was abandoned in Kentucky in the mid-1950's and was supplanted by dense-graded aggregate. Voids in the macadam base, together with inadequate filter courses over the soil, incomplete choking with fines, and trench-type construction (soil shoulders) impounded water under the pavement. Heavy loads squeezed mud up and through the macadam base. On the very first section of the Watterson Expressway (a two-lane road, southward from US 60), dense-graded aggregate was used on top of and under waterbound. The Kentucky Turnpike consisted of 9 inches of portland cement concrete on 4 inches of dense-graded aggregate that extended through the shoulders and daylighted on the embankment slopes. This type of cross section was used on most interstate routes in Kentucky. Crowning the subgrade encouraged lateral drainage. Dense-graded aggregate could be planed easily with a grader or spread and shaped with other machinery.

This project was intended to provide evaluations of aggregate gradations that might be alternates to or supplant dense-graded aggregates. It was planned cooperatively with the Kentucky Crushed Stone Association's Technical Committee. The Committee desired evaluation of coarser and more freely draining gradations than the currently used dense-graded aggregate.

The KY 627 Winchester-Boonesboro Road was planned to study variations of gradations for dense-graded aggregate and the effects on pavement performance and load-carrying capacity. The project was planned cooperatively with the Kentucky Crushed Stone Association.

Construction activities were monitored and instrumentation installed to measure rutting and to weigh vehicles in motion. Data relative to gradation and compaction were obtained. Deflection measurements were obtained using both the Road Rater and the Benkelman beam. All measurements of densities and deflections were obtained at randomly selected locations.

Deflection measurements were obtained on the completed base and on the finished pavement soon after paving was completed. A series of deflection measurements also were obtained six years after completion of paving.

Automatic traffic counting devices were installed, but data-retrieval devices did not function properly. Thus, specific traffic colume data were not available. It was anticipated that vehicle weight data would be obtained using the weigh-in-motion system. Unfortunately, heavily loaded coal-hauling vehicles damaged the scale system, and little meaningful data were obtained relative to vehicle weights.

GRADATIONS

No particular gradation theory *(1, 2)* was brought to bear or guided the selections of base aggregates. At the beginning, three aggregate gradations were chosen for preliminary evaluation by laboratory testing. Each was prepared to contain three variations of the finer portions: coarse, medium, and fine (sometimes designated as high, medium, and low). These are shown in Figures 1, 2, and 3. Boundaries of maximum density gradations encompasing those maximum sizes are shown in Figure 4. These were checked for density (AASHTO T 180) in both the Research Laboratory and the Materials Laboratory. Those data are given in Table 1.

Gradation No. 1 is the 1976 standard for dense-graded aggregate. It is a broad-based gradation. The median gradation should approximate a straight line. The band widths are merely tolerances about the median. Wide deviations may be allowed if the gradation approximates a straight line. Stepping from one boundary across the median to the other side leads to gap gradings that often behave unpredictably, segregate, and are otherwise unmanageable. Gradations deficient in fines tend to degrade and produce more fines during compaction. Densities after compaction may approach a common value. Results of triaxial and permeability tests are given in Table 2 and in Figures 5 and 6. Differences were not significant. Nevertheless, gradations were chosen for construction.

TEST SECTIONS

The layout and deployment of sections is given in Figure 7. Base construction began April 12, 1976. Paving was completed August 1, 1976.

Pavement thicknesses were designed on the basis of CBR 9 (shaly rock subgrade). Although considerable amounts of shale and shaly limestone went into the rock subgrade, all of the subgrade equalled or far exceeded CBR 9. Two sites suspected of containing too much shale were surveyed and tested. The lowest CBR was 11.1.

Gradation variables were merged with structural variables. The basic design was for 5.5 inches of asphaltic concrete over 9.5 inches of dense-graded aggregate base. A sand-asphalt surface (5/8 inch) was not credited with

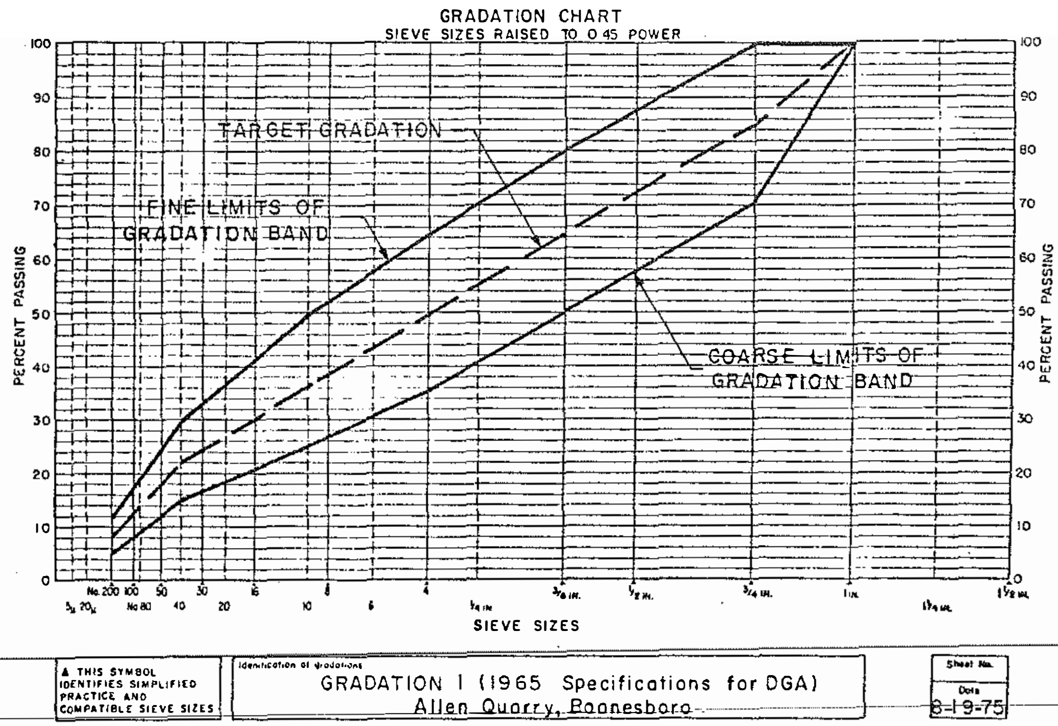


Figure 1. Gradation 1; Dense-Graded Aggregate, 1965 Specifications; Used in Sections 1, 5, 9 and 10; KY 627, Boonesboro-Winchester.

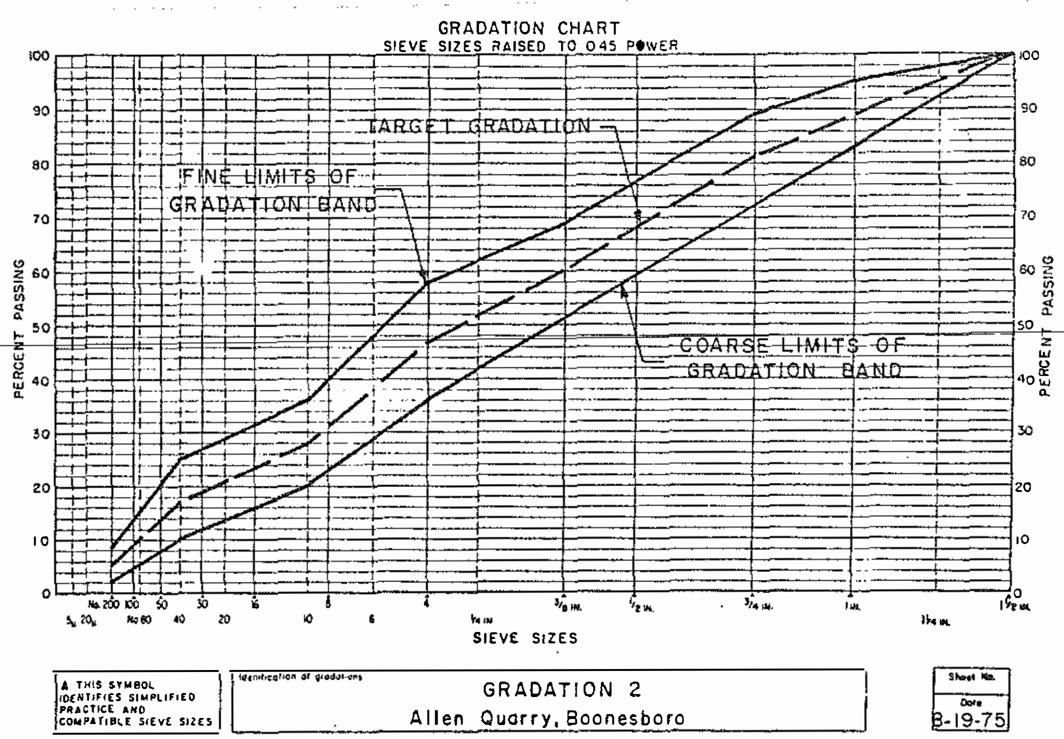


Figure 2. Gradation 2; Using 1½-inch Maximum Size Aggregate; Used in Sections 2, 4, 6, and 7; KY 627, Boonesboro-Winchester.

