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A TAR SURFACE-TREATED ROAD IN NORTH CAROLINA

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TAR SURFACE TREATMENT OF LOW COST ROADS

Report of a Cooperative Study by the Bureau of Public Roads and Representatives of the Tar Industry

BECAUSE of the extensive application of surface treatment to the construction of low cost roads and the need for obtaining additional information on this subject, representatives of the tar industry and the Bureau of Public Roads have recently made a field and laboratory study, in North Carolina, of surface-treated roads on which tar was used. The particular type of treatment investigated consists essentially of the application of a light tar to the untreated road or prepared base, followed by an application of hot tar with a cover of mineral aggregate. A third application of tar, sometimes called the seal, is applied with a mineral aggregate cover after the surface has been subjected to traffic for a period of time. This method of treatment is designed to provide a wear-resisting surface which will adequately protect the base from deterioration and which can be economically maintained in a satisfactory condition.

The development of the double surface treatment as practiced in North Carolina resulted from early experiments in which a light tar was used on gravel or macadam bases. These tar-treated surfaces were very satisfactory for some time, as the tar penetrated into the road, allaying the dust and producing temporarily a bonded surface. However, under summer conditions, these surfaces disintegrated under traffic, and only by repeated re-treatments could the road surface be kept in good condition.

Later, more viscous tars applied hot were used. It was found that these hot tars produced a more durable surface on clean, hard bases but would not penetrate any existing dust film on the road. Because of lack of bond with the base, the road surfaces often corrugated badly or were picked up by traffic.

In order to obtain the advantages of both materials, the double surface treatment was developed, in which cold application tar was used as a prime and hot application tar for the second coat. In this way a wearing surface of greater thickness and stability was developed, which did not pick up under traffic but remained plastic and smooth under a wide range of weather conditions. Later, this same method of surface treatment was applied to topsoil and sand-clay surfaces.

A Tar-Treated Surface in Good Condition

This report embraces a detailed study of 19 projects in North Carolina, where approximately 1,200 miles of this form of treatment have been built on many different kinds of bases and under varying subgrade conditions. Inspection of a considerable mileage of this type of construction indicated that these projects were representative of North Carolina conditions. They were situated in the Atlantic coastal section, the Piedmont section, and the mountainous section in the western part of the State and were selected to cover a wide range of soil and climatic conditions as well as methods and materials of construction.

The detailed study of each project included an inspection to determine the appearance, condition, and riding qualities of the surface. Samples of bituminous mat, base, and subgrade representative of typical conditions were taken for analysis. For the purpose of this report the term "mat" is intended to describe the mixture of bituminous material and mineral aggregate immediately above the base. Information relative to details of construction, the type of maintenance employed and the amount of traffic carried was furnished by the State Highway Commission. Laboratory analyses of the bituminous mats were made and base material and subgrade samples were tested for grading and soil classification.

RESULTS OF SURVEY PROVE ADEQUACY OF TAR TREATMENT; IMPORTANCE OF SOIL STUDIES STRESSED

As a result of this survey the following conclusions seem warranted:

