such a complication of interests. Again cooperation and coordination of engineer, architect, and site planner are essential to a successful solution.

Figures 1, 2 and 3, illustrate the development of plans for improvement of an important urban center.

Site planning must extend beyond the limits of the highway and its right-of-way to unite in an over-all plan the development of the environment affected. It is in this cooperative study of the over-all development that the landscape engineer and the highway engineer can achieve a coordination of planning that should provide safety, efficiency, economy and harmony of planning. Utility and aesthetics will combine not merely to accomplish the "Complete Highway" but will relate that completeness to its environment and adjacent areas it serves as a most important part of comprehensive city planning.

I have referred constantly to the necessity of balancing various ideas and influences that are pertinent to the solution of a highway location problem. Our studies and our research might well be extended to these broad planning opportunities that are now confronting the large highway program ahead.

What Is the Ideal Location?

The ideal location is best determined by careful analysis of facts coupled with a vision of Aesthetic Values. This demands careful coordination of the work of the engineer and that of the landscape architect. It is the combination of the experienced technique of the engineer and the sensitive imagination of the landscape architect that will bring the highway location and construction into a closer approach to the ideals of the "Complete Highway" serving the combined needs of utility, safety, and appearance.

DEPARTMENT OF MATERIALS AND CONSTRUCTION

C. H. SCHOLER, *Chairman*

SEVEN YEARS' PERFORMANCE OF A BITUMINOUS SURFACE TREATMENT TEST ROAD

BY W. H. GOETZ, *Research Engineer, Joint Highway Research Project, Purdue University*

SYNOPSIS

A performance survey of a bituminous surface treatment test road seven years old has recently been made. The test road is 10 miles long, is located in Northern Indiana on the State Highway system, and consists of 51 experimental sections constructed with three types of bituminous materials and aggregate from two sources. Other variables included the amount and method of application of bituminous material and size of aggregate. The results obtained during construction and through the first year of service were reported in the Engineering Bulletin of Purdue University in a paper by T. E. Shelburne entitled, "Bituminous Surface Treatment."

The performance survey after seven years of service was broad in scope and detailed in nature. Visual ratings were made of each section by two different methods. In one method, the various sections were given an over-all rating by a number of observers; in the other the same observers estimated the percentage area of failure of each of four types. Surface texture measurements were made of each section in at least two locations by means of a texture profilometer. Four specimens were removed from the road and were tested for stability on a minitrack machine. Two surface samples were taken at representative areas in each section, one in the wheel track area and one between wheel tracks. These samples were analyzed in the laboratory for bitumen content and grading of the bitumen-free aggregates. Surface-area values were calculated from the grading results.

The results of the survey show that the average surface area of the aggregates has increased about 500 or 600 percent over that at the time of construction (be

fore mixing and rolling). Since 1939, due to traffic and weathering, the average surface area of the aggregates has increased about 200 percent of the late 1939 value. Likewise, the bitumen content of some sections has increased as much as 100 percent over that at the time of construction. The average values show that the percentage of bitumen by weight is now about 50 percent greater than it was in late 1939. Again referring to average values, the results show that the tar sections increased most in bitumen content, the asphalt emulsion sections least, with the asphalt cut-back sections occupying an intermediate position; on the contrary, the average surface area results show the sections constructed with tar to have increased least in surface-area of the aggregate, the AES-3 sections to have increased most, with the RC-3 values again occupying an intermediate position.

The test road has shown rather remarkable performance and longevity which is attributed chiefly to generally good soil conditions, high-level profile, adequate base, low traffic density, and especially, careful workmanship during construction. However, even with very careful construction by experienced personnel, the bitumen content, surface-area of the aggregate, and performance of road-mix bituminous surface treatment may be expected to vary markedly. Successful performance depends more upon uniformity of mixture and grading of aggregate than upon type of bituminous material or source of aggregate.

The work of the Joint Highway Research Project with bituminous surface treatment dates from the inception of the Project in 1936. In that year field inspections were made of surface treatments throughout the State of Indiana. These roads were given ratings which included the type and extent of failure and some 200 samples were collected and analyzed in the laboratory. These preliminary studies served to demonstrate the magnitude of the problem and to isolate variables that needed evaluation. Wide variation was found in bitumen content, aggregate gradation, and surface texture while at the same time it was demonstrated that failures could not be attributed to any of the commonly used types of materials themselves.

Research in the field of bituminous surface treatment was continued during 1937, 1938, and 1939 with a program in which selected 1936 and 1937 surface treatment contracts were followed in detail. Complete information regarding materials used in construction, construction procedures, and weather conditions during and following construction were obtained. The treatments were carefully surveyed and their performances were rated for the following two years. In addition, a group of surface treatments constructed in 1937 was selected for study including periodic sampling at intervals up to 22 months after construction.

The results of these studies showed that surface-treatment performance cannot be successful without adequate base support. Also, it was shown that any surface-treatment is subject to failure if it is constructed during adverse weather conditions or so late in the season that the surface does not receive sufficient curing and compaction from traffic during warm weather. The periodic samplings showed a marked increase in both bitumen content and surface area of the bitumen-free aggregate with time. Those roads treated with asphalt cut-back (RC-3) contained a higher average bitumen content than those with asphalt emulsion (AES-3), while the increase in surface area of the aggregates showed a straight-line relationship with time up to 660 days (last sampling). These surface-area results led to a study of the crushing resistance of surface-treatment aggregates under road rollers.[1, 2]

Although much was learned about surface-treatment work as practiced in Indiana from these early studies,[3] it seemed desirable to build a surface-treatment test road for the purpose of verifying these results and especially to study the effects of construction variables. So many construction features were variables in the roads that had been studied that definite relationships could not be established. Consequently, Test Road

[1] Shelburne, T. E., "Crushing Resistance of Surface-Treatment Aggregates," *Engineering Bulletin of Purdue University*, Vol. XXIV, No. 5, Sept., 1940.

[2] Shelburne, T. E., "Degradation of Aggregates Under Road Rollers," *Proceedings, ASTM*, Vol. 39, p. 950 (1939).

No. 3 was constructed in the summer of 1939. It consisted of 51 experimental sections, each approximately 1,000 ft long, constructed on State Road 8 in northern Indiana. A complete description of this test road including the working plan, preliminary investigations, construction procedure and equipment, together with the results obtained during construction and through the first year of service were reported by T. E. Shelburne in 1941.[3]

It was planned to follow the performance of this test road in detail throughout its life. Although cursory inspections were made from time to time, war conditions made the undertaking of detailed surveys impractical. Undoubtedly, much was lost because of this situation and because traffic during the war was not normal. However, a detailed survey and analysis of this test road was undertaken in the spring of 1946. This paper reports the results of this survey and analysis so far as they have been determined. The outline and table form established by Mr. Shelburne have been followed for the most part so that the reader may readily compare results with those contained in the earlier report.

