Combination Waterbound-Macadam and Dense-Graded Aggregate Base for Flexible Pavements

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This paper is concerned with a flexible base designed primarily to improve the riding qualities of high-type bituminous pavements. Difficulties in control of grades and sections with modern methods of macadam base construction have emphasized needs for effective finishing procedures.

In the project described, an 8-in. base was built in two courses, the lower waterbound macadam being overlain by a dense-graded-aggregate material suitable for spreading and shaping with a power grader. The base was then surfaced with two courses of a hot, bituminous plant-mix.

Observations and measurements showed that the combination could be built satisfactorily; construction entailed more equipment but less manpower for the blade-spread course than for the waterbound macadam; the dense-graded aggregate produced a high base density; and the possibilities for finishing to uniform section were much better with the dense-graded aggregate than with the macadam.

● TRADITIONALLY, the majority of bases in flexible pavement construction in Kentucky have consisted of waterbound macadam. Experience with it carries back over a period of more than 40 yr. Within the past 5 yr., definite design criteria based on subgrade bearing values and prevailing traffic have been developed for thickness. Those criteria, and the research through which they originated, were described earlier.[1]

From the standpoint of load-bearing capacity, pavements of this design have been satisfactory. From the standpoint of riding qualities, however, they have been unsatisfactory, particularly those built recently. Through investigation of many projects built since the war, poor riding qualities were traced to difficulties in maintaining consistent transverse sections during construction of the waterbound-macadam base.

Variations on the base course were, for the most part, reflected in the finished pavement surface. This was so because of the fact that equipment placing each of the overlying bituminous courses traveled upon the course beneath it, beginning with the base. Hence the contour of the finished base had a direct bearing on the contour of the finished surface, unless adjustments of the screed on the bituminous paver could be made to compensate for the unevenness.

Experience showed that it was not feasible to smooth out high and low spots in the base even with so-called leveling or crown-control mechanisms that have been developed for paving equipment. In fact, additional roughness was sometimes introduced through excessive manipulation of controls in an effort to achieve uniformity of crown.

At any rate, since the fault lay in the base, attention was centered on that part of the pavement. Roughness so prevalent now was attributed to several factors which were not represented in prewar construction. Most prominent among these was the speed in placement of base material. The rate has practically doubled in the past 10 yr. As in all other types of construction speed is emphasized and within reason this seems necessary to keep costs as low as possible.

In addition to speed, there were scarcities of personnel and also the increased cost of labor both for controlling the sections and for applying the hand work necessary to maintain uniformity in surface contour of macadam containing very-coarse aggregates.

In view of all these conditions, it was evident that any means for overcoming the problem must be mechanized and essentially elimi-

[1] Baker, R. F., and Drake, W. B., "Investigation of Field and Laboratory Methods For Evaluating Subgrade Support in the Design of Highway Flexibile Pavements," Proceedings, Highway Research Board, Vol. 28, 1948.

nate hand labor. Also, it must carry forward in such a way that measurements for control could be kept at a minimum. However, since some irregularities resulting from fast-moving construction were almost inevitable, the procedure should be such that those flaws detected could be smoothed out easily. Finally, all the other desirable attributes, including strength or stability of the base, must be maintained.

DESIGN

The project, which was only 1.1 mi. in length, essentially provided a connecting link between two principal highways, at the edge of an urban area, just south of Lexington. Finished pavement width was 30 ft., and thickness design for the pavement was based on the CBR method developed several years ago and applied to the flexible-pavement-design evaluation carried out in 1948.