1. Surface treatment provides a satisfactory low-cost wearing surface on several types of base.
2. Surface treatment has the advantage over the thicker surface mats in that it is more pliable and can, therefore, adjust itself to the movement on a flexible base with a minimum amount of cracking.
3. New roads or base construction should be subjected to traffic for some time before being surface-treated, in order to produce adequate compaction and to determine the suitability of the base for surface treatment. Compaction under traffic is valuable as a means of detecting an excess of plasticity in the base, a condition which should be corrected.
4. In order to avoid failures in surface treatments resulting from unstable bases, research should be directed toward finding a means of reducing the plastic properties of the clay present, particularly in the natural soils.
5. A priming application is desirable as a final preparation of the base, not only to stabilize and waterproof the top but also to insure a bond between the base and the surface mat.
6. Tar of light consistency, because of its excellent penetrating and binding properties, makes a very satisfactory prime or stabilizing material.
7. Hot application tars are more satisfactory for the second application; medium and heavy cold application tars have many advantages in seal and re-treatment work.
8. A tough aggregate should be used as cover material in order to reduce crushing under traffic to a minimum so that the original texture of the surface and the stability of the mat may be retained.
9. Very fine sand or roadside material should not be used for blotting purposes because it has a tendency to produce either a brittle or an unstable surface.
10. A seal application is highly desirable as the final step in insuring a dense and waterproof surface.
11. Cold application tar is preferable to hot application tar in re-treatment work because it permits dragging and blading of the cover stone to produce a smoother surface. The finished road shows less tendency to bleed and is likely to retain its original texture for a longer time.
12. The principal requirement of bases for surface treatment is that they shall neither soften nor undergo appreciable change in volume with current changes of climatic or ground moisture conditions.
13. Soil tests serve to disclose those characteristics of the base material which materially affect the performance of surface treatments. In this connection the mechanical analysis is of assistance but by itself is not adequate for distinguishing good from poor base materials.
14. Determining the suitability of base soils according to their physical characteristics instead of by rule of thumb methods may show that the natural road soil, either alone or in some combination with other local soils, will serve as well or better than the more expensive base materials of recognized value.
15. A content of clay binder as low as 5 per cent has proved satisfactory in surface-treated bases. However, clays with capillary and cohesive properties as high as those of average or "statistical" soils[1] and shrinkage properties considerably lower, may not prove detrimental in base mixtures even when present in amounts as great as 20 per cent. More than 10 per cent of highly plastic clay and all cases of highly micaceous material should be regarded with suspicion.
16. Some method of correcting unsatisfactory base material may often prove desirable. Fine sand is used satisfactorily as an admixture to reduce clay content. Coarse material has not much value for this purpose and may be used to better advantage as a top course. The best method and material to use in stabilizing a soil will depend upon the character of the particular soil or base material. Often a thin top course of suitable material will increase the stability of the base sufficiently. In other cases, it may be advantageous to use a tar primer or to mix tar into the base.

VARIOUS BASES USED FOR SURFACE TREATMENT

The essential requirements of bases for surface treatment are that they shall carry the load imposed upon them and shall remain stable irrespective of moisture conditions without undergoing any change sufficient to injure the surface treatment. Among the more important materials used in base construction are the local topsoils, sand clay, sand-clay-gravel, shell rock, and various crushed materials. In North Carolina, topsoil and sand-clay, because of their greater prevalence, have been used more extensively than other materials in this type of construction.

The bases which were used on the sections discussed in this report were, with one exception, originally constructed to serve as topsoil, sand-clay, or sand-clay-gravel roads. The exception was a base of sand-clay-gravel built to be surface-treated immediately.

The topsoil and sand-clay used for surfacing consisted of a mixture of sand and clay either obtained from local deposits or produced by incorporating sand or clay with the natural soil. The surfaces were usually built with a compacted thickness of 6 to 9 inches at the center and feather-edged to the full width of the roadway.

The gravel surfacing material was a mixture of gravel, sand, and clay binder obtained largely from pits or stream beds. It was hauled to the roadway, spread, bladed, and compacted under traffic. The cross section was either of uniform thickness for a definite width or tapered to the full width of the roadway. The compacted thickness of the course ranged from 4 to 10 inches, depending on the character of the subsoil.

In the mountainous areas where subsoil and moisture conditions were unusually bad a subbase, made up of hammer-broken field stone, approximately 6 inches thick, was built before the construction of the gravel course. Projects 13, 14, and 15 were of this type.

[1] The significance of the term "statistical soils" is discussed on p. 15. See also PUBLIC ROADS, vol. 12, No. 5, July, 1931, p. 131.

CONDITIONING THE ROAD FOR SURFACE TREATMENT

Before applying the surface treatment it was generally necessary to do considerable work in the preparation of the base. The particular method followed and amount of work required depended on its condition.

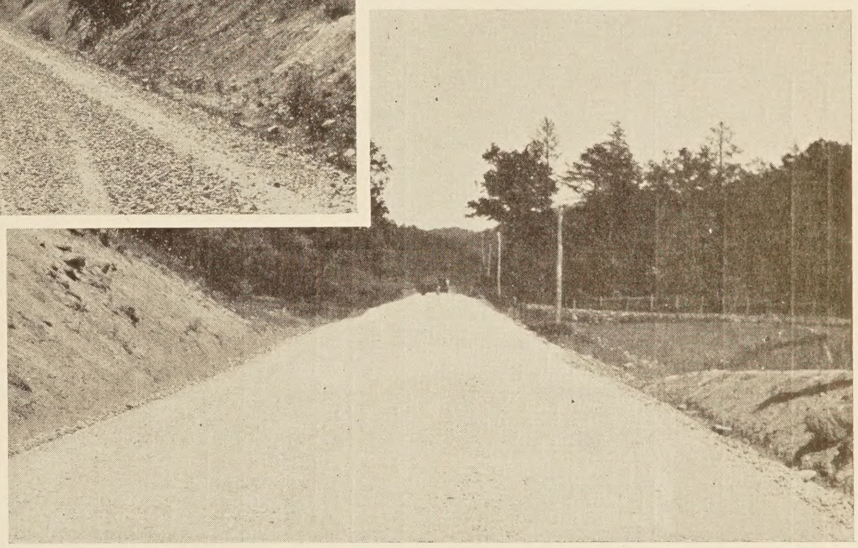
If the base course was of sufficient thickness and composed of satisfactory materials the preparation generally consisted of light blading or dragging to obtain a smooth, uniform surface. If the thickness was insufficient new material was added and worked into the base course to produce a uniform andcompacted condition of the surface.