HISTORY OF THE TEST ROAD

The bituminous surface treatment test road is located in the northern part of Indiana on State Road No. 8. The section selected is ten miles long; it is located in a sandy soil region, and base conditions are generally good. The traffic is relatively light. Before the war it was reported to be between 300 and 550 vehicles per day (average) with about 25 percent of these being trucks. Traffic during the war period may have been somewhat less. The base consists of traffic-bound stone and water-bound macadam averaging about 7 in. in depth and about 114 lb per cu ft dry density. Other preliminary investigations included a soil profile, surface texture measurements, and the placing of steel plates in the road surface for the purpose of making stability determinations in the laboratory on a minitrack apparatus.

The surface treatment was constructed by road-mix methods during the latter half of August and first part of September, 1939. Weather conditions were in general favorable for this type of work, although some cloudy, cool, and rainy weather was experienced. Forty-eight 1,000-ft test sections were constructed using three types of liquid bituminous materials, cut-back asphalt (RC-3), asphalt emulsion (AES-3), and tar (TH) combined with crushed limestone aggregate from two sources. Twenty-four sections were constructed with limestone A and 24 with limestone B. One-third, or eight, of the sections were constructed with each of the three bituminous materials in each case. Three additional sections were constructed, one 800 ft long with AES-3 and limestone B (Section A-9-b), and two, 2,500 and 2,000 ft long with RC-3 and limestone A (Sections R-9-a and R-10-a). The layout plan is shown in Table 1. Each of the listed sections was constructed with both limestones A and B. The bituminous material applications listed in the table refer to (1) prime, (2) mixing, and (3) seal applications.

In addition to studying the effect of type of bituminous material and source of aggregate, one of the primary purposes of this test road was to study the effect on construction and service performance of the amount and method of application of the bituminous material and the size of both the covering and chipping aggregates. The grading specifications for the aggregate sizes used are shown in Table 2. These gradations represent the extreme limits which determine suitability for use from all sources of supply, but the gradation from any one source should be reasonably uniform.

During construction detailed records were kept of the quantities of materials used and the application temperatures of the bituminous materials. Samples were collected of the aggregate from the road surface immediately before the second application of bituminous material for the purpose of determining moisture content. In addition, careful records were kept of the manner in which each mixture performed during construction and deviations from standard procedure or the design quantities, and the reasons for such changes, were carefully noted.

VISUAL RATINGS

The 51 test sections were rated visually by a number of observers at intervals during the early part of their lives. At that time very

[3] Shelburne, T. E., "Bituminous Surface Treatment," *Engineering Bulletin of Purdue University*, Vol. XXV, No. 4, July, 1941.

little serious failure had occurred and practically all of the sections were rated fairly high. In general, those sections constructed with size No. 8F covering aggregate (¾-in. to No. 4 sieve) rated lowest in performance, while these sections constructed with size No. 9 covering aggregate (⅜-in. to No. 30 sieve) rated highest. Those sections constructed with size No. 11 covering aggregate (½-in. to No. 8 sieve) were given an intermediate rating. Limestone from both sources performed equally well. Likewise, very little difference was found in the performances of the three types of bituminous material, although the average rating on the tar sections was slightly lower because of some raveling on one or two of these sections. Of those constructed with No. 8F covering aggregate, the procedure used on the No. 5 sections gave the highest ratings, while of those constructed with No. 11 covering aggregate, the greater quantity of bituminous material used on the No. 7 sections appeared to be beneficial.

TABLE 1
LAYOUT PLAN FOR TEST ROAD NO. 3

	Section No.							
	R1	R2	R3	R4	R5	R6	R7	R8
Bituminous Material								
Type—Liq. Asph.	RC-3	RC-3	RC-3	RC-3	RC-3	RC-3	RC-3	RC-3
Amount (gal. per sq. yd.)	0.45	0.45	0.55	0.55	0.55	0.55	0 55	0 45
Application (1)	0.30	0 15	0.35	0.20	0.15	0 15	0.15	0.15
(2)	0.15	0.20	0.20	0.35	0 25	0 25	0 25	0.20
(3)		0.10			0 15	0.15	0.15	0.10
40 lb. Covering Aggregate Size No.[a]	8F	8F	8F	8F	8F	9	11	11
10 lb. Chips Size No	11 12	11 12	11 12	11 12	11 12	12	12	12
	Section No.							
	A1	A2	A3	A4	A5	A6	A7	A8
Bituminous Material Type—Em. Asph	AES-3	AES-3	AES-3	AES-3	AES-3	AES-3	AES-3	AES-3
Amount (gal. per sq. yd)	0.45	0 45	0.55	0 55	0.55	0.55	0.55	0.45
Application (1)	Agg.	0.10	Agg.	Agg.	0.10	0.10	0.10	0.10
(2)	0.30	0.25	0.40	0.35	0.30	0 30	0.30	0.25
(3)	0.15	0.10	0 15	0.20	0.15	0.15	0.15	0.10
40 lb. Covering Aggregate	Aggregate Same as RC-3 Section							
	Section No.							
	T1	T2	T3	4T	T5	T6	T7	T8
Bituminous Material Type—Tar	TH	TH	TH	TH	TH	TH	TH	TH
	Otherwise Same as RC-3 Section							

[a] Indiana State Highway Commission designation.

Figure 1 shows a general view of the west end of the test road as it appeared during the past summer. At this time, the 51 sections were carefully rated by methods very similar to those used in the earlier ratings. However, because considerable failure of the test sections is now evident, the latest ratings were divided into two parts.

Each observer was asked to estimate first the percentage area of each type of failure occurring on each section. Four types of surface failure were recognized; scuffing, raveling, bleeding, and pulling. Scuffing failure occurs when the chipping aggregate is lost from the surface. See Figure 2. Raveling is the failure resulting from the loss of both the chipping aggregate and the covering aggregate. See Figure 3. Bleeding denotes an excess of bituminous material on the surface causing "fat" spots which are slippery, especially in wet weather. See Figure 4. Pulling failure results when the mixture becomes tacky during the mixing operation and will not spread out evenly behind the

TABLE 2
SIZES OF BITUMINOUS SURFACE-TREATMENT AGGREGATE
(From Indiana Specifications)

Size No.	Total Percentage by Weight Retained on Sieves (Sq. Openings)						
	$\frac{3}{4}$ in.	$\frac{1}{2}$ in.	$\frac{3}{8}$ in.	No. 4	No. 8	No. 30	No. 100
8F	0	40–70		95–100	99–100		
9	0	10–15		85–100		99–100	
11		0	5–25	70– 95	95–100		
12		0		0– 60	65–100	96–100	99–100

Figure 1. General View of Test Road 3 (West End)

blade of the mixing drag. Spots are left on the surface which are bare of covering aggregate. See Figure 5. This failure is readily distinguished from raveling failure by the shape of the area and its occurrence. Figure 6 shows a portion of one of the better-performing sections.