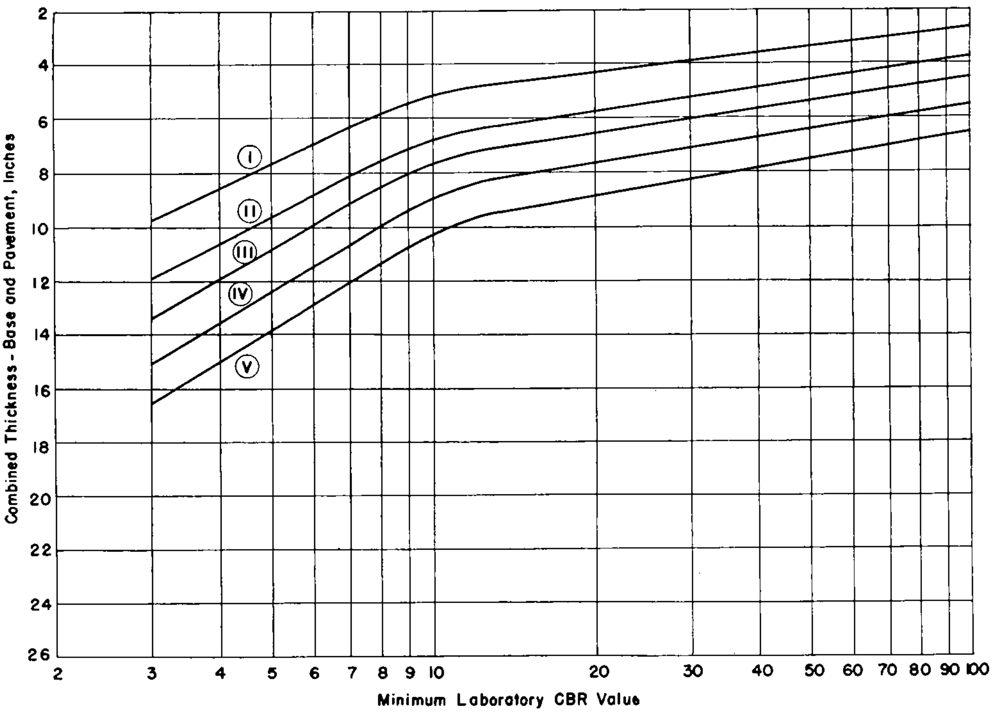

Figure 1. Flexible-pavement design curves.

One of the approaches which has been made by the Kentucky Department of Highways to overcome roughness is a combination base in which the waterbound macadam was retained as a foundation and topped with a dense-graded crushed aggregate small in top size. This paper gives a description of the first of four projects with combination bases that were in the construction program this past year and describes some of the data which have been obtained from observations and measurements on the project.

From the 1948 investigation of subgrade bearing values beneath pavements in service, the curves shown in Figure 1 were developed. These are used for standard flexible pavement design by the Kentucky Department of Highways. The five curves represent five groupings of traffic in equivalent 5,000-lb. wheel loads. Anticipated traffic on the project under consideration fell in Class V. Minimum measured CBR was 6.5, and average of all samples taken before construction was 9.3. General distribution of bearing values was typical of variations encountered on most projects throughout the state, but the range of values was somewhat higher than the average for the state. In this instance greater than usual weight was placed on the minimum CBR, and

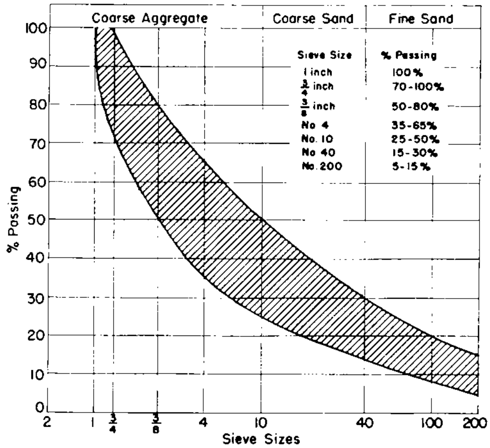

Figure 2. Aggregate gradation range for dense-graded base courses.

the design thickness was 11¾ in. made up of the following:

2¾ in. of asphaltic concrete
4 in. of dense-graded aggregate
4 in. of waterbound macadam
1 in. of insulation or leveling over the subgrade

11¾ in.—Total

Actually the design could be considered conservative since the average CBR for tests taken during construction indicated bearing values still higher than the average of 9.3 determined before construction was started.

The gradation range of the dense-graded aggregate specification is shown in Figure 2. One-hundred percent passes the 1-in. screen with 5 to 15 percent passing the No. 200. In many instances this material can be produced crusher-run, particularly where the plant includes a hammer mill. However, for this project, as will be seen later, two separate aggregates were combined to provide this gradation. It was recognized that a high moisture content was necessary for shaping and compaction of the dense aggregate base. Also, completed sections would be vulnerable to raveling under construction traffic unless the moisture content was kept high. For that reason, specifications required application of calcium chloride to each of the courses of dense-graded material. There was no specified requirement for watering other than a general statement that water should be applied as directed by the engineer. Actually this received a great deal of emphasis at the time of construction.