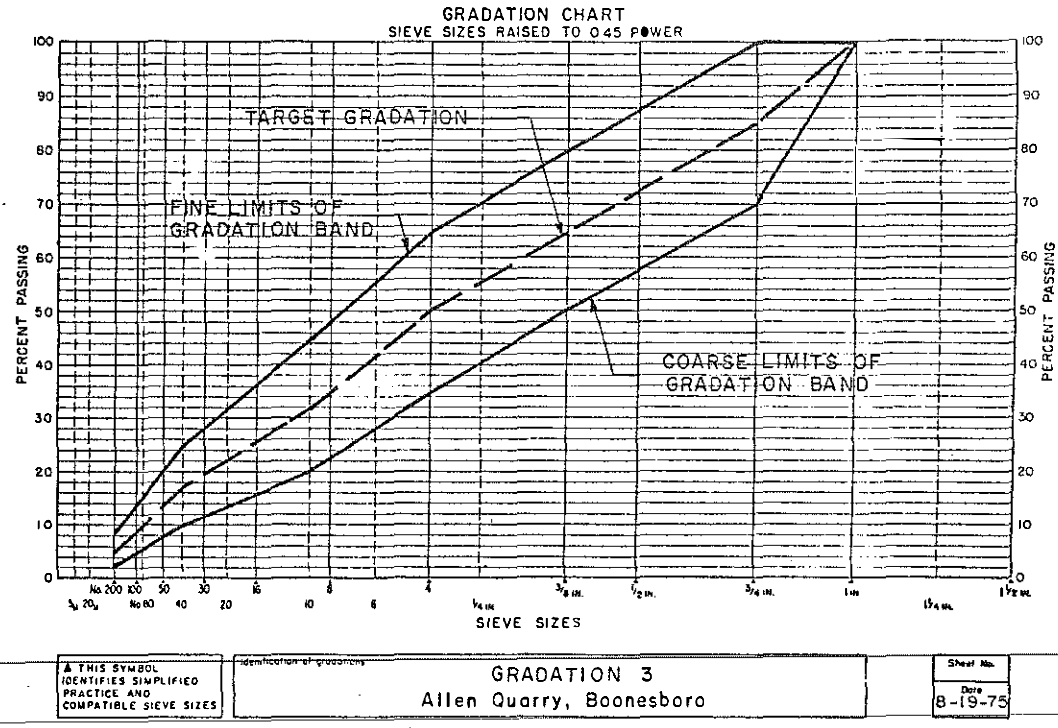


Figure 3. Gradation 3; Using 3/4-inch to 1-inch Maximum Size Aggregate and Reduced Fines; Used in Sections 3 and 8; KY 627, Boonesboro-Winchester.

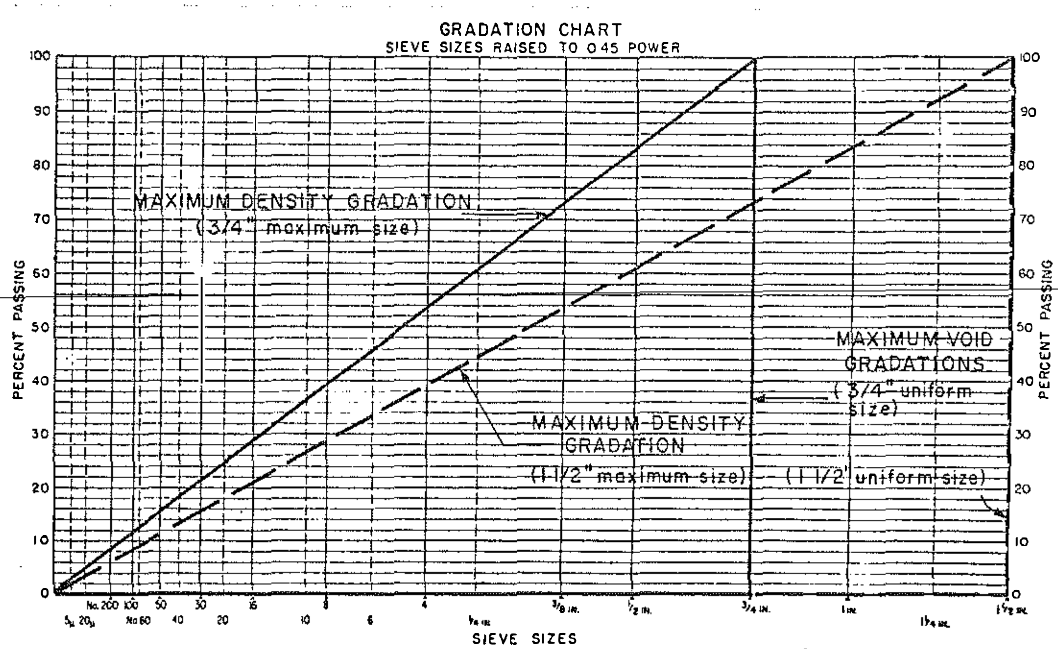


Figure 4. Maximum Density Gradation Limits Utilizing 3/4-inch and 1½-inch Maximum Size Aggregate. Maximum voids would be achieved by single-sized particles (vertical lines on graph).

TABLE 1. LABORATORY MOISTURE-DENSITY TEST RESULTS
(KY 627, WINCHESTER-BOONESBORO ROAD)

GRADATION		AASHTO T 180(D)					AASHTO T 99			
		TRANSPORTATION RESEARCH PROGRAM			DIVISION OF MATERIALS		DIVISION OF MATERIALS[a] (-3/4-in. MATERIAL)		TRANSPORTATION RESEARCH PROGRAM[b]	
UMBER	CONTENT OF FI ES	MAXIMUM DRY DENSITY (lb/ft³)	OPTIMUM MOISTURE CONTENT (%)	THEORETICAL SOLID VOLUME (%)	MAXIMUM DRY DENSITY (lb/ft³)	OPTIMUM MOISTURE CONTENT (%)	MAXIMUM DRY DENSITY (lb/ft³)	OPTIMUM MOISTURE CONTENT (%)	MAXIMUM DRY DENSITY (lb/ft³)	OPTIMUM MOISTURE CONTENT (%)
1	High	144.2	6.1	87.4	147.9	4.7	147.9	4.8	135.0	3.6
	Medium	149.6	4.2	90.7	149.0	4.2	149.0	3.3	140.8	6.8
	Low	149.5	5.4	90.6	151.0	5.1	147.9	3.9	141.2	6.7
	Average[c]	148.4	4.7							
2	High	147.7	5.9	89.4	147.9	5.3	146.9	5.6	140.4	6.5
	Medium	149.9	4.7	90.7	151.0	5.2	147.9	5.1	141.6	6.5
	Low	147.1	5.5	89.0	150.0	4.6	145.9	4.1	141.4	6.1
	Average[c]	148.3	5.1							
3	High	145.7	6.5	88.3	147.9	6.0	146.9	4.3		
	Medium	148.2	4.5	89.8	147.9	5.1	145.9	5.8		
	Low	146.6	4.3	88.9	147.9	6.3	149.0	5.8		
	Average[c]	147.3	5.4							
-3/4" Maximum Density Gradation		148.9	4.4							
1-1/2" Maximum Density Gradation		150.4	4.5							

[a]Arnall, D. L.; "DGA Base for Project RF 167(13), Clark and Madison Counties," Memorandum Report to Director of Materials, Kentucky Department of Transportation, November 25, 1975.

[b]Allen, D. L.; "Engineering Properties of Six Dense-Graded Aggregates," Memorandum Report, Division of Research, Kentucky Department of Transportation, April 1974.

[c]Average of all AASHTO T 180(D) test data.

TABLE 2. OTHER PHYSICAL PROPERTIES OF AGGREGATES (KY 627, WINCHESTER-BOONESBORO ROAD)

GRADATION			STRENGTH PARAMETERS	
NUMBER	CONTENT OF FINES	PERMEABILITY (ft/day)	COHESION (lbs/sqft)	ANGLE OF INTERNAL FRICTION (°)
1	High	0.052	0	53
	Medium		16.1	56
	Low		0	53
2	High	0.082	0	53
	Medium		0	53
	Low		0	57
3	High	0.141	0	53
	Medium		12.5	56
	Low		0	53

		CALIFORNIA BEARING RATIO[a]	
		+3/4" MATERIAL	-3/4" MATERIAL
"Old" DGA	High	140	76
	Medium	149	82
	Low	183	121
	Average[b]	125	
"Old" DGA Modified	High	134	160
	Medium	205	119
	Low	274	225
	Average[b]	186	
"New" DGA	High	143	134
	Medium	238	125
	Low	197	176
	Average[b]	169	

[a]Data reported by Division of Materials, November 25, 1975, D. L. Arnall; Kentucky Method 64-501-68.

[b]Average of all CBR's for gradation.