A layer of crushed stone screenings was applied to the surface of the south portion of project 19, prior to surface treatment, to reduce the plastic condition of the topsoil road.

On projects 4 and 5, where a loose and nonuniform condition of the topsoil and sand-clay existed, the soils were stabilized previous to treatment by road-mixing the soil with tar to form a compacted mat 2 to 3 inches in thickness.

With the exception of project 15, the bases were subjected to traffic for a considerable time prior to surface treatment. The compaction and bond obtained

LOOSE AGGREGATE ON SURFACE OF BASE DISTRIBUTED AND ROLLED IN PREPARATION FOR APPLICATION OF PRIMER



LOOSE AGGREGATE BLADED UNIFORMLY AND READY FOR APPLICATION OF PRIMER

FIGURE 1.—SAND-GRAVEL BASES READY FOR SURFACE TREATMENT

Where the material contained excess clay, fine sand was often added to reduce the clay content. Coarse material, such as gravel or crushed stone, was also used in some cases to improve the condition of the base. When so used it was generally applied as a thin surface course rather than being incorporated into the base material. If the surface was loose because of insufficient or unsatisfactory binder material, as was the case when comparatively clean sand-gravel was used in the base course, a somewhat heavier application of tar primer was used.

On project 12, where the untreated surface cracked excessively in dry weather and was slippery in wet weather, a ¾-inch layer of creek sand was mixed into the top 4 inches of the road surface to reduce the plastic properties of the topsoil and to provide a more stable base for the subsequent surface treatment.

On the sand-clay portion of project 18 a layer of crushed stone 2½ inches to 1 inch in size, was rolled into the surface to stabilize its loose, unbonded condition.

depended upon their time in service and the character of the materials used in their construction.

Immediately prior to surface treatment the bases were generally dragged or bladed lightly to obtain a smooth uniform surface. On those projects where the surface was well bonded it was swept. If the surface was loose, as on the projects where relatively clean sand-gravel was used, the loose material was spread uniformly over the surface before priming.

Table 1 gives the mechanical analysis of sand-clay-gravel materials taken from the base courses of a number of projects, determined by the method commonly used in studying materials to be used for base construction. It is evident, however, that this method does not provide sufficient information, as it does not distinguish between silt and clay nor does it indicate the character of the clay.

Tables 2 and 3 give more definite and complete information on the properties of the various materials

TABLE 1.—*Mechanical analysis of material taken from the base courses of a number of typical sand-clay-gravel roads which have been surface-treated*