CONSTRUCTION METHODS

The single course of waterbound macadam was placed in the normal manner. Wooden forms were set along the edge of the base and the large No. 1 (1½- to 3½-in.) stone was spread with a mechanical spreader (see Fig. 3). This stone was rolled and No. 10 screenings were spread with tailgate spreader boxes. These screenings were broomed and rolled dry, then wet thoroughly and rolled and broomed further (see Fig. 4). The completed waterbound course was tight and apparently well keyed.

Figure 3. No. 1 stone in place for the 4-in. course of waterbound. A 1-in. insulation and leveling course consisting of No. 5 and No. 10 stone in equal proportions can be seen in the foreground. Edge boards were removed immediately following the placement of coarse stone and prior to rolling. Three 10.5-ft. lanes were placed, the center lane being the last to go down.

The dense-graded courses were constructed of limestone for which there were special gradation requirements, as outlined in Figure 2. Because the limestone was very dense and hard, it was necessary to add fines to crusher-run stone to secure this gradation. The mixture consisted of 75 percent crusher-run material passed through the 1-in. screen and 25 percent fine agricultural limestone. Figures 5 and 6 illustrate the way in which the two materials were placed on the road separately.

After the aggregate for a 2-in. course had been placed, it was watered and immediately with successive passes of the patrol grader this material was rolled along the blade to the opposite lane (see Fig. 8). More water was added as needed. The final consistency was about that of a dry concrete mix, with moisture contents averaging about 8 percent. Usually after the windrow had been moved two or three times, a thorough mixture was obtained.

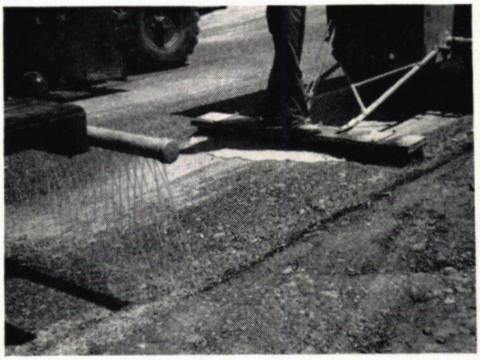

Figure 4. Watering, brooming, and rolling on the waterbound construction. Note slurry in front of the broom.

Figure 5. Spreading the coarser of two aggregates used for the dense-graded base course construction. This stone was crusher run through a 1-in. screen with approximately 3 percent passing the No. 200 screen.

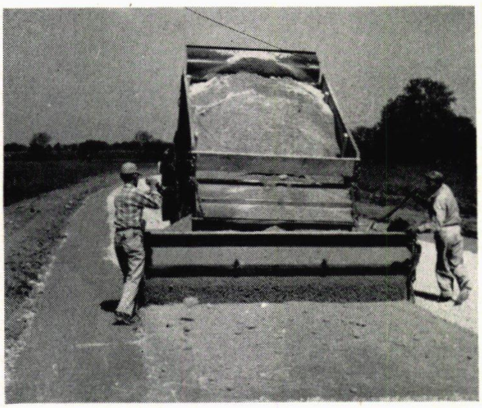

Figure 6. Placing finer aggregate for the dense-graded course over the crusher run material shown in Figure 5. Because of the insufficient quantity of material finer than the No. 200 mesh in the first stone placed, it was necessary to add fines which are normally sold for agricultural lime from this quarry. This fine fraction represented 25 percent of the total aggregate.

Figure 7. Water was applied to thoroughly wet the stone prior to application of calcium chloride. This was done to assure an adequate moisture content and prevent segregation as well as facilitate manipulation during the mixing process that followed.

calcium chloride was applied with a fertilizer spreader at the rate of 1 lb. per sq. yd. This operation is illustrated in Figure 7. Two passes of the spreader were made for each application, and an obviously uniform distribution was obtained by this method.