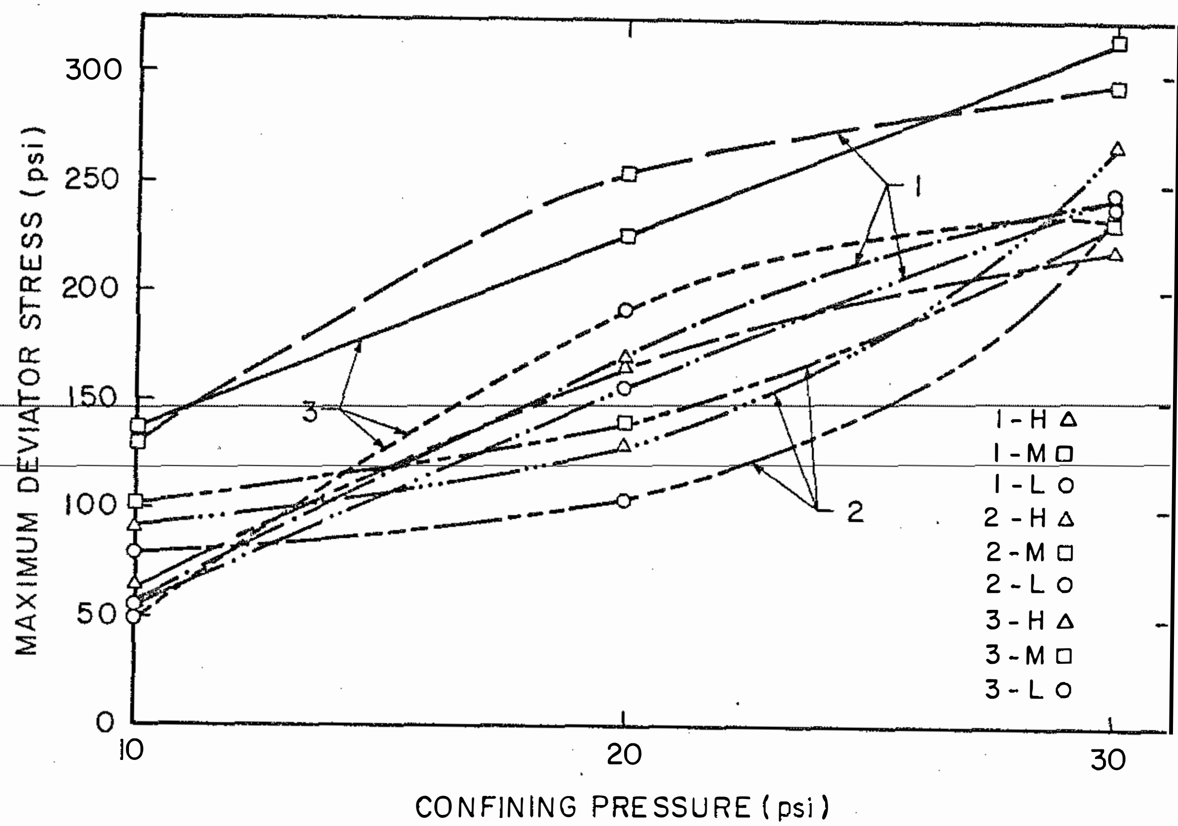


Figure 5. **Maximum Deviator Stress from Triaxial Tests as a Function of Confining Pressures; All Gradations.**

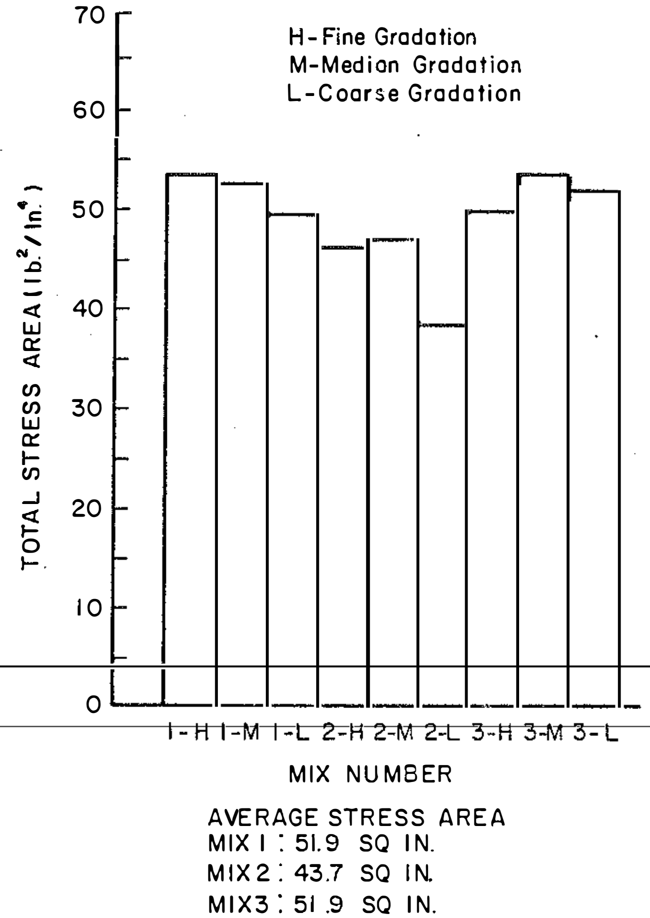


Figure 6. Relative Strengths of the Three Gradations with High and Low Variations; Based on Triaxial Shear Tests. Bar graph shows areas under maximum deviator stress-strain curve.

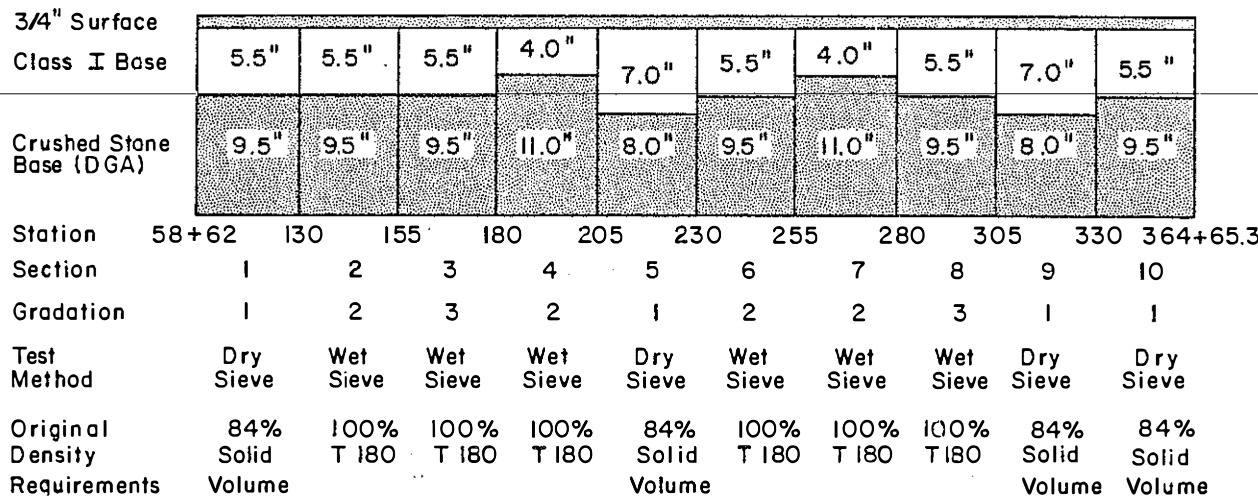


Figure 7. Layout of Test Sections on KY 627, Boonesboro-Winchester.

strength. The 5.5 inches of asphaltic concrete were increased 1.5 inches and decreased 1.5 inches in the experimental sections. The total thickness of pavement structure was kept constant. Sections 1 and 10 are twin control sections; but Sections 2, 3, 6, and 8 should be equal to them structurally.

A consideration of the time pertained to excesses of fines or dust in standard dense-graded aggregate when controlled in the field by dry-sieving. In some instances, so much dust clung to coarser particles that density could not be achieved. The excesses were discovered by wet-sieving . About 7 or 8 percent passing the No.-200 sieve has been considered optimum. In Figure 7, notations indicate the method of controlling that part of the gradations on construction.

Densities and triaxial tests on a series of gradations similar to those already reported were reported to the Division of Materials in the spring of 1974. The source of aggregate was not identified. The oven-dry specific gravity is the same as that of the Allen Company's stone used on KY 627. Those data along with explanatory footnotes are given in Tables 3 and 4.

Spreading and compacting procedures agreed upon at the preconstruction conference were not followed in construction. Density growth curves could not be developed accurately. Rolling patterns were irregular. Results are shown in Figure 8. Densities, otherwise, are shown in Figure 9. Official construction values are shown separately in Figure 10. Eighty-four percent of theoretical solid volume density was not achieved in Sections 6, 7, and 8. Change orders were approved. It was recommended that acceptance be based on percentage of compaction rather than on solid volume. It also was recommended that the standard (target) density be established by trial (test strips) on the site. This would have required strict obedience to a set (approved) rolling pattern and monitoring compliance on a control chart. Confusion arose from the contractor's use of patrol graders and planers during placement and after density tests had been made final.

STRUCTURAL ANALYSES

Benkelman beam deflections (Figure 11) were taken on the aggregate bases and on the asphalt surface (May 6 and 7, and September 21, 1976). Those data are available for future performance evaluations but will not be evaluated in this report. Road Rater measurements were made on the subgrade (August 25, 1975), on the crushed stone bases (May 6 and 7, 1976), and on the surface (September 21, 1976) (Figure 12).