Laboratory number	6206	6063	6064	6060	6061	6062	6203	6196	6197	6199	6198	6201
Project number	1	2	2	7	7	7	11	13	14	15	16	16
Hole number	35	10	12	7	8	9	23	18	19	21	20	22
Total retained on—	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
3-inch screen	-------	-------	-------	-------	-------	-------	10	9	0	7	0	-------
2½-inch screen	-------	-------	-------	-------	-------	-------	19	16	45	12	5	0
2-inch screen	-------	-------	-------	0	0	0	23	23	51	19	22	14
1½-inch screen	-------	-------	-------	4	3	8	28	26	57	36	29	28
1¼-inch screen	0	-------	-------	4	3	8	32	30	60	39	32	30
1-inch screen	2	-------	0	7	8	12	37	33	63	44	41	32
¾-inch screen	4	0	3	13	11	12	42	39	68	51	46	39
½-inch screen	6	2	9	17	14	15	49	45	73	57	52	45
¼-inch screen	14	11	17	22	21	20	58	54	77	65	57	52
No. 10 sieve	27	23	27	29	29	27	66	65	80	73	62	58
No. 20 sieve	43	39	37	40	42	39	75	75	82	80	67	63
No. 30 sieve	49	48	41	45	49	41	79	79	83	83	69	65
No. 40 sieve	58	60	47	51	57	44	84	84	84	86	72	68
No. 50 sieve	66	69	52	56	64	48	89	89	86	88	74	72
No 80 sieve	73	78	61	62	72	59	94	94	89	90	79	80
No. 100 sieve	75	79	67	63	-------	61	95	95	90	91	81	82
No. 200 sieve	82	84	75	66	79	70	97	97	93	93	86	88
Percentage of original sample over ¼ inch	14	11	17	22	21	20	58	54	77	65	57	52
Percentage of original sample under ¼ inch	86	89	83	78	79	80	42	46	23	35	43	48
Percentage of silt and clay (by washing)	18. 1	16. 0	24. 4	33. 6	22. 2	30. 0	3. 0	2. 4	6. 9	7. 5	13. 9	11. 3
Condition of bituminous surface December, 1931	Good.	Good.	Cracked.	Good.	Good.	Wavy.	Good.	Wavy.[1]	Slightly wavy.[1]	Good.	Good.	Slightly cracked

[1] Base corrugations not removed before surface treating.

TABLE 2.—*Analyses of base and subgrade materials on projects having sand-clay-gravel base*

Identification, location, and description of sample					Mechanical analysis						Physical characteristics of material passing No. 40 sieve						Soil group	Condition of wearing surface, December, 1931
		Laboratory No.			Particles larger than 2 millimeters	Particles smaller than 2 millimeters, per cent							Shrinkage		Moisture equivalent			
Project No.	Hole No.	Base	Subgrade			Coarse sand [1]	Fine sand [2]	Silt [3]	Clay [4]	Colloids [5]	Liquid limit	Plasticity index	Limit	Ratio	Centrifuge	Field		
1	36	S-6369	--------	4 inches thick	24	36	35	8	21	16	34	19	18	1. 8	17	23	A-2 plastic	Badly cracked.
1	35	S-6206	--------	3½ inches thick	30	57	20	8	15	12	32	15	20	1. 7	18	24	do	Good.
1	35	--------	S-6194	14 inches thick; 4 inches below surface	0	7	41	37	15	8	17	3	15	1. 9	17	16	do	
2	10	S-6063	--------	3 inches thick	30	58	20	8	14	12	29	13	19	1. 7	19	24	do	Do.
2	10	--------	S-6057	4½ inches thick; 4½ inches below surface	1	15	55	15	15	11	19	0	18	1. 8	8	18	A-3	
2	12	S-6064	--------	5 inches thick	26	32	35	11	22	17	34	18	17	1. 8	18	22	A-2 plastic	Cracked.
2	12	--------	S-6059	2 inches thick; 6 inches below surface	0	47	37	7	9	6	19	0	21	1. 7	7	20	A-3	
7	7	S-6060	--------	5 inches thick	30	34	19	11	36	30	48	28	18	1. 7	30	27	A-7	Good.
7	7	--------	S-6054	6¼ inches below surface	1	11	20	21	48	32	61	29	31	1. 5	34	42	A-5	
7	8	S-6061	--------	4¼ inches thick	34	52	20	15	13	5	12	2	29	1. 5	12	11	A-2	Do.
7	8	--------	S-6055	6 inches below surface	0	6	23	28	43	27	46	24	16	1. 8	34	32	A-7	
7	9	S-6062	--------	5¾ inches thick	32	30	36	25	9	5	18	4	18	1. 8	11	17	A-2	Wavy.
7	9	--------	S-6056	3 inches thick; 7 inches below surface	2	26	29	22	23	18	29	14	16	1. 8	18	21	A-2 plastic	
11	23	S-6203	--------	4½ inches thick	71	66	25	5	4	3	21	0	28	1. 5	10	25	A-3 highly micaceous	Good.
11	23	--------	S-6173	6½ inches below surface	1	17	37	16	30	18	33	15	21	1. 7	28	25	A-2 plastic	
13	18	S-6196	--------	6 inches thick	66	68	24	3	5	3	23	0	29	1. 5	7	28	A-3	Wavy; base corrugations not removed before treatment.
13	18	--------	--------	Broken stone 6 inches thick	----	----	----	----	----	----	----	----	----	----	----	----		
13	18	--------	S-6170	13 inches below surface	0	20	47	15	18	14	28	6	24	1. 6	27	31	A-2 plastic; highly micaceous.	
14	19	S-6197	--------	4 inches thick	45	25	47	17	11	6	25	7	24	1. 6	14	24	do	Slightly wavy; base corrugations not removed before treatment.
14	19	--------	--------	Broken stone 6 inches thick	----	----	----	----	----	----	----	----	----	----	----	----		
14	19	--------	S-6171	Under 6-inch stone base	32	9	29	32	30	9	44	11	33	1. 4	37	40	A-5 highly micaceous	
15	21	S-6199	--------	4 inches thick	38	46	29	18	7	4	26	0	(6)	-----	22	28	A-2	Good.
15	21	--------	--------	Broken stone 6 inches thick	----	----	----	----	----	----	----	----	----	----	----	----		
15	21	--------	S-6200	Under 6-inch stone base	55	21	32	29	18	8	26	7	23	1. 7	23	25	A-2 plastic; appreciable mica.	
16	20	S-6198	--------	7½ inches thick	53	31	42	16	11	5	19	0	23	1. 7	13	19	A-2 slightly micaceous	Good.
16	20	--------	S-6172	8½ inches below surface	0	17	31	23	29	17	43	19	26	1. 6	37	33	A-7	
16	22	S-6201	--------	12 inches thick	58	41	38	13	8	4	22	0	24	1. 6	10	21	A-3	Slightly cracked.
16	22	--------	S-6202	13 inches below surface	44	29	43	19	9	7	25	0	29	1. 5	17	27	A-2 highly micaceous	