Mixing operations began immediately after the calcium-chloride application. The mixture was windrowed to the side of the road, then

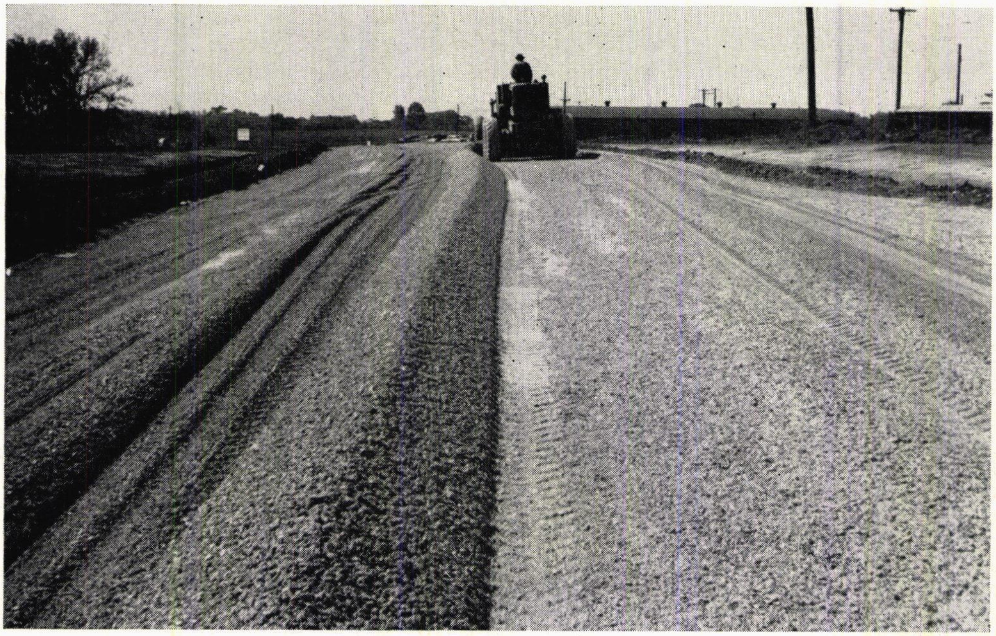

Figure 8. Mixing the stone, calcium chloride, and water with a patrol grader. The mixture was windrowed, then portions of the windrow were rolled along the blade across the road. Thorough mixing was accomplished after several passes with the patrol graders.

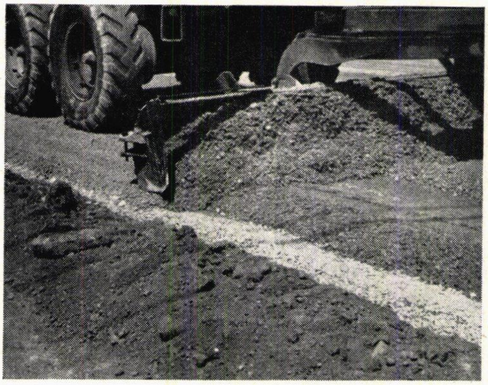

Figure 9. Placing the edge of the dense-graded base with an edge board that was attached to the blade for the last few passes in the layingout process. This attachment could be easily removed or replaced. A neat and uniform edge was obtained in this manner.

Material was then brought to the center of the road and laid out. Edges were kept straight by using an edger attached to the mold board of the blade, as shown in Figure 9. During the laying out process, a pneumatic roller (Fig.

Figure 10. Pneumatic Rolling. This operation was begun during the final shaping of the blade-spread base.

10), was operated continually not only for compaction but also to emphasize irregularities that carried through from the waterbound course or developed in the placement of the blade-spread courses. Pronounced irregularities could be taken out readily by turning the blade square with the road and square blading for a short distance. Material removed from high spots was carried to the depressions. Finished-rolling of the dense-graded base was accomplished with the pneumatic and a 10-ton three-wheel roller in combination. Final passes were always made with the three-wheel roller. After rolling was completed the base was sprinkled and allowed to cure. If an irregularity had been overlooked, reshaping and rolling as late as two days after placement was possible. It was necessary to wet the mixture thoroughly in order to recompact it after reshaping.

Figure 11. Appearance of the finished dense-graded base at the time priming for the bituminous pavement was started.

The dense-graded base was placed, mixed, laid out, and rolled in approximately 2,000-ft. sections, with the first-2 in. course finished throughout the project before the second course was begun. There was no particular waiting period between completion of the first and the beginning of the second course; however, following completion of the second course, a 10-day curing period was allowed before the tar prime was applied.