Road Rater testing and analyses serve to deduce remaining life-expectancy. Differences among sections may be explained entirely by the thicknesses of asphaltic concrete. Deflection data were obtained at various stages of construction. Interim deflection data will not be presented in this report. However, those data will be maintained for future performance evaluations. Deflection data obtained September 21, 1976, on the finished pavement sections were analyzed using elastic theory. Pavement behavior is expressed as an effective thickness of reference-quality asphaltic concrete on the as-constructed thickness of dense-graded aggregate for an estimated subgrade strength that results in a theoretical deflection bowl best duplicating the measured deflection bowl. Estimates of the effective pavement behavior and potential fatigue life are presented in Table 5 and Figure 13. Deflection data were also obtained at those same locations on October 28, 1982. Analysis procedures were identical. A summary of the results from those data is presented in Table 6 and Figure 14. Estimates of the

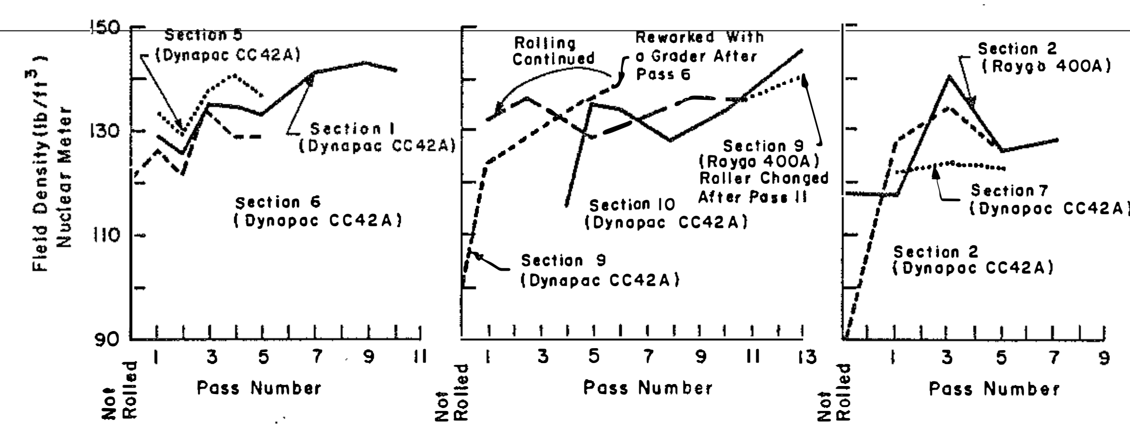


Figure 8. Roller Passes versus Density (Density Growth Curves); Three Sites on KY 627, Boonesboro-Winchester.

TABLE 3. GRADING AND BULK OVEN-DRY SPECIFIC GRAVITY OF 1974 SERIES OF SAMPLES

SIEVE FRACTION	SAMPLE NUMBER AND PERCENT OF EACH FRACTION					
	#1C	#1F	#1M	#2C	#2F	#2M
1-1/2" - 1"	20.0	0	10.0	0	0	0
1" - 3/4"	15.0	5.0	10.0	30.0	0	12.0
3/4" - 3/8"	21.0	17.0	19.0	20.0	20.0	23.0
3/8" - #4	14.0	18.0	16.0	15.0	15.0	15.0
#4 - #8	9.0	15.0	12.0	8.8	12.6	10.2
#8 - #50	15.0	27.0	21.0	13.6	27.4	20.5
#50 - #200	4.0	8.0	6.0	6.6	5.0	8.3
-#200	2.0	10.0	6.0	6.0	20.0	11.0
Specific Gravity	2.66	2.63	2.65	2.65	2.63	2.64

NOTE: Make an approximately 10,000-gram sample of each of the above six gradings. If re-use of aggregate is necessary, the above fractions (except -#200) should be prepared by washing over the 1", 3/4", etc. sieves. (The aggregate sizes furnished (exclusive of -#200) had been thoroughly washed over the sieves on which they were retained. Due to subsequent disintergration of some shale present in the aggregate samples, the various fractions may contain a very small quantity of undersized particles. It is not felt that undersized particles introduced are sufficient to be of significance; therefore, no re-screening was necessary.)

Determine for *each* of the six gradings:
(1) T 99 Maximum Density, Optimum Moisture, and Percent Solids
(2) Permeability of each at T 99 Density
(3) Triaxial Strength at T 99 Density (saturated and at 10 psi or other lateral pressure, if necessary)

Determine for *one* of the six gradings:
(1) T 180 Maximum Density, Optimum Moisture, and Percent Solids
(2) Permeability at T 180 Density
(3) Triaxial Strength at T 180 Density (same moisture condition and lateral pressure as above)

If feasible, determine triaxial strength of *one* grading compacted such that the percent of solids is in the range of 84.0 to 84.5 percent. Use that grading that yielded the highest percent of solids.

TABLE 4. SUMMARY OF TEST RESULTS FROM 1974 SERIES OF SAMPLES

SAMPLE NUMBER	MAXIMUM DRY DENSITY (lbs/ft^3)	OPTIMUM MOISTURE CONTENT (%)	PERCENT SOLIDS	PERMEABILITY (feet/day)	SHEAR STRENGTH* (psi)
T 99(D) Compaction					
1C	135.0	3.6	81.3	101.0	49.9
1M	140.8	6.8	85.1	1.40	63.5
1F	141.2	6.7	86.0	0.26	108.2
2C	140.4	6.5	84.9	0.61	91.5
2M	141.6	6.5	85.9	0.13	96.0
2F	141.4	6.1	86.2	0.01	79.5
T 180(D) Compaction					
2M	151.0	4.6	91.7	0.05	65.6
Less than T 99(D) Compaction**					
2F	138.3	---	84.3	---	33.9

*Unconsolidated undrained (saturated specimen) triaxial test with lateral confining pressure of 10 psi. Strain rate of 0.002 inch per minute. No pore-pressure measurements.

**Each of the three layers were compacted with approximately 80 percent of the compactive effort of T 99.

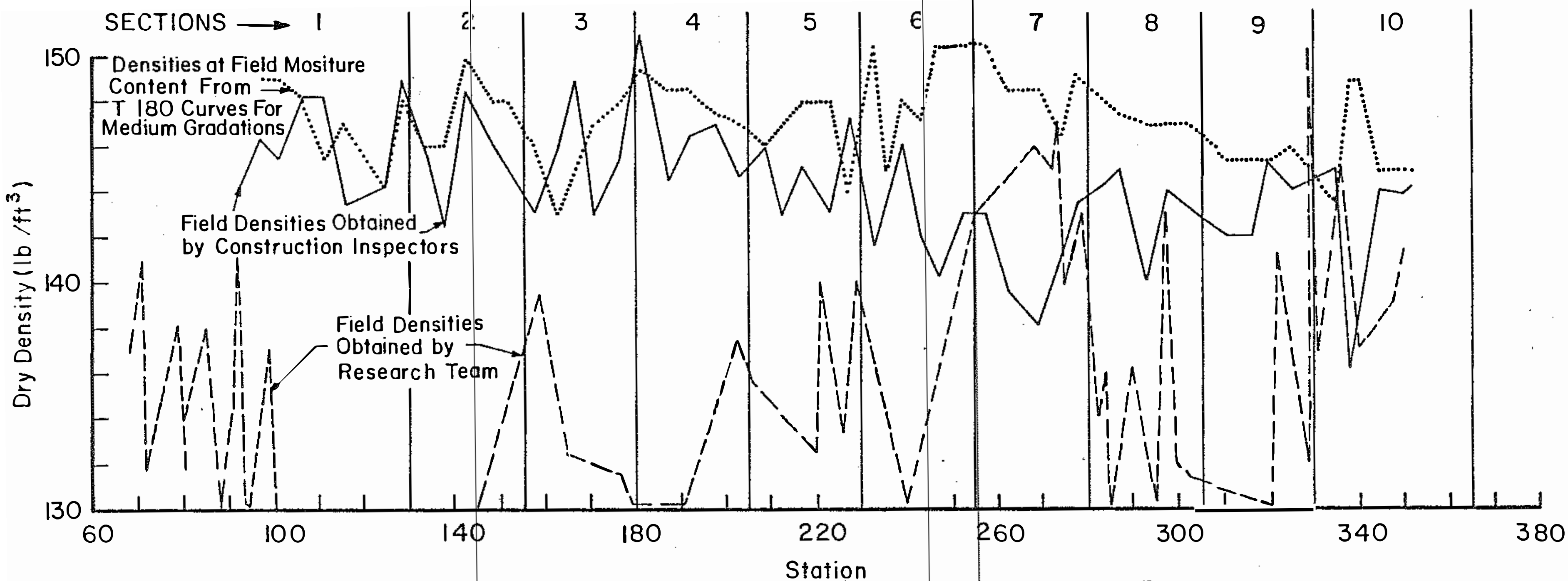


Figure 9. Control Chart for Density; All Sections; All Testing; KY 627, Boonesboro-Winchester.