After estimating the percentage area of each type of failure on each section, the observers were then asked to give a comparative rating to each section, as was done in the earlier surveys, using a letter system of A, B, and C with plus and minus values. As before, these ratings were converted to a numerical

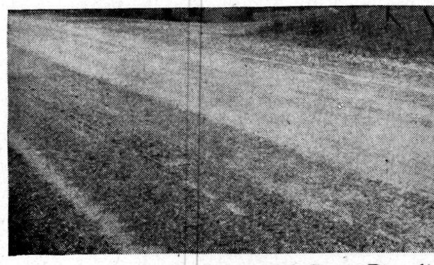

Figure 2. Scuffing Failure with Some Raveling

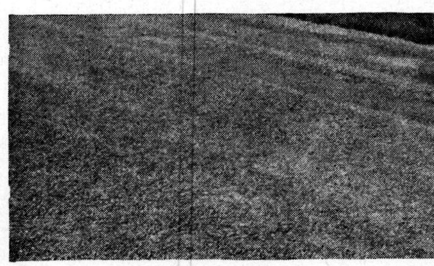

Figure 3. Severe Raveling Failure in a Local Area

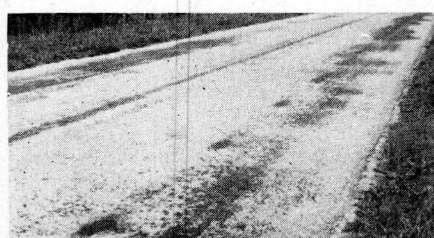

Figure 4. Fat spots Caused by Bleeding of Bitumen

scale. It must be emphasized that these ratings are strictly comparative and the tie-in with results from the earlier visual ratings is lacking. Better rating methods are needed—methods which will form a reliable permanent record and which will not be subject to the human element. In this regard, the Project is now investigating a method which consists of photographing the road surface on continuous film in stereo from a low-flying plane.[4] An aerial strip-map of this type has been obtained of the full 10-mile length of Test Road No. 3, but its value for use in rating bituminous surface treatment has not yet been fully determined. A small portion of this aerial strip-map is shown in Figure 7.

The results of the visual survey are given in Table 3. Two separate evaluations are shown, one as the percentage of area of each of four recognized types of failure, and the other as a numerical rating. Any one section may not have exactly the same comparative rating in both systems because opinions varied as to how much the section should be penalized for the different types of failure. This was particularly true of bleeding. Before discussing the detailed differences in performance that are shown by the visual ratings, it must be pointed out that this road has performed remarkably well in general. The fact that it was constructed on a sandy soil and provided with a good base is responsible, in large measure, for this outstanding performance. Contributing, also, is the fact that the workmanship was especially good. Base and edge failures are not entirely absent and in some localized areas are quite serious. However, they represent a very small percentage of the total area of the road. After seven years of service, long life for surface treatment construction in general, and with very little maintenance, most of the road can probably be restored to satisfactory condition with only a limited amount of patch work followed by a seal treatment.

In the earlier surveys, no difference was found in the performance of the two aggregates. The results shown in Table 3 tend to substantiate this conclusion, although some slight differences can be found. Limestone A is indicated to be slightly more susceptible to scuffing and raveling if the 8F sizes alone are considered. Size No. 9 limestone A with AES-3 is rated appreciably lower than the corresponding section with limestone B. However, most of the difference is probably due to the mixing as indicated by the fact that the former section pulled considerably. Appreciably more bleeding occurred on the limestone A sections with AES-3 and TH bituminous materials particularly with No. 9 and No. 11 stone. Table 9 also shows that the average surface area of the bitumen-free aggregate after seven years service is somewhat greater for limestone A than for limestone B.

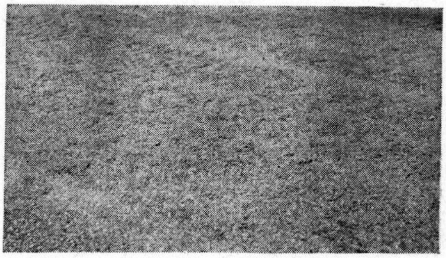

Figure 5. Failure Caused by Pulling in the Mixing Operation

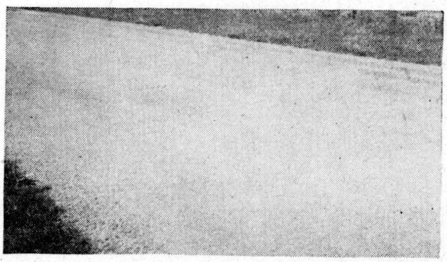

Figure 6. Good Performance with Size No. 9 Covering Aggregate

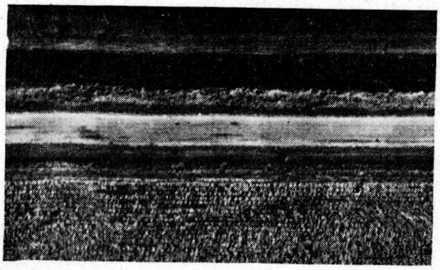

Figure 7. Portion of an Aerial Strip-Map of Test Road 3

The differences attributable to the bituminous materials, as shown by these ratings, are not great. The average results for stones A and B show almost identical values for RC-3 and AES-3 with the exception of the results for Size No. 9. This is due to a large difference between AES-3 and RC-3 with stone A. The construction records show that

[4] Hittle, J. E., "Application of Aerial-Strip Photography to Highway and Airport Engineering," *Proceedings*, Highway Research Board, Vol. 26 (this volume), p. 226.

considerable difficulty was experienced in mixing the A-6-a section because the emulsion broke too soon. The ratings on the tar sections show somewhat inferior performance for this material principally because of scuffing and raveling in the case of the size No. 8F stone, and because of bleeding with the finer sizes of aggregate. Thus it is indicated that, for the sections constructed with tar, bitumen content may be somewhat more critical.

The greatest differences in performance, according to these results, seem to be due to the use of different sizes of stone. In general, those sections constructed with No. 9 stone have the highest ratings, although they are somewhat susceptible to bleeding. Sections constructed with No. 11 stone have the next highest ratings, while those sections constructed No. 8F stone were rated lowest in performance. Sections constructed with No. 8F aggregate are more susceptible to scuffing and raveling. From an earlier survey, it was concluded that, of the sections constructed with No. 8F aggregate, the procedure used in the No. 5 sections seemed to give the best results. Results from this survey do not refute this statement although the differences are not great.