[1] 2.0 to 0.25 millimeter.
[2] 0.25 to 0.05 millimeter.
[3] 0.05 to 0.005 millimeter.
[4] Smaller than 0.005 millimeter.
[5] Smaller than 0.001 millimeter.
[6] No shrinkage. Soil swelled.

Table 3.—*Analyses of base and subgrade materials on projects having topsoil or sand-clay base*

Project No.	Hole No.	Laboratory No.: Base	Laboratory No.: Subgrade	Identification, location, and description of sample	Mechanical analysis: Particles larger than 2 millimeters	Particles smaller than 2 millimeters, per cent: Coarse sand [1]	Fine sand [2]	Silt [3]	Clay [4]	Colloids [5]	Physical characteristics of material passing No. 40 sieve: Liquid limit	Plasticity index	Shrinkage: Limit	Shrinkage: Ratio	Moisture equivalent: Centrifuge	Moisture equivalent: Field	Soil group	Condition of wearing surface, December, 1931
TOPSOIL BASE PROJECTS																		
4	1	S-6043	--------	7 inches thick	0	40	40	11	9	4	16	0	20	1.7	5	18	A-3	Lean.
	1	--------	S-6044	6 inches thick, 10¼ inches below surface.	4	32	24	21	23	16	28	13	17	1.8	21	20	A-2 plastic	
	2	S-6045	--------	1 inch thick	3	46	26	16	12	5	16	3	16	1.8	14	15	A-2	Spongy and cracked.
	2	--------	S-6046	5½ inches below surface	3	23	20	23	34	21	49	22	27	1.6	40	36	A-7	
	3	S-6047	--------	6½ inches thick	0	37	40	14	9	4	14	0	19	1.8	7	15	A-3	Good.
	3	--------	S-6048	2½ inches thick overlying sand soil.	3	40	30	14	16	11	21	8	18	1.8	15	18	A-2 plastic	
6	4	S-6049	--------	18 inches thick	1	52	22	12	14	8	15	5	13	1.9	11	13	A-2	Do.
	5	S-6050	--------	2 inches thick	4	51	18	14	17	10	20	8	17	1.8	18	16	A-2 plastic	Do.
	5	--------	S-6051	8 inches below surface	4	37	22	20	21	16	42	16	29	1.5	35	34	A-5	
	6	S-6052	--------	8½ inches thick	2	41	32	9	18	13	13	2	14	1.9	8	12	A-3	Do.
	6	--------	S-6053	10 inches below surface	1	21	26	19	34	26	47	20	28	1.5	35	36	A-7	
8	14	S-6165	--------	6 inches thick	0	20	35	29	16	6	19	4	17	1.8	18	19	A-2 plastic	Rough and wavy.
	33	S-6190	--------	6½ inches thick	0	33	21	29	17	11	20	5	19	1.9	18	19	A-2 highly micaceous	Badly cracked.
	33	--------	S-6205	5½ inches thick	59	21	30	27	22	14	27	11	25	1.7	23	21	A-2 plastic	
	33	--------	S-6191	13 inches below surface	0	7	26	39	28	18	47	23	23	1.6	38	34	A-7	
9	15	S-6166	--------	7 inches thick	13	34	30	22	14	8	14	3	15	1.9	14	14	A-2 plastic	Good.
	15	--------	S-6167	8¼ inches below surface	0	18	12	26	44	34	52	27	19	1.7	37	39	A-7	
	16	S-6168	--------	7 inches thick	0	47	22	17	14	10	18	4	17	1.8	13	16	A-2 plastic	Slightly cracked.
	16	--------	S-6169	7¾ inches below surface	0	25	23	23	29	18	41	21	19	1.7	29	28	A-7	
10	24	S-6174	--------	8 inches thick	0	27	38	16	19	14	24	8	19	1.8	20	21	A-2 plastic	Good.