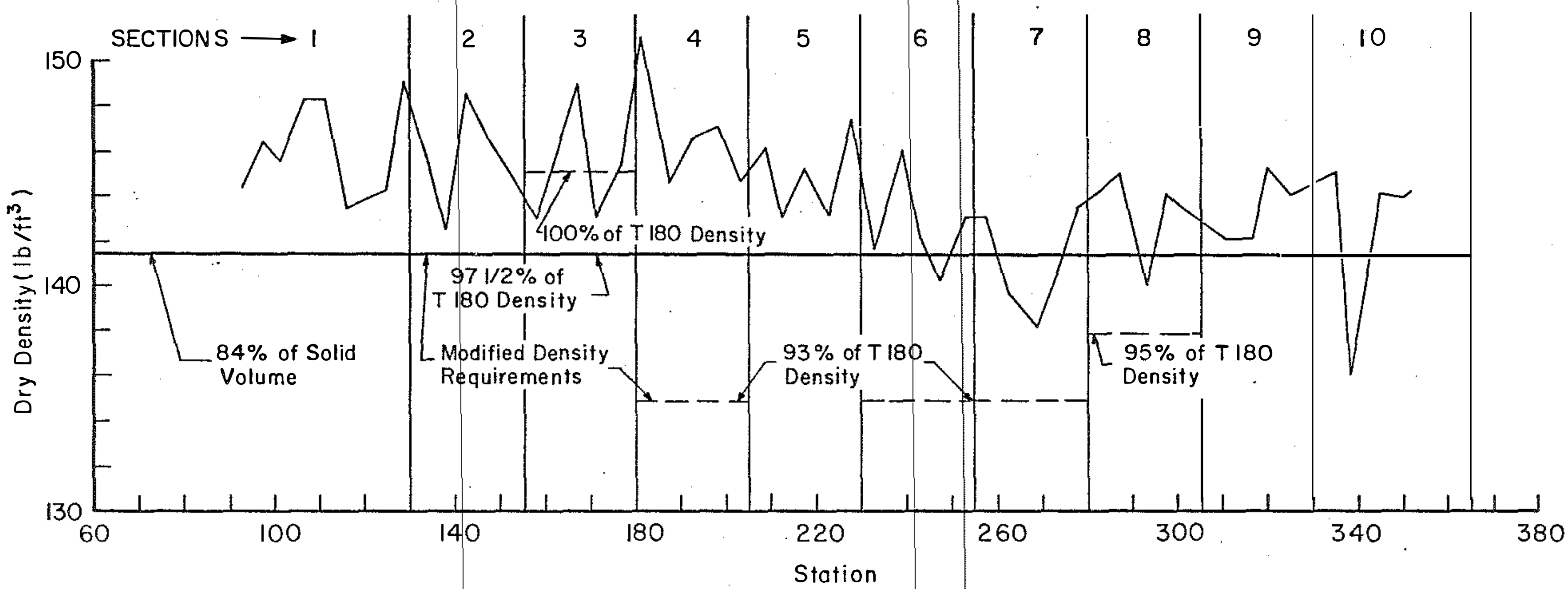
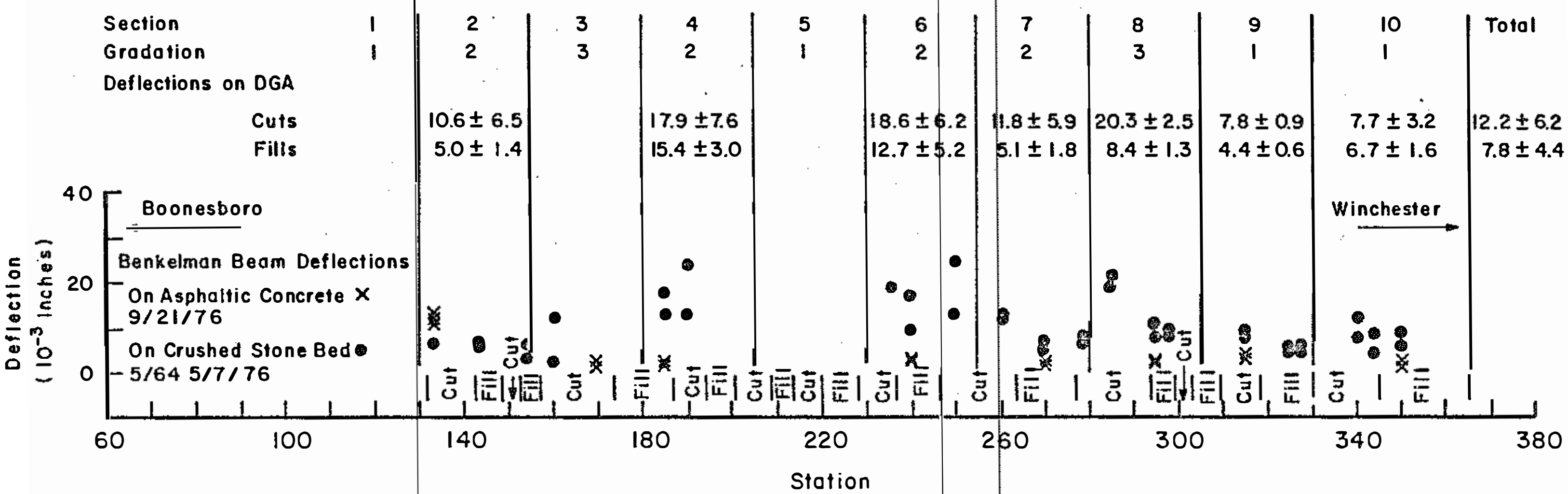


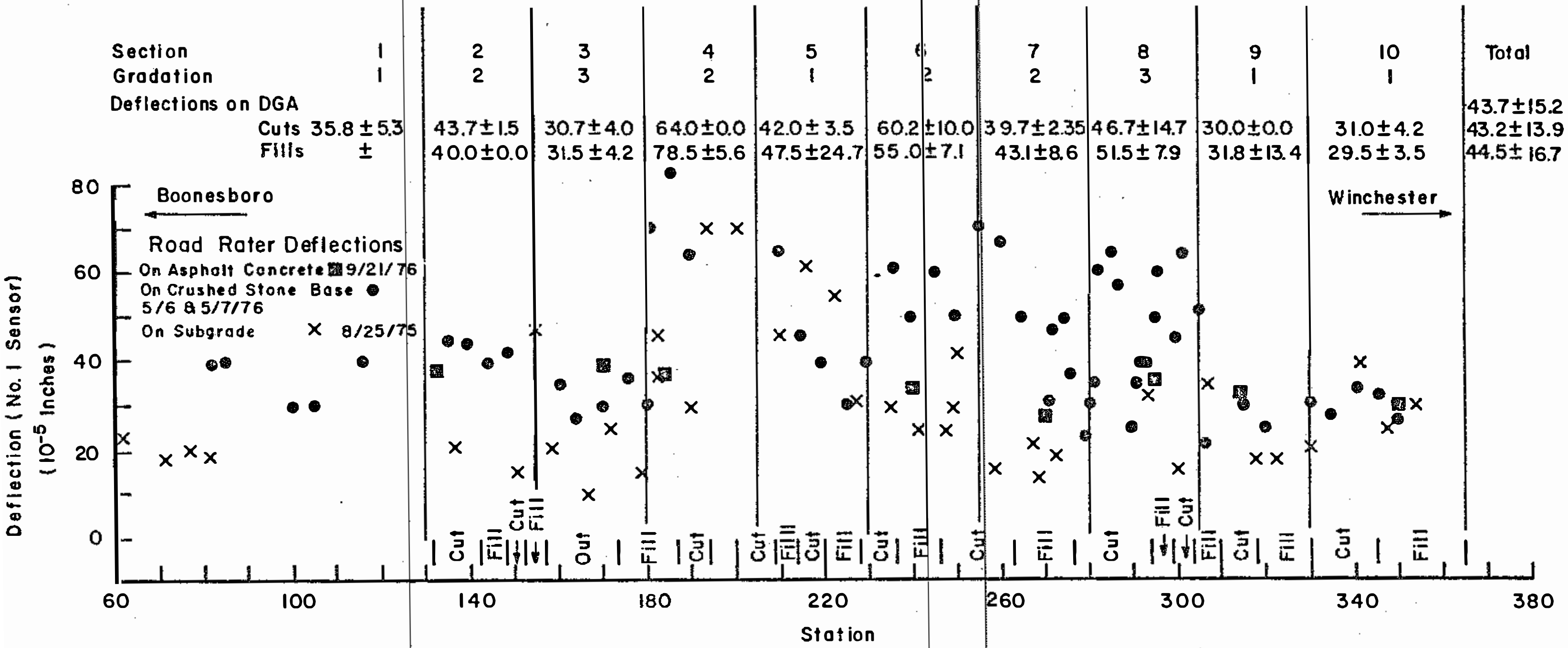
Figure 10. Control Chart Showing Bases of Densit Acceptance; KY 627, Boonesboro-Winchester. Change orders admitted other than originally planned requirements.



SUMMARY OF BENKELMAN BEAM DEFLECTIONS (10^{-3} inches)

	CUTS	FILLS	TOTAL
DEFLECTIONS ON CRUSHED STONE BASE			
8-inch Thickness	7.8±0.9	4.4±0.6	5.6±2.0
9-1/2-inch Thickness	12.5±7.0	7.7±3.4	10.2±6.0
11-inch Thickness	13.8±6.5	10.3±6.3	12.4±6.3
Gradation 1	7.8±2.5	5.1±1.4	6.4±2.4
Gradation 2	14.5±6.5	8.6±5.3	12.5±6.4
Gradation 3	13.7±8.7	8.5±1.3	11.1±6.4
Overall	12.2±6.2	7.8±4.4	

Figure 11. Benklemen Beam Deflections; KY 627, Boonesboro-Winchester.