TABLE 3
COMPARISON OF VISUAL RATINGS
After Seven Years' Service

	Section No.	Tar TH					RC-3					AES-3					Size of Aggregate
		Percentage of Area					Percentage of Area					Percentage of Area					
		Scfd.[a]	Ravld.[a]	Bldg[a]	Pulld[a]	Rating	Scfd.	Ravld.	Bldg	Pulld.	Rating	Scfd.	Ravld.	Bldg	Pulld.	Rating	
Stone A	1	20	25	0	0	57	15	0	Sl.	0	77	10	0	5	0	77	8F
	2	20	15	0	0	57	15	5	Sl	0	70	10	0	10	0	75	8F
	3	25	20	0	0	62	15	Sl	Sl	0	73	20	Sl.	5	0	68	8F
	4	30	15	Sl.[b]	0	60	20	Sl.	0	0	78	20	Sl	5	0	72	8F
	5	20	10	0	Sl	62	10	0	0	0	80	10	0	15	0	67	8F
	6	0	0	50	5	77	0	0	Sl	0	93	15	0	10	5	70	9
	7	0	0	60	5	68	5	5	Sl	0	78	0	0	20	5	72	11
	8	0	5	20	10	58	5	0	5	10	68	0	0	20	10	72	11
	9						Sl.	0	20	Sl	75						8F
	10						15	10	0	0	70						8F
	Avg.—Size 8F	23	17	0	0	60	13	2	3	0	75	14	0	8	0	72	8F
	Avg.—Size 9	0	0	50	5	77	0	0	0	0	93	15	0	10	5	70	9
	Avg.—Size 11	0	3	40	8	63	5	3	3	5	73	0	0	20	8	72	11
	Avg.—Stone A	14	11	16	3	63	10	2	3	1	76	11	0	11	3	72	8F, 9, 11
Stone B	1	15	Sl.	5	0	75	15	10	0	0	70	10	Sl	0	Sl	73	8F
	2	20	5	Sl	0	65	15	Sl.	0	0	73	10	0	Sl.	0	77	8F
	3	20	5	10	0	73	5	0	5	0	75	10	0	Sl.	0	80	8F
	4	20	Sl.	5	0	67	10	0	5	0	75	10	5	5	0	72	8F
	5	10	0	10	0	73	10	Sl	5	0	70	10	5	10	0	70	8F
	6	Sl.	0	5	0	80	5	0	10	5	80	Sl.	0	Sl.	0	82	9
	7	5	0	Sl.	0	80	Sl.	Sl.	5	5	75	5	Sl	Sl.	Sl	73	11
	8	10	5	5	Sl.	68	5	Sl.	5	5	67	5	Sl.	5	0	77	11
	9											10	5	5	0	68	8F
	10																8F
	Avg.—Size 8F	17	2	6	0	71	11	2	3	0	73	10	3	3	0	73	8F
	Avg.—Size 9	0	0	5	0	80	5	0	10	5	80	0	0	0	0	82	9
	Avg.—Size 11	8	3	3	0	74	3	0	5	5	71	5	0	3	0	75	11
	Avg.—Stone B	13	2	5	0	73	8	1	4	2	73	8	2	3	0	76	8F, 9, 11
Stones A & B	Avg.—Size 8F	20	10	3	0	66	12	2	3	0	74	12	2	6	0	73	8F
	Avg.—Size 9	0	0	28	3	79	3	0	5	3	87	8	0	5	3	76	9
	Avg.—Size 11	4	3	22	4	69	4	2	4	5	72	3	0	12	4	74	11
	Avg.—Grand	14	7	11	2	68	9	2	4	2	75	10	1	7	2	74	8F, 9, 11

[a] Scfd.—Scuffed—loss of chipping aggregate; Ravld.—Raveled—loss of chipping and mixing aggregate; Bldg—Bleeding of bituminous material; Pulld.—Pulled—did not spread evenly during construction.
[b] Sl.—Slight.

SURFACE TEXTURE MEASUREMENTS

Surface texture measurements have been made of the surface-treatment test sections at intervals starting with the completion of the road. These measurements were made with a texture profilometer designed and built by members of the Project staff. This device records on a roll of graph paper, to actual scale, the texture profile of the road surface. It consists of a small glass-cutter with a lever arm attachment which transfers the profile to a chart as the glass-cutter wheel is moved over the road surface. The results are obtained by connecting the high points of the surface texture after seven years' service at two or three locations within the section at points where the previous measurements had been made. Seven measurements across the road, each taken parallel to the centerline, were made at each location. Thus, each value obtained is the average of at least 14

TABLE 4
COMPARISON OF SURFACE TEXTURE MEASUREMENTS (IN.)
(Average Values of Seven Maximum Readings)

Section	Stone A				Stone B				Average of Stones A and B			
	At Completion	After 7 Months	After 12 Months	After 7 Years	At Completion	After 7 Months	After 12 Months	After 7 Years	At Completion	After 7 Months	After 12 Months	After 7 Years
No. 8F Covering Aggregate												
T1	.28		.34	.37	.26	.36	.34	.30				
T2	.27		.31	.40	18	.37	.32	36				
T3	.25		.34	.38	.24	.41	36	35				
T4	.33		.39	38	.34	.30	28	33				
T5	.22		29	.35	.26	.30	.26	25				
Average	.27		33	.38	26	35	31	32	27	.35	.32	.35
R1	.24	.28	30	.33	.30		35	32				
R2	.28	.33	.32	38	.22		33	31				
R3	.26	.27	.31	.27	.28		31	.27				
R4	.22	.29	.35	31	32	.34	35	26				
R5	.29	.29	.37	38	.19	.26	28	19				
R9	.16	.29	.27	23								
R10	42	.30	.38	.28								
Average	.27	.29	.33	.31	26	30	32	.27	.27	.30	33	.29
A1	.29	.28	.26	.29	24	.27	.32	.28				
A2	.21	.30	.31	27	.22	.28	36	.27				
A3	23	.30	.33	36	16	23	.26	.24				
A4	.35	.32	.34	.34	22	.23	.26	.26				
A5	.26	.25	.28	.23	26	.29	.27	31				
A9					.36	.30	.32	.20				
Average ..	.27	.29	.30	.30	.24	.27	.30	26	.26	.28	.30	.28
Grand Avg.	.27	.29	.32	.33	.25	.31	31	.28	.27	.31	.32	.31
No. 9 Covering Aggregate												
T6	.18		.16	.12	.20	.30	.26	23				
R6	.16	.20	.24	.27	.18	.22	.20	.20				
A6	.28	29	.25	.28	.16	21	24	22				
Average	.21	25	.22	.22	.18	24	.24	22	.20	.25	23	.22
No 11 Covering Aggregate												
T7	.16		.18	17	.16	20	.20	.19				
T8	.22		22	.19	.18	21	.20	20				
R7	.12	.14	18	.23	.20	22	.19	.19				
R8	.20	.22	24	29	.14	.16	.22	24				
A7	.20	.18	18	18	.16	.18	19	.17				
A8	.10	19	.22	19	14	19	.21	.25				
Average	.17	.18	.20	21	16	.19	.20	.21	.17	19	20	21

profile with a straight line and either measuring the maximum deviation from the straight line to obtain a maximum value, or by planimetering the area between the profile and the straight line to obtain an area value or an average deviation value.