	24	--------	S-6175	9 inches below surface	1	14	33	33	20	12	46	13	40	1.3	38	45	A-5 highly micaceous	
	25	S-6176	--------	5½ inches thick	23	18	27	32	23	13	34	12	25	1.6	27	29	A-4 appreciable mica and gravel.	Cracked.
	25	--------	S-6204	6 inches below surface	0	14	51	17	18	14	42	12	36	1.4	25	41	A-5 highly micaceous	
12	30	S-6186	--------	7¼ inches thick	0	40	34	10	16	9	19	4	15	1.9	17	19	A-2 plastic	Good.
	30	--------	S-6188	8 inches below surface	2	25	26	19	30	24	46	19	29	1.5	28	36	A-5 highly micaceous	
	31	S-6187	--------	5¼ inches thick	2	35	20	21	24	14	39	16	23	1.7	28	30	A-2 plastic	Slightly cracked.
	31	--------	S-6189	6 inches below surface	0	32	33	23	12	8	53	0	47	1.2	34	55	A-5 highly micaceous	
17	29	S-6184	--------	10 inches thick	0	39	33	13	15	12	18	6	16	1.9	17	16	A-2 plastic	Good.
	29	--------	S-6185	11 inches below surface	1	17	24	18	41	33	53	24	25	1.6	33	36	A-7	
18	27	S-6180	--------	4 inches thick	0	25	30	19	26	17	29	10	21	1.7	28	24	A-2 plastic	Rutted.
	27	--------	S-6181	4¾ inches below surface	0	22	41	20	17	13	40	12	36	1.4	24	39	A-5 highly micaceous	
19	28	S-6182	--------	6 inches thick	0	36	26	13	25	13	27	10	17	1.8	23	20	A-2 plastic	Good.
	28	--------	S-6183	7 inches below surface	0	1	38	30	31	22	56	22	32	1.5	40	46	A-5 highly micaceous	
SAND-CLAY BASE PROJECTS																		
2	11	S-6058	--------	2½ inches thick	1	10	65	10	15	11	18	0	21	1.7	8	18	A-3	Good.
3	13	S-6195	--------	6¼ inches thick	0	60	20	7	13	10	23	10	16	1.9	13	18	A-2 plastic	Pitted.
	13	--------	S-6164	7 inches thick 8 inches below surface.	0	25	33	32	10	4	16	0	20	1.7	12	12	A-2	
5	34	S-6192	--------	10½ inches thick	0	55	12	7	26	23	39	18	23	1.6	24	28	A-2 plastic	Good.
	34	--------	S-6193	12½ inches below surface	0	68	16	6	10	7	15	0	18	1.8	5	17	A-3	
18	26	S-6177	--------	4 inches thick. Stone veneer added.	0	56	20	10	14	10	23	7	19	1.7	20	21	A-2 plastic, some mica	Do.
	26	--------	S-6178	3½ inches thick 6½ inches below surface.	0	36	23	13	28	20	46	22	26	1.6	31	33	A-7 appreciable mica	
	26	--------	S-6179	10 inches below surface	0	31	45	10	14	10	34	0	38	1.3	19	36	A-2 some mica	

[1] 2.0 to 0.25 millimeter. [2] 0.25 to 0.05 millimeter. [3] 0.05 to 0.005 millimeter. [4] Smaller than 0.005 millimeter. [5] Smaller than 0.001 millimeter.

used as bases on these projects, and similar information regarding the subgrade soils. Table 2 gives the mechanical analyses and also the results of the physical tests performed on samples taken from the sand-clay-gravel projects. Table 3 gives corresponding data on samples taken from the topsoil and sand-clay projects. The significance of these test results in determining the suitability of the materials is discussed subsequently in this report.