There was no brooming of the base prior to priming, even though there was some floater material created by the reshaping operations in a few places and by passing traffic which used the road during the waiting period. One section, about 1,500 ft. in length, had an unusual amount of floater, and in order to tack down that material satisfactorily, there was an overrun of 2,240 gal. in the prime. Application of the prime is illustrated in Figure 11.

The binder and surface courses were placed shortly after priming. Coarse-textured hot mix binder material was placed approximately 1½ in. thick. The surface course was a plant mix of medium texture (Kentucky Type B) approximately 1¼ in. in thickness.

OBSERVATIONS AND TEST RESULTS

Observations and tests were directed mainly toward four aspects of the work: (1) gradation of the stone in the dense-graded courses, (2) density of the completed dense-graded courses, (3) profiles and sections of the road at various stages of construction, and (4) relative requirements of men and machines for the water-bound and dense-graded base course construction. The intent of this information was to show whether the desired gradation could be maintained; whether the indicated structural capacity of the dense-graded base was adequate; whether improvement in contour of the pavement could be brought about with the new type base; and whether the new type base was economically sound.

There were numerous other observations and records most of which were best obtained photographically. From that standpoint a complete record of operations was made with still photographs, and in addition, 16-mm. movies were taken from time to time as a means of realistically illustrating the important features of the work and the results produced. Finally, there were incidental tests, such as those pertaining to soils, which were included as part of the record.

Aggregate Gradation

Gradation samples of the two aggregates used in the dense-graded mix and samples of the mix itself were taken at frequent intervals. Most of the fine aggregate samples were taken from stockpiles at the plant, but a few spot-check samples were taken from the trucks as they reached the job. The crusher-run aggregate was sampled after placement on the road, with the material being taken from a trench one shovel wide and running throughout the depth and width of the spread (usually a 10-ft. lane). This quantity was split successively until a test sample of reasonable size was obtained.

There was some segregation of the crusher-run aggregate in the trucks and this generally resulted in a concentration of coarser material early in the spread with a corresponding increase in fineness toward the end of the spread. Because of this, effort was made to take several samples from a selected spread. Also, in anticipation of this, it was decided at the outset to place the crusher-run aggregate in two passes of the spreader, and to that extent overcome segregation.

change from No. 10 material to agricultural lime at the principal source of aggregate. For this type construction, the percentage passing the No. 200 sieve was regarded as a critical factor and particular effort was made to keep this well above the minimum of 5 percent required by the specification.

TABLE 1
SOILS TEST DATA

Location (Station)	Date	Sample No.	Proctor Compaction		Field Density	Laboratory C.B.R.	L.L.	P.I	H.R.B. Classification
			Max. Den.	Opt. MC					
61+00	3-12	1	98.6	23.5	—	6.5	46.6	19.6	7-6 (10)
53+00	3-12	2	99.8	22.3	—	7.0	38.7	13.3	6 (7)
38+00	3-12	3	100.9	22.6	—	12.2	35.6	12.8	6 (9)
23+00	3-12	4	104.2	20.5	—	11.5	35.2	11.0	6 (5)
48+00	4-23	1[a]	105.4	19.6	104.4	12.7	40.5	20.4	7-6 (12)
56+90	4-23	2[a]	105.1	19.2	105.1	18.1	37.8	16.7	6 (11)
43+00	4-23	3[a]	106.4	18.1	105.0	17.8	36.2	16.9	6 (11)
38+00	4-23	4[a]	112.2	16.4	110.6	7.8	39.5	24.3	6 (12)
33+00	4-23	5[a]	105.8	17.9	98.7	45.4	35.4	14.7	6 (10)
28+00	4-23	6[a]	109.0	17.7	111.1	16.1	35.6	15.4	6 (10)

[a] Reported by Division of Materials, May 28, 1952.