Each of the test sections was measured for measurements. Table 4 gives the measurements, grouped according to size of covering aggregate, for not only the measurements made after seven years' service, but also for those made at completion and after seven and twelve months' service. Maximum values have been used because the earlier measurements had been recorded in this way and a comparison with these earlier values was desirable.

Inspection of Table 4 shows that some sections increased in roughness with age while others either remained fairly constant or became smoother. These values apparently reflect a greater amount of scuffing and raveling in the first instance, and more bleeding and (or) breakdown of the aggregate in the latter instance. It is interesting to note that even though all of the aggregate sizes increased greatly in surface area with time, as will be shown in the discussion of the surface samples, the surface-texture measurements continue to reflect chiefly the differences in texture produced by the different sizes of covering aggregate. Over a seven-year period, size No. 8F covering aggregate has consistently shown the greatest surface roughness values while No. 9 and No. 11 covering aggregates have shown lower values more nearly equal to each other. With all aggregate sizes the greatest change in roughness occurred during the first seven months of service or during the first winter and spring season.

The sections constructed with No. 9 and No. 11 covering aggregates, according to the surface-texture results, show no difference between aggregates A and B. However, in the case of sections constructed with No. 8F aggregate, the average value of the surface texture measurements after seven years of service is considerably less for stone B than the average value for stone A. Also, considering the size 8F sections only, a greater change in surface texture occurred over the seven-year period in the TH sections than in the RC-3 and AES-3 sections.

In Table 5 the surface-texture measure-

TABLE 5
VISUAL RATINGS COMPARED WITH SURFACE TEXTURE MEASUREMENTS
After Seven Years' Service

Section	Tar TH Stone		RC-3 Stone		AES-3 Stone		Average Stone	Average Stone	Average Stone	Size of Aggregate
	A	B	A	B	A	B	A	B	A & B	
Comparison of Visual Ratings										
1	57	75	77	70	77	73	70	73	72	No. 8F
2	57	65	70	73	75	77	67	72	70	No. 8F
3	62	73	73	75	68	80	68	76	72	No. 8F
4	60	67	78	75	72	72	70	71	71	No. 8F
5	62	73	80	70	67	70	70	71	71	No. 8F
6	77	80	93	80	70	82	80	81	81	No. 9
7	68	80	78	75	72	73	73	76	75	No. 11
8	58	68	68	67	72	77	66	71	69	No. 11
9			75			68	75	68	72	No. 8F
10			70				70		70	No. 8F
Average	63	73	76	73	72	76	70	74	72	
	68		75		74					
Grand Avg.	72									
Surface Texture Measurements (in.)[a] After Seven Years' Service										
1	.37	.30	.33	.32	.29	28	.33	.30	.32	
2	.40	.36	.38	31	.27	.27	.35	.31	.33	
3	.38	.35	.27	.27	.36	.24	.34	29	.32	
4	.38	33	.31	26	.34	.26	.34	28	.31	
5	.35	.25	.38	19	.23	.31	.32	.25	.29	
6	.12	23	.27	20	.28	.22	22	.22	22	
7	.17	.19	23	.19	.18	.17	19	.18	19	
8	.19	20	.29	24	19	.25	.22	.23	23	
9			.23			.20	.23	20	22	
10			28				28		.28	
Average	.30	.28	.30	.25	.27	.24	.29	.26	.28	
	.29		.28		.26					
Grand Avg	.28									

[a] Average value of 7 maximum readings.

ments and the visual ratings after seven years of service are compared. The visual ratings do not parallel the surface-texture measurements in many cases, probably because a section could be rated low because of either scuffing and raveling or because of bleeding. These factors are opposed in the surface-texture measurements. However, the size 8F sections with limestone A and TH which rate lowest because of excessive scuffing and raveling do have the highest roughness values. Also, the high visual rating given the No. 6 and No. 7 sections is reflected in the low roughness values obtained for these sections.

In Table 6, the surface-texture values for the sealed and unsealed and the broomed and unbroomed sections are compared to determine whether the values reflect these differences in construction procedure. These average values show that the sealed sections are slightly smoother than the unsealed ones, and that the broomed sections are slightly smoother than the unbroomed sections after seven years of service. This result is almost the same as that obtained after twelve months' service, although in each case considerable overlapping of maximum and minimum values occurs.

MINITRACK SPECIMENS

Twelve steel plates, ½ in. thick and 2 ft in diameter, were imbedded in the road surface previous to the construction of the surface treatment. Six of these plates were placed in a section where RC-3 and No. 8F aggregate were used and six were placed in sections where TH and No. 8F aggregate were used. One specimen from each group was removed at the ages of 2, 6, 11, and 23 months and the two remaining in each group were removed at the age of 80 months. They were tested in the laboratory on the Kriegil Minitrack machine,[5, 6, 7] a machine designed to measure stability under moving wheel loads. Also, the densities of these specimens were determined as well as the bitumen contents and the gradings of the bitumen-free aggregate. Surface area of aggregate was computed from this grading.

The results of these tests are shown in Table 7. They indicate that from November (age 2 mo.) until February (age 6 mo.) there was no increase in the relative strength of either the TH or RC-3 specimens. However, from February until July (age 11 mo.) there was a slight increase in relative strength for the TH specimen and a considerably greater increase for the RC-3 specimen. The relative strengths of both the TH and RC-3 specimens continued to increase with age up to and including 80 mo. At all ages through 23 mo., the RC-3 specimens showed greater relative strengths than did the TH specimens, but at the age of 80 mo. they were about equal. The density of these specimens was quite uniform and no change in density with time is apparent. Unfortunately, the bitumen content and surface area values were not determined for the 80-mo. minitrack specimens themselves; but based on the results from the