SUMMARY OF ROAD RATER DEFLECTIONS (10^{-5} inches)

	CUTS	FILLS	TOTAL
DEFLECTIONS ON ASPHALTIC CONCRETE	38.3±0.4	33.3±3.8	34.5±4.0
DEFLECTIONS ON CRUSHED STONE BASE			
8-inch Thickness	39.0±6.6	37.0±17.2	37.8±13.4
9-1/2-inch Thickness	42.2±12.8	43.0±11.9	42.5±12.5
11-inch Thickness	50.8±22.4	53.4±19.0	52.3±19.5
Gradation 1	35.6±5.9	35.1±15.0	35.7±10.4
Gradation 2	50.5±15.3	52.4±16.3	51.8±15.2
Gradation 3	41.4±14.6	44.2±11.8	42.3±13.4
Overall	43.2±13.9	44.5±16.7	43.7±15.2
DEFLECTIONS ON SUBGRADE	26.9±13.6	35.8±18.7	30.9±16.5

Figure 12. Road Rater Deflections; KY 627, Boonesboro-Winchester.

TABLE 5. SUMMARY OF STRUCTURAL EVALUATION, SEP 21, 1976
KY 627, BOONESBORO-WINCHESTER ROAD, CLARK COUNTY

SECTION	CONSTRUCTED THICKNESS (inches)	MEAN BEHAVIORAL THICKNESS OF ASPHALTIC CONCRETE (inches)	MEAN BEHAVIOR OF SUBGRADE MODULUS (psi)	MEAN BEHAVIOR OF SUBGRADE CBR	WORST EXPECTED CBR
1	6.25 AC 9.5 DGA				
2	6.25 AC 9.5 DGA	3.9 AC 9.5 DGA	37,970	25.3	15.2
3	6.25 AC 9.5 DGA	4.1 AC 9.5 DGA	32,790	21.9	13.1
4	4.75 AC 11.0 DGA	2.4 AC 11.0 DGA	44,770	29.9	17.9
5	7.75 AC 8.0 DGA				
6	6.25 AC 9.5 DGA	3.2 AC 9.5 DGA	42,870	28.6	17.1
7	4.75 AC 11.0 DGA	2.0 AC 11.0 DGA	53,160	35.4	21.3
8	6.25 AC 9.5 DGA	3.9 AC 9.5 DGA	50,500	33.7	20.2
9	7.75 AC 8.0 DGA	5.5 AC 8.0 DGA	43,190	18.8	17.3
10	6.25 AC 9.5 DGA	3.7 AC 9.5 DGA	58,630	39.1	23.4

Note: AC – Asphaltic Concrete Pavement
DGA -- Dense-Graded Aggregate Base

loss in fatigue life are presented in Table 7.

The middle portion of Table 7 presents data for the initial structural evaluation after completion of the project. At that time, the pavement was curing and deflection measurements were highly variable. This may be noted when comparing estimates of fatigue life with design values. On the other hand, situations may be encountered where the design CBR or subgrade strength is much less than the actual worst expected subgrade condition. Therefore, deflection measurements may indicate a fatigue life greater than design expectations.

The third portion of Table 7 presents data for the most recent structural evaluations. The column to the far right, "Remaining Fatigue Life" is the fatigue life associated with the most current deflection testing series. It should be noted that the remaining life stratifies according to thickness of asphaltic concrete. Thicker layers of constructed asphaltic concrete result in greater fatigue life for similar subgrades. Variations in remaining fatigue life for the same layer thicknesses may be associated with variations in subgrade strength and more remotely with variations in gradation of the dense-

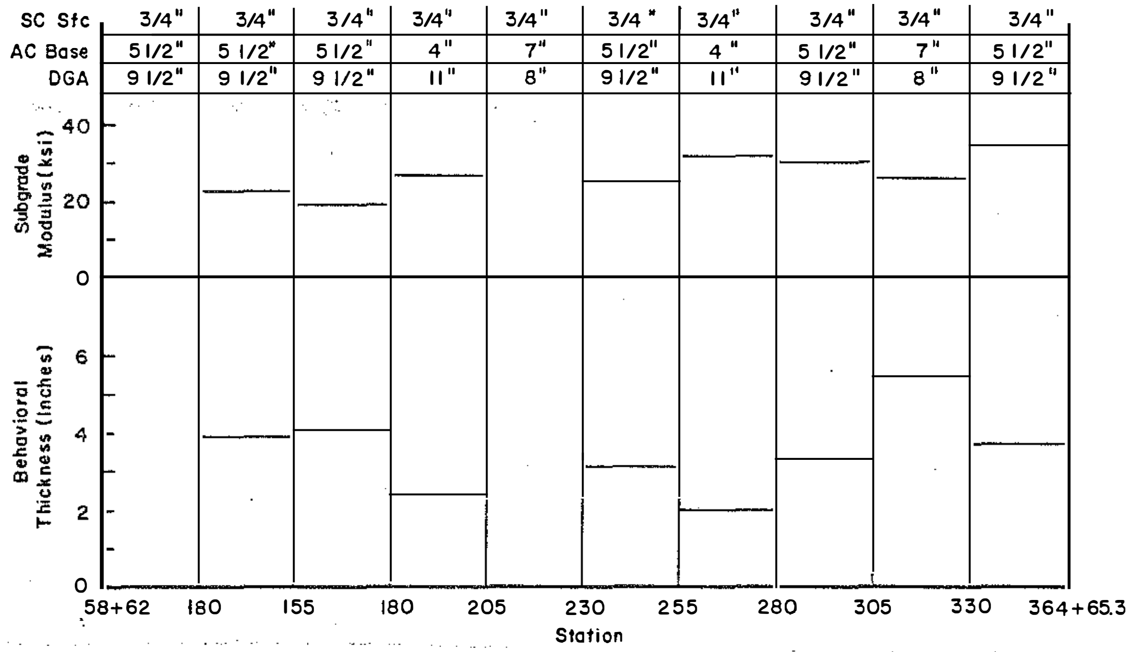


Figure 13. Strip Map Presenting Results of Deflection Analyses, by Section; KY 627, Boonesboro-Winchester; September 21, 1976.

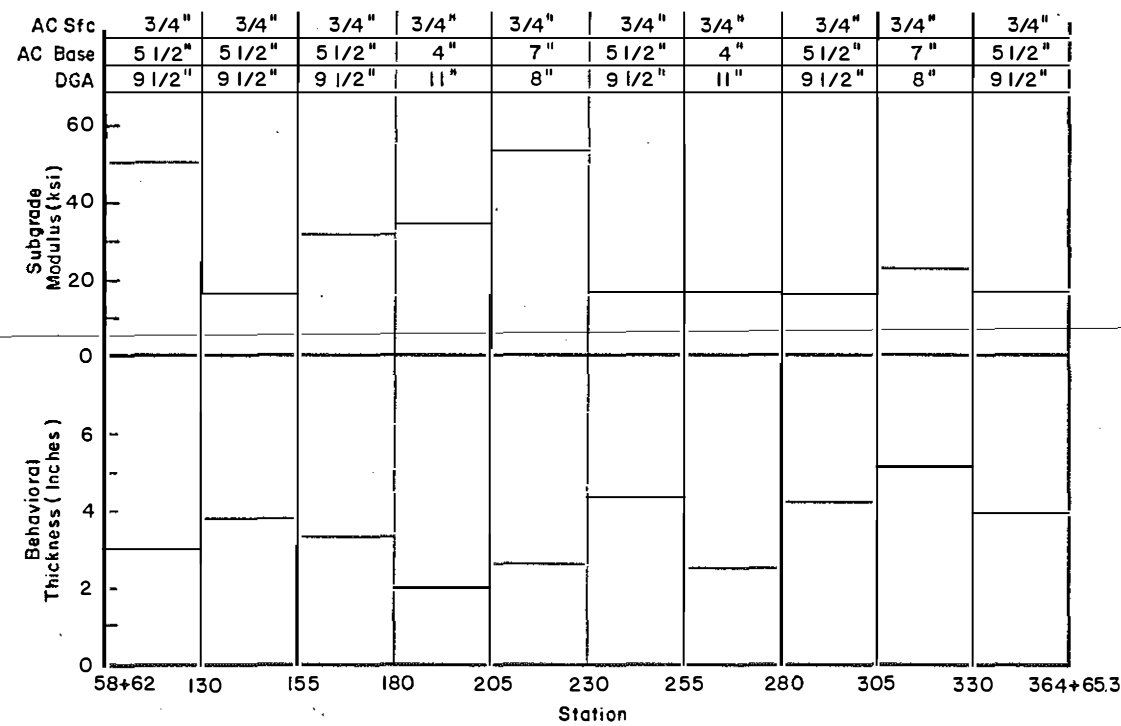


Figure 14. Strip Map Presenting Results of Deflection Analyses, by Section; KY 627, Boonesboro-Winchester; October 28, 1982.