TABLE 2
GRADATION OF AGGREGATE IN DENSE-GRADED BASE COURSES

Station	Date	Percent Passing Sieve Sizes						
		1-in.	¾-in.	⅜-in.	No. 4	No. 10	No. 40	No. 200
45+00	5-6	100.0	99.8	89.2	58.8	29.9	12.9	8.5
30+00	5-7	100.0	98.3	80.8	53.3	29.6	13.2	8.7
25+00	5-7	100.0	97.6	83.6	61.4	28.0	11.0	7.0
12+00	5-8	100.0	96.6	79.3	54.6	32.6	14.2	8.9
44+00	5-9	100.0	97.0	74.4	53.8	31.9	14.4	9.2
36+50	5-12	100.0	97.6	77.7	52.3	29.5	13.3	8.7
32+00	5-12	100.0	99.3	94.2	77.0	49.1	20.6	12.0
11+50	5-12	100.0	98.4	91.4	75.5	48.1	20.1	11.7
60+00	5-15	100.0	100.0	90.5	72.4	48.8	23.6	14.7
55+00	5-15	100.0	100.0	89.6	67.7	42.8	20.9	14.0
50+00	5-15	100.0	100.0	90.7	68.6	40.1	18.2	11.3
45+00	5-15	96.1	96.1	84.0	63.0	41.2	19.7	12.7
40+00	5-15	100.0	100.0	89.5	68.7	43.1	19.9	12.5
25+00	5-16	100.0	93.3	89.3	69.0	42.6	18.6	11.4
30+00	5-16	100.0	100.0	87.2	63.9	37.7	16.4	10.9
25+00	5-16	100.0	100.0	89.4	68.6	40.8	18.3	11.8
20+00	5-16	100.0	99.0	90.1	71.2	43.1	19.7	12.8
15+00	5-16	100.0	100.0	82.3	61.9	37.5	16.8	11.0

Note: First samples (taken 5-6 to 5-12) were from windrow of mixed aggregate. Remainder of samples were taken from completed base at time of density test.

After the fine aggregate had been spread and before water or calcium chloride had been applied, the total aggregate was sampled more or less as a control measure. In some instances outstanding gradation deficiencies were noted, and it was necessary to blade some materials forward to minimize their effect on the composition of the final mix.

The greatest difficulties developed with the finer stone sizes early in the operations, but these were overcome through changes in the source of stone at one point and, finally, a

The results listed in Table 2 pertain to samples taken after the full amount of aggregate and the calcium chloride had been applied and the mixture worked into the windrow, or to samples cut from the completed base at the time density tests were made. None of these samples was taken for control purposes but rather to provide representative values of the gradation finally achieved. It will be noted that in several places the gradation did not strictly conform with specification requirements outlined in Figure 2; however, the per-

TABLE 3
MEASURED DENSITIES AND MOISTURE CONTENTS OF DENSE-GRADED BASE COURSES

Station	Dry Density	Moisture Content
	lb./cu. ft	*% dry wt.*
15+00	153.0	3.07
20+00	145.1	2.77
25+00	152.5	2.95
30+00	148.3	2.79
35+00	151.3	3.00
40+00	161.8	2.64
45+00	152.1	1.61
50+00	150.0	1.47
55+00	157.4	2.42
60+00	159.7	2.99
Average.......	153.1	2.57

carefully saved, and the volume of the excavated hole determined by the rubber-balloon method. Moisture contents were relatively low in comparison with those originally taken at the time of mixing. However, at the time these tests were made the base had been completed, and three to seven days had elapsed since the materials had been placed and compacted. Variations in the recorded densities were not great, considering the test limitations. Obviously the densities were high from any point of view. Calculated on the basis of percentage voids in the compacted aggregate having a specific gravity of 2.70, the condition