CONSTRUCTION OF THE SURFACE TREATMENT

A prime coat is the initial application of a tar having low viscosity to the original untreated road surface for the purpose of hardening and moistureproofing the upper portion of the existing road. It produces a dust-free surface to which the subsequent application of more viscous tars will readily adhere.

In cases where the base was well bonded the surface was swept to remove dust and other objectionable material, prior to the application of the primer. Where the surface of the base was loose sweeping was omitted and the loose material was spread uniformly and sometimes rolled. Figure 1 shows two examples of such a surface ready for priming. The two upper views of Figure 2 illustrate the excellent surface which can be obtained by proper prime treatment of a loose base. The material used as a primer was a cold application tar, generally having a specific viscosity [2] of 8 to 13 at 40° C. However, 13-to-18 and 18-to-25 viscosity tars were used where the surfaces were open or loose. The amount of primer used on most projects was a third of a gallon; on others as much as 0.4 or 0.5 gallon was used. On projects 4 and 5, where the tar priming material was used to construct a mixed base; 1.2 and 1.5 gallons were used. The kinds and amounts of tar primer used on the various projects are given in Table 4, and typical specifications and test values are given in Table 5.

[2] Unless otherwise specified, statements regarding viscosity refer to the specific viscosity (Engler) at 40° C.

TABLE 4.—*Details of construction and re-treatments of projects studied*

Project No.	1	2	3	4	5	6	7	8	9	10
Length in miles	8.33	9.432	10.3	5.0	6.7	8.5	15.841	5.0	7.955	9.4
CONSTRUCTION OF BASE										
Date constructed	December, 1927	December, 1927	April, 1928	July, 1923	1926	July, 1923	May, 1929	May, 1927	July, 1928	December, 1928.
Material	Sand-clay-gravel	Sand-clay-gravel	Sand-clay	Topsoil	Sand-clay	Topsoil	Sand-clay-gravel	Topsoil	Topsoil	Topsoil.
Width in feet	24	24	24	18	30	30	18	18	30	24.
Depth in inches (center)	4	4	4	10	10	10	6	6	9	6.
Subbase										
Surface behavior: Dry weather	Compacted	Compacted	Compacted	Raveled	Raveled	Raveled	Compacted	Compacted	Compacted	Compacted.
Surface behavior: Wet weather	Shallow ruts	Shallow ruts	Shallow ruts	Compacted	Compacted	Compacted	Shallow ruts	Shallow ruts	Shallow ruts	Slippery.
PREPARATION OF BASE										
Preliminary preparation										
Condition at time of priming	Bonded, smooth	Bonded, smooth	Bonded, smooth	Generally loose and nonuniform.	Generally loose and nonuniform.	Bonded, smooth	Bonded, smooth	Bonded, smooth	Bonded, smooth	Bonded, smooth.
SURFACE TREATMENT [1]										
Date constructed	October, 1928	July, 1928	April, 1929	July, 1928	1927	1928	September, 1929	July, 1928	September, 1928	May, 1923.
Prime coat:										
Grade of tar	TC-1	TC-1	TC-1	TC-3 [2]	TC-4 [2]	TC-1	TC-1	TC-1	TC-1	TC-1.
Gallons per square yard	⅓	⅓	⅓	1.2	1.5	⅓	⅓	⅓	⅓	⅓.
Second application:										
Grade of tar	TH-1	TH-1	TH-1	(3)	(3)	TH-1	TH-1	TH-1	TH-1	TH-1.
Gallons per square yard	⅓	⅓	⅓			⅓	⅓	⅓	⅓	⅓.
Cover material:										
Type	Granite	Granite	Limestone			Granite	Granite	Granite	Granite	Limestone.
Size	1 to ⅜ inch	1 to ⅜ inch	1¼ to ⅜ inch			1 to ⅜ inch	1 to ⅜ inch	¾ to ¼ inch	1 to ⅜ inch	1 to ⅜ inch.
Pounds per square yard	35	35	38			35		45		
Cost of double application	$2,191.78	$2,100.32	$1,574.02				$1,745.08	[4] $4,224	$1,946.97	$2,020.14.
Seal coat:										
Date of application	March, 1930	July, 1929	November, 1929	August, 1928	1928	1929	September, 1930	April, 1929	June, 1929	October, 1929.
Grade of tar	TC-4	TC-4	TC-5	TC-3	TC-4	TC-4	TC-5	TH-1	TC-4	TC-4.
Gallons per square yard	0.3	⅓	⅓	0.4	½	⅓	0.3	¼	⅓	0.3.
Cover material:										
Type	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Limestone.
Size	¾ to ⅜ inch	¾ to ⅜ inch	¾ to 3/16 inch	1 to ⅜ inch	1¼ to ⅜ inch	¾ to ⅜ inch	¾ to ⅜ inch	¾ to ¼ inch	1 to ⅜ inch	¾ to ⅜ inch.
Pounds per square yard	20	20	20	20	35		20	25		16.
RE-TREATMENT										
First re-treatment:										
Date								May, 1930		
Grade of tar								TH-1		
Gallons per square yard								0.3		
Cover material—										
Type								Limestone		
Size								¾ to ⅜ inch		
Pounds per square yard								32		
Second re-treatment:										
Date										
Grade of tar										
Gallons per square yard										
Cover material—										
Type										
Size										
Pounds per square yard										