TABLE 6. SUMMARY OF STRUCTURAL EVALUATION, OCT 28, 1982
KY 627, BOONESBORO-WINCHESTER ROAD, CLARK COUNTY

SECTION	CONSTRUCTED THICKNESS (inches)	MEAN BEHAVIORAL THICKNESS OF ASPHALTIC CONCRETE (inches)	MEAN BEHAVIOR OF SUBGRADE MODULUS (psi)	MEAN BEHAVIOR OF SUBGRADE CBR	WORST EXPECTED CBR
1	6.25 AC 9.5 DGA	3.0 AC 9.5 DGA	88,130	55.4	33.3
2	6.25 AC 9.5 DGA	3.8 AC 9.5 DGA	26,470	17.6	10.6
3	6.25 AC 9.5 DGA	3.3 AC 9.5 DGA	52,300	34.9	20.9
4	4.75 AC 9.5 DGA	1.5 AC 9.5 DGA	57,200	38.1	22.9
5	7.75 AC 8.0 DGA	2.6 AC	88,660	59.1	35.5
6	6.25 AC 9.5 DGA	4.4 AC 9.5 DGA	27,820	18.5	11.1
7	4.75 AC 11.0 DGA	2.5 AC 11.0 DGA	44,702	29.8	17.9
8	6.25 AC 9.5 DGA	4.2 AC 9.5 DGA	26,480	17.7	10.6
9	7.75 AC 8.0 DGA	5.1 AC 8.0 DGA	37,860	25.2	15.1
10	6.25 AC 9.5 DGA	3.9 AC 9.5 DGA	27,830	18.6	11.1

Note: AC -- Asphaltic Concrete Pavement
DGA -- Dense-Graded Aggregate Base

graded aggregate.

Pavement behavior from Road Rater deflection analyses was expressed as some thickness of reference quality asphaltic concrete, the constructed crushed stone thickness, and a predicted subgrade strength (modulus of elasticity or CBR). That combination of thicknesses and subgrade strength was representative of the best combination of layer thicknesses and layer strengths that result in deflection measurements most closely approximating measured deflections. Care should be used when interpreting deflection analyses. For example, two series of deflection measurements at the same location may result in two seemingly different deflection patterns. A first test series may indicate a very weak or thin effective asphaltic concrete behavior in combination with a very strong subgrade modulus of elasticity or CBR. On the

TABLE 7. FATIGUE ANALYSIS USING RESULTS OF DEFLECTION TESTING (Tables 5 and 6)
KY 627, WINCHESTER-BOONESBORO, CLARK COUNTY

	DESIGN CONDITIONS					STRUCTURAL EVALUATION SEP 21, 1976			STRUCTURAL EVALUATION OCT 28, 1982		
	THICKNESS (inches)										
	ASPHALTIC CONCRETE										
SECTION	SURFACE	BASE	DENSE-GRADED AGGREGATE	CBR	EAL ($x10^5$)	EFFECTIVE THICKNESS OF ASPHALTIC CONCRETE (inches)	ESTIMATED CBR	EAL ($x10^5$)	EFFECTIVE THICKNESS OF ASPHALTIC CONCRETE (inches)	ESTIMATED CBR	EAL[a] ($x10^5$)
1	0.75	5.50	9.5	9	7.5				3.00	33.3	6.0
2	0.75	5.50	9.5	9	7.5	3.88	15.2	6.0	3.83	10.6	3.0
3	0.75	5.50	9.5	9	7.5	4.08	13.1	4.0	3.34	20.9	6.0
4	0.75	4.00	11.0	9	2.0	2.43	17.9	3.0	2.00	22.9	2.0
5	0.75	7.00	8.0	9	15.0				2.60	35.5	10.0
6	0.75	5.50	9.5	9	7.5	3.15	17.1	4.0	4.36	11.1	3.0
7	0.75	4.00	11.0	9	2.0	2.00	21.3	3.0	2.50	11.0	2.0
8	0.75	5.50	9.5	9	7.5	3.35	20.2	7.0	4.20	10.6	2.0
9	0.75	7.00	8.0	9	1.5	5.50	17.3	20.0	5.10	15.1	10.0
10	0.75	5.50	9.5	9	7.5	3.73	23.4	11.0	3.94	11.1	3.0

[a] Also remaining fatigue life.

other hand, a second test series may indicate stronger asphaltic concrete behavior in combination with a weaker subgrade strength. If the two sets of data are then used as input into Kentucky's flexible design curves, estimates for available fatigue life may be very nearly the same.

TRAFFIC EFFECTS

Weigh-in-motion platforms were installed in the pavement at Station 141 + 50 during construction. Those were operated only a short time; weights exceeded the capacity of the scales and eventually destroyed them. Aggregate was hauled from Boonesboro toward Winchester; and coal was hauled from Winchester toward Boonesboro (Kentucky Utilities power plant at Ford). The weigh-in-motion platforms were installed in the southbound (Winchester-Boonesboro) lane and thus were subjected to the coal-haul traffic. Rutting in wheel paths was anticipated, and linear variable differential transformer devices and miniature settlement gages were inset in the pavement (Station 141 + 50) to measure changes in the surface profile. Those details and analyses were reported separately *(3, 4, 5)*. Rutting of approximately 1.2 inches has been observed in some locations.

Pavement temperatures and air temperatures were recorded continuously from August 1976 to August 1978 *(4, 5)*. That was done in connection with the investigation of rutting.

In conjunction with the instrumentation to measure rutting, samples of crushed stone base material were taken from the road for laboratory testing. Figure 15 shows moisture content versus degree of saturation. Figure 16 shows cohesion and angle of internal friction from triaxial shear tests. Figure 17 shows permanent strain (creep) during 1,000 cycles of loading as a function of degree of saturation. Figure 18 shows the resilient modulus, determined by the resonant column method, as a function of moisture content and confining pressure. Those data and other information related thereto were more expressly reported previously *(3)*. All triaxial shear parameters, densities, permeabilities, and resilient moduli may now be compared to a larger set of data contained in a previous report *(5)*.

It appeared, from the instrumentation installed to measure rutting, that the dense-graded aggregate swelled approximately 1/2 inch during the first winter and did not subside thereafter. That phenomenon also was observed at an instrumented site on KY 55, south of Campbellsville. Subgrade elevation remains unchanged. Frost heave may have occurred. Of the 0.3-inch rutting at Station 141 + 50, approximately half appeared to be in the asphaltic concrete and half appeared to be due to subsidence of the dense-graded aggregate surface.

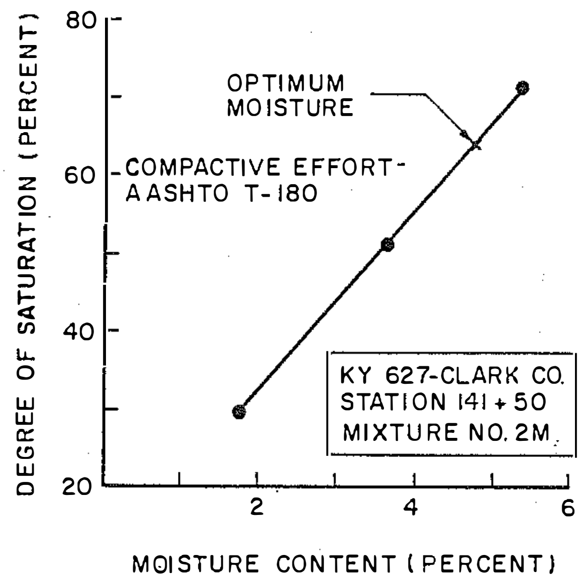


Figure 15. **Degree of Saturation versus Moisture Content, Aggregate 2M, T 180; KY 627, Station 141 + 50; Boonesboro-Winchester.**

It became necessary to do patching (leveling) in the area about Station 141 because of roughness and subsidences. Other maintenance for leveling ruts is anticipated (at the upgrade from Boonesboro).

Traffic and weight data were not included here. On the bases of 10,000 vehicles per week and typical weights from the weigh-in-motion installation before its demise, it was estimated that the accumulation of 18-kip equivalent axleloads had been 2.1 million EAL's in 6.5 years. The design EAL was less than 750,000. Automatic traffic recorders were installed, but malfunctions produced unreliable data. Some manual volume and vehicle classification data were obtained.

Road Rater deflections indicated that the rock subgrade, in place, was effectively equivalent to a mean CBR of about 20. A worst-expected CBR on a 90th-percentile basis corresponds to a CBR of 13. The design CBR was 9.

Both Benkelman beam deflections and Road Rater deflections (Figures 11 and 12) show apparent decreases in stiffness with increasing thicknesses of crushed stone bases having no pavement over them. It may be that the rock subgrade was somewhat stiffer than the crushed stone when the measurements were made. Such behavior also may be, however, the nature of uncovered dense-graded bases. Such apparent contradictions to rationality may be resolved in analyses of Road Rater data taken after completion of the overlying pavement and after time to seat and mature.