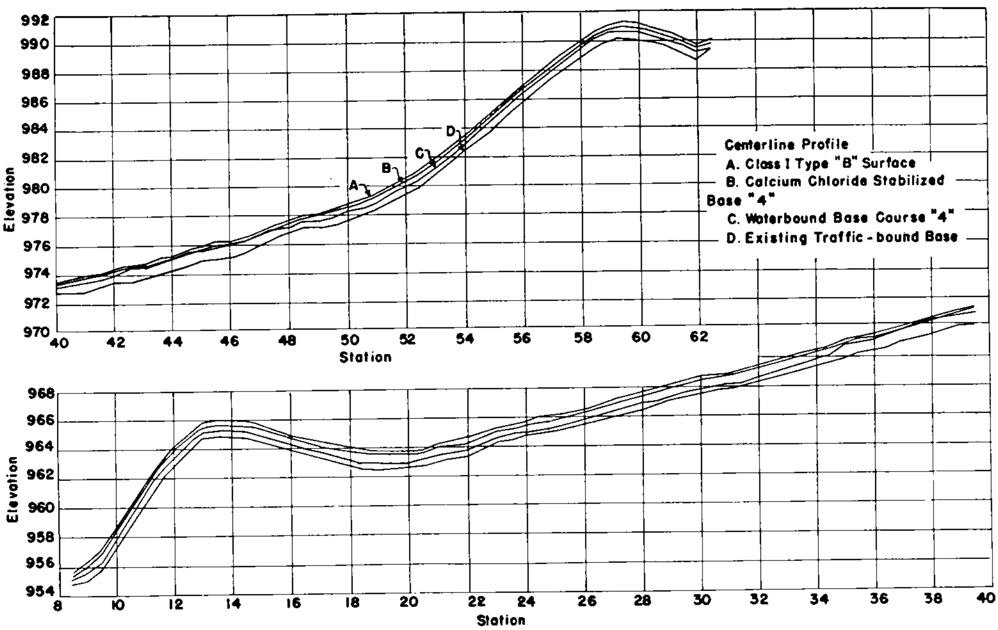

Figure 12.

centages passing the No. 200 sieve were kept well above the minimum and up toward the maximum after the work had progressed to the point where initial difficulties were overcome.

Density Determinations

Measurements of density in the blade-spread courses were made at 10 locations throughout the project, as listed in Table 3. For these determinations, holes approximately 3 in. in diameter were cut through the full depth of the dense-graded base by means of a hammer and chisel. All the material thus excavated was

of the base ranged from 4 to 13.8 percent and averaged 9.2 percent voids.

Profiles and Sections

Centerline profiles were taken every 50 ft. at five different times during construction, and transverse sections were taken in detail at 50-ft. intervals within one 400-ft. section of the road. These measurements were to provide a basis for judging the effectiveness of each type of construction toward elimination of surface irregularities.

The centerline profiles, which were read to the nearest 0.1 ft., represented the top of the

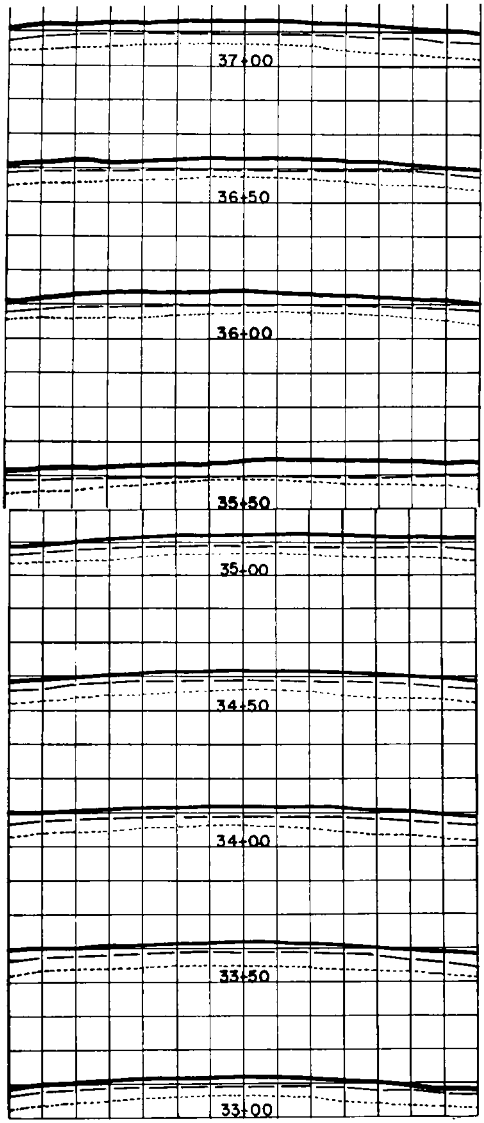

Figure 13. Cross sections taken over waterbound base course, dense-graded-aggregate base course, and bituminous surface. Pavement width was 30 ft.; dense-graded base design was 4 in.; bituminous binder and surface thickness was 2.75 in.

existing traffic bound prior to the beginning of pavement construction, elevations after completion of the waterbound course, second dense-graded course, bituminous binder course, and the bituminous surface course. A plot of four of these five sets of elevations is shown in Fig. 12. Those for the bituminous binder course were omitted in the interest of clarity.