TABLE 6
COMPARISON OF SEALED SECTIONS WITH UNSEALED AND BROOMED SECTIONS WITH UNBROOMED
After Seven Years' Service

Sealed		Unsealed		Broomed		Unbroomed	
Section	Profile Reading	Section	Profile Reading	Section	Profile Reading	Section	Profile Reading
T-2a	.40	T-1a	.37	A-1b	.28	T-1a	.37
T-5a	.35	T-3a	.38	A-2b	.27	T-2a	.40
R-2a	.38	T-4a	.38	A-3b	.24	T-3a	.38
R-5a	.38	R-1a	.33	A-4b	.26	T-4a	.38
A-1a	.29	R-3a	.27	A-5b	.31	T-5a	.35
A-2a	.27	R-4a	.31	A-9b	.20	R-2a	.38
A-3a	.36	R-1b	.32	T-1b	.30	R-3a	.27
A-4a	.34	R-3b	.27	T-2b	.36	R-4a	.31
A-5a	.23	R-4b	.26	T-3b	.35	R-9a	.23
T-2b	.36	T-1b	.30	T-4b	.33	R-10a	.28
T-5b	.25	T-3b	.35	T-5b	.25	A1-a	.29
R-2b	.31	T-4b	.33			A2-a	.27
R-5b	.19					A3-a	.36
A-1b	.28					A4-a	.34
A-2b	.27					A5-a	.23
A-3b	.24					R1-b	.32
A-4b	.26					R2-b	.31
A-5b	.31					R3-b	.27
						R4-b	.26
						R5-b	.19
Average	.30		.32		.29		.31

[5] Tyler, O. R., Goetz, W. H., and Slesser, C., "Natural Sandstone Rock Asphalt," *Engineering Bulletin of Purdue University*, Vol. XXV, No. 1, January, 1941, p. 22.

[6] Graves, L. D., "Aggregate—Bitumen Mixtures as Used for Patching and Surface Treating Indiana Roads," unpublished report to the Advisory Board, Joint Highway Research Project, Purdue University, July, 1940.

[7] Graves, L. D., "A Laboratory Study of Bituminous Road Mixtures," A Thesis submitted to the Faculty, Purdue University, August, 1940.

surface samples it seems quite certain that these values increased materially with time.

SURFACE SAMPLES

During the past summer (1946) each of the 51 test sections was sampled in an area that appeared by visual inspection to be representative of the section as a whole. Two samples were taken at each location, one in the wheel track and another between the wheel tracks. Thus 102 samples were taken in all. In each case the sample taken was about 15 in. square and 2 to 3 in. thick. In the laboratory, the top portion representing the surface treatment was stripped off and the bitumen content and grading analysis of the bitumen-free aggregate determined. Recovery of the asphalt from solution is also being attempted on some samples, but these data are not complete and they are not included here. Extraction of the bitumen was made with benzene in a Rotarex extractor, and both the bitumen content and surface area values were corrected for dust in the benzene solution. The results of these determinations are given in Tables 8 and 9.

Unfortunately, the original bitumen content in percentage of the aggregate cannot be calculated accurately even though the weights of the materials applied are known, because the bituminous materials were applied in two or three applications and the amount penetrating the old surface and serving to bind the new surface to the old one is not known. Also, earlier samplings of these sections were not so extensive as the present one. However, experience has shown that the amounts of bituminous material and aggregate applied in the treatment should produce a surface carrying from 4 to 5 percent bitumen by weight at the time of construction. These figures are verified by the results from the surface samples obtained in December, 1939, three months after construction. See Table 10.

If a value of 4 to 5 percent bitumen at the time of construction can be accepted, Table 8 shows that there has been a marked increase in bitumen content for practically all sections amounting to as much as 100 percent increase in some cases. This result verifies the one found by Shelburne from an analysis of periodic surface samples taken from state roads surface-treated in 1937. The increase in bitumen content can only be accounted for by loss of aggregate from the surface and (or) by bleeding of the bituminous material from below.

A comparison of the results for the two samples taken from the same section shows that these results in general are in close agreement. However, considerable differences in bitumen content exist between the various sections. The maximum value for any one section is 10.7 percent and the minimum is 4.4 percent. Though this difference is quite broad, it nevertheless represents considerable improvement over the maximum and minimum values of 13 and 2 percent, respectively, found on state roads surface treated in 1937.

TABLE 7
TEST RESULTS OF MINITRACK SPECIMENS

Specimen No.	Age	Percentage Bitumen	Density	Failure Position	Aggregate Percentage Retained					Surface Area
					½ in	No. 4	No. 16	No. 50	No. 200	
	mo		*lb per cu ft*							*sq. cm. per 100 gms.*
T-1-4	2	4 4	129	15 sec of 22nd @ 75°F						
T-1-5	6	4.5[a]	121	1 min of 21st @ 75°F	22.2	77.0	94.1	96.6	97 8	1943
T-1-6	11	3 5	127	15 sec. of 29th @ 75°F	30.3	80.6	93.2	96 1	98.0	1917
T-2-7	23			30 sec. of 19th @ 100°F						
T-2-8(WT)[b]	80	7 5	123	15 sec of 18th @ 125°F	15 0	61.0	83 1	90.6	96 1	3680
T-2-9(BWT)[b]	80	7 7	127	1 min of 20th @ 125°F	12.2	61.8	81 2	89.0	94.3	4760
R-10-1	2	3.5[a]	129	1 min of 12th @ 100°F	23 0	70 5	94 5	97.5	99 0	1388
R-10-2	6	3 3	119	1 min of 8th @ 100°F	25 7	87.0	96 1	98 0	99 4	978
R-10-3	11	3 4	124	1 min. of 18th @ 100°F	33 5	84.3	94 3	96.1	97 7	2032
R-10-10	23			15 sec of 12th @ 125°F						
R-10-11(WT)[b]	80	7 6	122	1 min of 23rd @ 125°F	3 9	49.7	74 0	86 3	94.6	5080
R-10-12(BWT)[b]	80	6.9	125	1 min of 18th @ 125°F	15 1	52.6	79.5	89 5	96 0	3940

[a] Estimated. [b] Percentage Bitumen, Grading, and Surface Area values from surface samples of corresponding section

Also, the great majority of the values shown in Table 8 lie between 7 and 10 percent. The sections constructed with stone A have an average bitumen content 1 percent