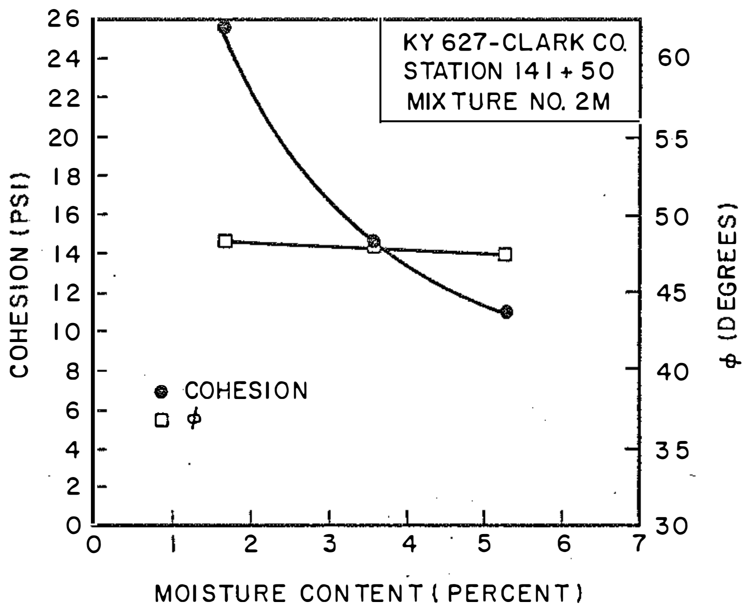


Figure 16. Cohesion, Angle of Friction, and Moisture Content; Gradation 2M, Station 141 + 50; KY 627, Boonesboro-Winchester.

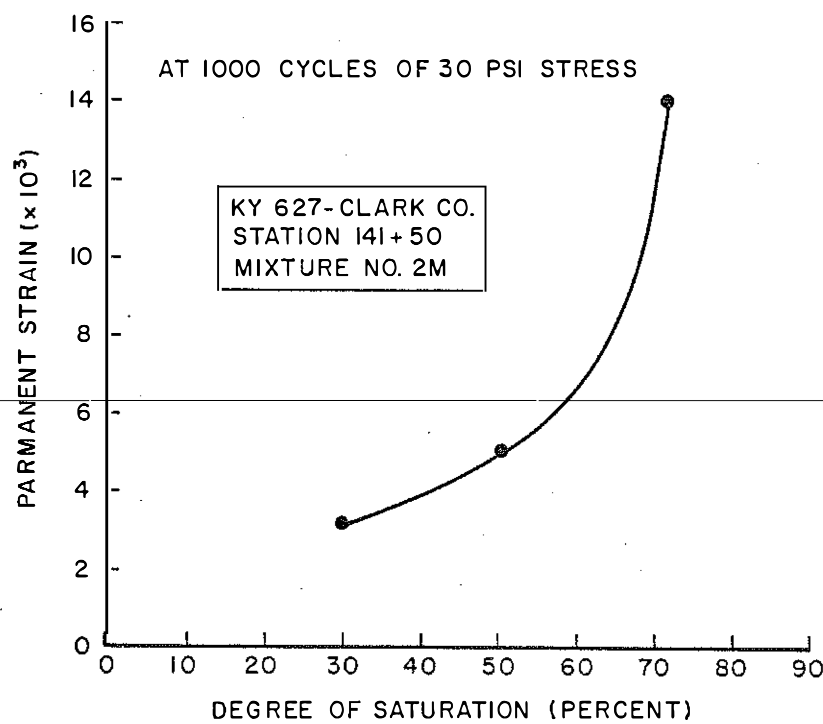


Figure 17. Permanent Strain (Creep) versus Degree of Saturation; Gradation 2M, Station 141 + 50, 1000 Cycles, 30 psi; KY 627, Boonesboro-Winchester.

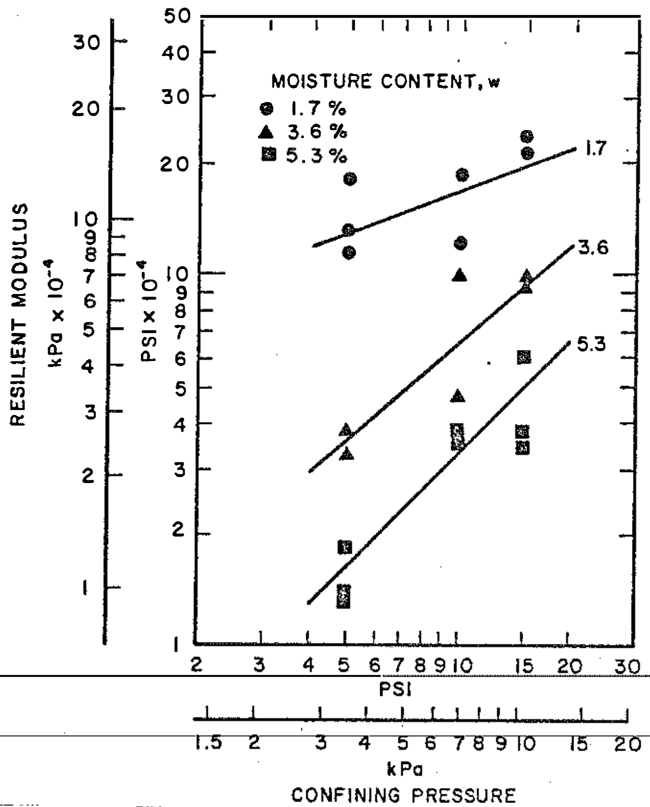


Figure 18. Resilient Modulus versus Confining Pressure, Three Levels of Moisture Contents; KY 627, Boonesboro-Winchester.

The surface course consisted of sand asphalt. Skid-resistance measurements are reported elsewhere *(6)*.

The concrete box culverts at Stations 123 + 95 and 268 + 30 were instrumented with pressure cells and settlement gages during earthwork construction. Those details and findings are given in other reports *(7, 8)*.

SUMMARY AND DISCUSSION

Dense-graded aggregate remains a marvelous product for base courses. It withstands plowing, grading, planing and various abuses sometimes associated with construction activities. It is reasonably resistant to segregation. It is dense and does not drain (percolate) water rapidly. It does perch water on top -- and this may be its worst fault. Tampering with the gradation -- which is not too critical -- may lead to unwanted side effects such as tendencies toward segregation. Moisture content at compaction is critical. At optimum moisture content, a slight sheen of water appears behind roller wheels. Economy in production and convenience in construction are remarkable attributes of this material. Significant differences in Road Rater responses attributable to gradation of base aggregate were not found at KY 627.

Instrumentation on KY 627 indicated 1/2-inch heave or swell at the top of the DGA -- even in the wheelpaths. This may be attributed to frost, or to floatation.

At this time, all analyses have failed to distinguish significant variations in structural behavior that may be attributed to more open gradations. Therefore, it is recommended that conventional gradations continue to be used. This project will continue to be monitored to determine any long-term variations.

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ADDENDUM TO

CRUSHED ROCK BASES
Research Report UKTRP-83-15

DIFFICULTIES ENCOUNTERED

PROBLEMS ASSOCIATED WITH BASE COMPACTION PROCEDURES

Normal granular base construction procedures generally involve placement and shaping of aggregates using spreading and grading equipment. Compaction equipment is then used to compact base materials to desired densities. This process may be repeated for a number of layers until the desired thicknesses of aggregate base is obtained.

It was observed that some sections of aggregate base on the KY-627 project were ploughed deeply (with a grader) behind the spreader box, and some sections were "re-worked" by a patrol grader after final density measurements had been obtained for the particular "lift" of base material. Those observations were random in nature but nonetheless resulted in general concern for quality of compaction efforts for this project. Segregation was likely.

PROBLEMS ASSOCIATED WITH WEIGH-IN-MOTION EQUIPMENT

Weigh-in-motion equipment was installed in the southbound (Winchester-Boonesboro) lane in anticipation of heavily loaded vehicles transporting coal to the Kentucky Utilities facility at Ford. Problems resulted at the installation in the form of heavily loaded vehicles destroying the frames housing the weighing transducers. It was nearly impossible to maintain the weighing facility under those conditions. Therefore, the effort was eventually abandoned pending modification of the frame design and development of weighing transducers capable of accommodating larger loadings. A prototype of a modified frame was developed in-house. Transducers capable of accommodating heavier wheel loadings have not been developed by the manufacturer of the weigh-in-motion equipment used for this study.

Vandalism of equipment also was a problem. Specifically, the electric power metering device was destroyed following one day of data collection when a weight enforcement officer checked several vehicles for possible overload in the vicinity of the weigh-in-motion equipment.

EFFECTS OF PROBLEMS ON STUDY RESULTS

The report indicates constructed gradations of base course aggregate may not have been varied sufficiently to result in measureable variations in pavement performance. Construction of this project on a rock subgrade further limited the sensitivity of structural condition measurements because of the very stiff foundation material. Improper or abnormal placement of aggregate base materials would likely further complicate interpretation of structural evaluation data.

Weigh-in-motion data were to have been used to determine realistic estimates of the dynamic loading applied to the pavement that could be used to estimate accumulated pavement fatigue for the pavement sections. Equipment-related problems prohibited the accumulation of sufficient data for meaningful evaluations. Therefore, problems associated with weigh-in-motion equipment did limit the effectiveness of this study.