Indications are that the blade-spread base did remove some pronounced irregularities of the waterbound and traffic-bound courses. However, the plots of Figure 12 convey the impression that considerable irregularity remained after the blade-spread operations and even after the bituminous surface was placed.

From the standpoint of actual riding qualities it is difficult to establish the significance of these slight irregularities when it is realized that they carry over a distance of 50 ft. Pavements with outstandingly poor riding qualities often have abrupt changes in elevation over distances that are hardly greater than the length of a car. Irregularities at longer

TABLE 4
EQUIPMENT AND PERSONNEL REQUIRED FOR THE TWO TYPES OF BASE

Equipment			
Dense-Graded Base	Days Used	Waterbound Base	Days Used
1. Adnun spreader	7	Apsco spreader	9
2. 3-Wheel roller	8	3-Wheel roller	16
3. Pneumatic roller	8	Water wagon	11
4. Water wagon	17		
5. Grader	13		
6. $CaCl_2$ spreader	5		
Total equipment days	58		36

Personnel			
Dense-Graded Base	Man Days	Waterbound Base	Man Days
1. Supt. and foreman	17	Supt. and foreman	27
2. Skilled	28	Skilled	46
3. Semi-skilled	27	Semi-skilled	65
4. Unclassified	37	Unclassified	85
Total man days	109		223

intervals can give an undulating or roller-coaster effect. The profiles of Figure 12 show that there are no irregularities of that type in this surface.

Studies of surface irregularities and riding qualities[2] in the past few years have positively identified the majority of poor riding qualities with inconsistencies in cross section. As a means of checking for such inconsistencies, sections were determined at 50-ft. intervals between Stations 33+00 and 37+00.

Here again it was realized that pronounced variations in sections at intervals of less than 50 ft. account for the poorest riding qualities,

[2] Report No. 2 on "Measurements of Surface Irregularities and Riding Qualities of High Type Bituminous Pavements," Kentucky Department of Highways, Materials Research Laboratory, December, 1950. (Unpublished)

but limitations in time and personnel made it a choice of sections at closer intervals throughout a 100-ft. distance or sections at greater intervals over a longer distance.

A stringline stretched between blue tops, and measurements down to the surface, were used in the determination of cross sections. Measurements to the nearest 1/8 in. were made on the top of the waterbound course, the top of the second dense-graded course, and the finished pavement surface. Plots of the sections are contained in Figure 13.

Invariably the blade-spread courses had a contour which was much more uniform than the contour of the waterbound course, and almost invariably the newly formed surface more nearly approached the theoretical design section that the finished pavement was supposed to meet. In one or two instances there was very little crown in the dense-graded courses.

Generally speaking, two passes of the paver laying the bituminous courses did not improve the sections. At Stations 35+50, and 36+50, the sections of the finished pavement were decidedly poorer than the corresponding sections of the blade-spread base. It appears that settings of the paver screed were unnecessarily altered at these locations, particularly on operations in the center lane. Despite this and other influences, the few measured sections indicate that with the blade spread courses in place the paver had a better surface on which to operate than it would have had with the waterbound course alone.

Manpower and Machinery

Insofar as possible, records were made to determine the equipment and personnel requirements for construction of each of the two types of base. Approximately the same quantity of stone was required for each 4-in. course, and essentially the use of trucks and similar equipment was the same also. Consequently, these factors and some others such as spreader boxes for fine aggregate were disregarded in the summation of required manpower and machinery.

The various pieces of equipment were tabulated and a record was made of the days each piece was in use. Similarly records were made of the labor by class and by time spent. This compilation is given in Table 4. While the dense graded courses required more equipment-hours than did the waterbound construction, their requirement in man-days of labor was less than half that of the waterbound construction.

On the basis of rental rates applicable to equipment operated by the department and minimum wage rates applicable to this particular project in Fayette County, the relative costs on the factors in which the two types of construction differed were $4,536 for the waterbound base and $3,464.40 for the dense-graded aggregate base. This comparison, of course, applies only to the 1.1 mi. of construction in this instance, and it contains several approximations. For construction in other parts of the state, the relative costs would vary, at least, in accordance with variations in the minimum wage rates.