TABLE 8
COMPARISON OF BITUMEN CONTENT (PERCENTAGE)
After Seven Years' Service

Section No.	Stone Size	Tar TH						RC-3						AES-3						Average		
		Stone A			Stone B			Stone A			Stone B			Stone A			Stone B			Stone A	Stone B	Stones A & B
		WT[a]	BWT[a]	Avg.	WT	BWT	Avg.	WT	BWT	Avg.	WT	BWT	Avg.	WT	BWT	Avg.	WT	BWT	Avg.			
1	8F	7.5	8.3	7.9	7.9	7.7	7.8	7.5	9.0	8.3	7.9	7.6	7.8	10.2	10.4	10.2	7.1	6 4	6 8	8 6	7.4	8.1
2	8F	7.5	7.7	7.6	3.2	6.9	7.6	7.4	6.6	7.0	7 2	7.6	7.4	9.8	8 3	9.1	7.1	7 3	7 2	7 9	7.4	7.6
3	8F	8.1	8 5	8.3	9.4	7 8	8.6	8.7	9.1	8.4	7.4	7 3	7 4	7.7	7.5	7.6	7 2	7.6	7.4	8 1	7.8	7.9
4	8F	7.5	7.8	7 7	9.5	7.2	8.4	9.1	8.4	8.8	8.0	9.0	8 5	8.7	9.4	8.6	6 3	7.4	6.9	8 3	7.9	8.1
5	8F	7.9	8.3	8.1	7.7	8.6	8.2	8.1	8.4	8.3	7.8	9.1	8.5	9 2	8.9	9.1	4.4	6 3	5.4	8 5	7.3	7.9
6	9	10.0	10 7	10.4	7.8	7.8	7.8	6.9	6.5	6.7	9.5	8.3	8.9	9 0	8.0	8.5	4 6	4 5	4 6	8.5	7 1	7.8
7	11	8.5	9.3	8.9	8.3	7.6	8.0	8 6	8.6	8.6	9 0	7.1	8.1	10 2	9.4	9 8	4 4	5.6	5.0	9.1	7.0	8.1
8	11	6.5	6.9	6.7	8.5	6 2	7.4	8 9	9.4	9.2		7.6	7.6	6.5	7.9	7.2	5.8	7.2	6.5	7.7	7.2	7.4
9	8F							8.9	9.3	9.1							7 3	6 2	6 8	9.1	6.8	7.9
10	8F							7.6	6.9	7.3										7 3		7.3
Avg. Size	8F	7.7	8.1	7.9	8.5	7.6	8.1	8 2	8.3	8 1	7.7	8.1	7.9	9.1	8 9	8.9	6.6	6.9	6 7	8.3	7.6	7.8
Avg. Size	9	10.0	10.7	10.4	7.8	7.8	7.8	6 9	6.5	6.7	9.5	8.3	8.9	9.0	8.0	8.5	4.6	4.5	4.6	8.5	7.4	7.8
Avg. Size	11	7.5	8 1	7.8	8.4	6 9	7.7	8.8	9.0	8.9	9.0	7 4	7.8	8.4	8 7	8 5	5.1	6.4	5.8	8.4	7 1	7.7
Average		7.9	8.4	8.2	8 4	7.5	7.9	8 2	8.3	8.1	8 1	8.0	8 0	8.9	8.7	8 7	6 0	6.5	6.3	8.3	7.3	7.8
Grand Avg		8.2						8.1						7.5								

[a] WT—Sample taken in wheel track; BWT—Sample taken between wheel tracks.

TABLE 9
COMPARISON OF AGGREGATE SURFACE AREA (SQ. CM. PER 100 G.)
After Seven Years' Service

Section No.	Stone Size	Tar TH						RC-3						AES-3						Average		
		Stone A			Stone B			Stone A			Stone B			Stone A			Stone B			Stone A	Stone B	Stones A & B
		WT[a]	BWT[a]	Avg	WT	BWT	Avg.	WT	BWT	Avg.	WT	BWT	Avg.	WT	BWT	Avg	WT	BWT	Avg.			
1	8F	4930	6070	6500	2760	3840	3300	5740	3840	4790	4390	4410	4400	3600	4000	3800	3870	3320	3600	4700	3770	4230
2	8F	3680	4760	4220	3180	2920	3050	2810	2450	2630	4620	4090	4330	3660	3790	3730	3670	3010	3340	3530	3570	3550
3	8F	4470	3970	4220	3010	3600	3310	3760	3510	3640	3990	4670	4330	4140	3800	3970	3060	3170	3120	3940	3580	3760
4	8F	4410	3240	4175	2570	2820	2700	3290	3400	3350	4460	3600	4030	4020	3860	3940	3630	4840	4240	3320	3650	3740
5	8F	4040	4450	4250	2830	3390	3110	2870	3010	2940	4270	3780	4030	4310	4290	4300	4690	4700	4700	3830	3940	3890
6	9	3900	3800	3850	3510	3830	3670	2580	3480	3030	2580	3170	2880	4670	4340	4510	3840	5120	4480	3800	3680	3740
7	11	5210	4550	4880	3760	3450	3610	2200	2830	2520	3930	3960	3950	4030	4310	4170	3580	4240	3910	3860	3820	3840
8	11	4360	4040	4200	3430	2990	3210	4590	3690	4140		3970	3970	3830	4720	4280	4140	4200	4170	4210	3780	3990
9	8F							3720	3980	3850							4800	4140	4470	3850	4470	4160
10	8F							5080	3940	4510										4510		4510
Avg. Size	8F	4306	4640	4470	2870	3310	3090	3900	3450	3670	4350	4110	4230	3950	3950	3950	3950	3860	3910	4030	3740	3890
Avg. Size	9	3900	3800	3850	3510	3830	3670	2580	3480	3030	2580	3170	2880	4670	4340	4505	3840	5120	4480	3800	3680	3740
Avg. Size	11	4790	4300	4540	3600	3220	3410	3400	3260	3330	3930	3970	3960	3930	4520	4220	3860	4220	4040	4030	3800	3920
Average	.	4380	4450	4410	3130	3360	3240	3660	3410	3540	4030	3960	3990	4030	4140	4090	3920	4070	4000	4010	3740	3880
Grand Avg.	..	3830						3770						4040								

[a] WT—Sample taken in wheel track; BWT—Sample taken between wheel tracks.

		Stone A	*Stone B*	*Average*
Original Surface Area,	Size 8F	650	460	550
	Size 9	690	500	600
	Size 11	760	540	650

Careful workmanship during construction is reflected in these values. higher than those constructed with stone B, the average for both stones A and B being

7.8 per cent after seven years of service. Considering the three bituminous materials, the average values show that the average bitumen content for those sections constructed with TH and RC-3 is about equal, while the average bitumen content for the AES-3 sections is somewhat lower. This result might be expected since the distillation results on the bituminous materials used show a greater quantity of water in the AES-3 than volatile matter in the TH and RC-3. The average values of bitumen content are about the same in the case of TH and RC-3 for sections constructed with each of the two aggregates. However, in the case of the AES-3 sections, the average bitumen content for sections constructed with stone A is 8.7 per cent while the average for sections constructed with stone B is only 6.3 per cent. This seems significant inasmuch as the AES-3 sections constructed with stone B, almost without exception, are lower in bitumen content than the corresponding section constructed with stone A. If these sections had comparable bitumen contents at the time of construction, and if increase in bitumen content is due to loss of aggregate, it might be concluded that the AES-3 used showed better adhesion for stone B than for stone A.

TABLE 10
INCREASE IN BITUMEN CONTENT AND SURFACE AREA
December, 1939, to April, 1946

	Section No.	Bitumen Content (Percentage)			Surface Area (sq. cm per 100 g.)		
		Dec.-'39[a]	April-'46[b]	Increase	Dec.-'39[a]	April-'46[b]	Increase
AES-3	A-1-b	4.6	6.8	2.2	910	3600	2690
	A-2-b	5.1	7.2	2.1	1200	3340	2140
	A-3-b	5.3	7.4	2 1	1050	3120	2070
	A-4-b	5.0	6.9	1.9	1070	4240	3170
	A-5-b	3.9	5.4	1.5	800	4700	3900
	A-6-b	3.9	4.6	0.7	1350	4480	3130
	A-7-b	4.6	5.0	0.4	1330	3910	2580
	A-9-b	7.3	6.8	−0 5	1760	4470	2710
	Average	5.0	6.3	1.3	1180	3980	2800
RC-3	R-5-a	4.3	8.3	4.0	1550	2940	1390
	R-5-b	6.1	8.5	2.4	1020	4030	3010
	R-9-a	7 5	9.1	1.6	1750	3850	2100
	Average	6 0	8.6	2.7	1440	3610	2170
TH	T-5-a	2.3	8.1	5.3	1770	4250	2480
	T-5-b	1.9	8.2	6.3	1470	3110	1640
	T-6-a	9.3	10.4	1.1	2540	3850	1310
	T-8-b	3.6	7.4	3.8	1480	3210	1730
	Average	4.2	8.5	4.3	1820	3610	1790
Grand Average		5.0	7.4	2.4	1400	3800	2400

[a] Values are result of one determination only.
[b] Values are average results from two samples.

It was thought at the time the sections were sampled that samples taken in the wheel track and samples taken between wheel tracks might show significantly different results. However, Table 8 shows that the values for bitumen content in these two areas are not greatly different. Likewise, the results shown in Table 9 indicate no appreciable difference in the average values for surface area for samples taken at these two locations. Apparently the low traffic density of this road is reflected in these results.

If the results given in Table 9 for aggregate surface area of the various sections are compared with the values for original surface area for different sizes of stone shown at the bottom of the table, it is at once apparent that all of the aggregates, regardless of source or size, have degraded very markedly in the seven-year period. The increase in surface area during this time is of the order of magnitude of 500 or 600 percent. The average values for stone A are somewhat greater than the corresponding values for stone B. However, the original surface area of stone A was greater than that of stone B for all aggregate sizes.

Comparison of the surface area values for samples from the same section shows rather large differences. Since those differences cannot be explained by position of sample, percentage of bituminous material, or condition of the section, it must be concluded that the differences are due chiefly to non-uniformity in spreading the aggregate during construction. As was the case for values of bitumen content, the average values of surface area for the TH and RC-3 sections are about the same, while the average for the AES-3 sections is somewhat different, in this case larger. Less bitumen content in the AES-3 sections may account for the higher average value of surface area.

In Table 10, the bitumen content and surface area values obtained in the 1946 sampling are compared with the values obtained in December, 1939. The average values for all sections show that the bitumen content increased 2.4 percent from December, 1939, to April, 1946, or about 50 percent based on the 1939 value. Likewise, the average values for all sections show that the surface area of the bitumen free aggregate increased 2400 sq. cm. per 100 g. from December, 1939, to April, 1946, or about 170 percent of the 1939 value. Considering the average values for the AES-3, RC-3, and TH sections, the bitumen content of the TH sections shows the greatest increase, the RC-3 sections the next highest, and the AES-3 sections the lowest. Also, the average values of surface area for these same sections show those sections having the greatest increase in bitumen content also have the least increase in surface area, and vice versa.

Also, it is interesting to note that those sections which had the lowest bitumen content values in 1939 in general show the greatest increase in bitumen content from 1939 to 1946. The converse of this statement also seems to be true. This might indicate that the increase in bitumen content with time is due chiefly to a loss of aggregate from the road surface.

CONCLUSIONS

Based on the results of this performance study of a bituminous surface treatment test road seven years old, including a comparison of these results with those obtained in earlier performance surveys of this road, the following conclusions seem warranted.

1. The general success of Test Road No. 3 and longevity of the surface treatment can be attributed chiefly to the following factors: generally good soil conditions, high-level profile, adequate base, low traffic density, and, especially, careful workmanship during construction.

2. Even with very careful workmanship during construction and experienced personnel, the bitumen content, surface area of the aggregate, and performance of road-mix bituminous surface treatment may be expected to vary quite markedly over a seven-year period.

3. The surface texture of a bituminous surface treatment, even after seven years of service, is dependent upon the size of aggregate used during construction even though the aggregate degrades very appreciably under traffic.

4. Although some slight differences in the two stones used on Test Road No. 3 were noted, performance on this road seems to be more dependent upon aggregate size than on aggregate source, with the finer and better graded aggregates (Size No. 9) producing the better results if the mixture is properly proportioned.

5. Successful surface treatment may be constructed with either RC-3, AES-3 or TH (RT-9), though there is some evidence on Test Road 3 that TH mixtures may be more susceptible to scuffing and raveling or to bleeding if the proper proportions are not used. However, successful performance is apparently dependent more on proper proportions and uniformity in the mixture than on type of bituminous material.

6. Since the results of the Test Road No. 3 study show that, (1) the better-graded aggregates produce better results under proper conditions of design and construction but (2) are more difficult to mix with uniformity by road-mix methods, and since the results of the study also show that, (3) the bitumen content of the mixture and (4) the aggregate surface area may be expected to vary markedly even when very careful workmanship is employed, the use of plant-mix methods should be investigated for use in bituminous-surface-treatment construction.

Acknowledgement

Since this paper reports the continuation of work on which Mr. T. E. Shelburne, now Director of Research, Virginia Department of Highways, spent many years, to him must be given more of the credit for this work than the author himself can claim. Professor K. B. Woods, Associate Director of the Joint Highway Research Project, has fostered and encouraged the work on surface treatment and has been directly responsible for much of the plan and execution of the Test Road 3 study, including the latest results being reported here. He and Mr. F. H. Green, Research Engineer on the Project staff, each rated the various road sections visually. Mr. W. B. Luttrell and Mr. C. L. Chang of the Project, with the cooperation of the LaPorte District Office, State Highway Commission of Indiana, obtained the surface samples at locations selected by Professor Woods and the author. Mr. C. L. Chang, Graduate Assistant, performed the extraction and grading analyses under the author's supervision.