CONSTRUCTION OF BASE

Project No.	11	12	13	14	15	16	17	18		19	
Length in miles	4.1	11.269	3.5	6.856	10.5	11.0	7.4	2.0	4.01	2.8	8.6
Date constructed	May, 1926	June, 1928	June, 1929	October, 1927	July, 1930	May, 1924	June, 1928	August, 1927		September, 1927	
Material	Sand-clay-gravel	Topsoil	Sand-clay-gravel	Sand-clay-gravel	Sand-clay-gravel	Sand-clay-gravel	Topsoil	Topsoil	Sand-clay.	Sand-clay.	Topsoil.
Width in feet	22	30	22	22	22	22	30	24	24	26	26.
Depth in inches (center)	10	9	5	5	5	4 to 12	9	9	9	9	9.
Subbase			6 inches field stone	6 inches field stone	6 inches field stone						
Surface behavior: Dry weather	Raveled	Raveled	Raveled	Raveled	Raveled	Raveled	Raveled	Compacted	Raveled		Compacted.
Surface behavior: Wet weather	Compacted	Compacted	Compacted	Compacted	Compacted	Compacted	Compacted	Rutted	Compacted		Slippery.

PREPARATION OF BASE

Project No.	11	12	13	14	15	16	17	18 (2.0)	18 (4.01)	19 (2.8)	19 (8.6)
Preliminary preparation		Layer of sand worked into surface December, 1928.							Surface course 2 inches of crushed stone.		Screenings worked into surface.
Condition at time of priming	Loose	Bonded, smooth	Loose, corrugated	Bonded, corrugated.	Loose	Bonded, corrugated.	Bonded, smooth	Bonded, smooth			Bonded, smooth.

SURFACE TREATMENT[1]

Project No.	11	12	13	14	15	16	17	18 (2.0)	18 (4.01)	19 (2.8)	19 (8.6)
Date constructed	October, 1926	June, 1929	October, 1930	August, 1928	May, 1930	August, 1925	August, 1928	October, 1928			October, 1928.
Prime coat:											
Grade of tar	TC-1	TC-1	TC-1	TC-1	TC-2	TC-1	TC-1	TC-1	TC-1		TC-1.
Gallons per square yard	0.4	⅓	⅓	⅓	0.4 to 0.5	⅓	⅓	⅓	0.4		⅓.
Second application:											
Grade of tar	TH-1	TH-1	TC-6	TH-1	TH-1	TH-1	TH-1	TH-1	TH-1		TH-1.
Gallons per square yard	0.4	⅓	⅓	⅓	0.4 to 0.5	⅓	⅓	⅓	0.4		⅓.
Cover material:											
Type	Granite	Limestone	Local stone	Limestone	Limestone	Limestone	Limestone		Limestone.		
Size	1 to ⅜ inch	1 to ⅜ inch	1 to ⅜ inch	1 to ⅜ inch	1 to ⅜ inch	⅝ to ⅜ inch	1 to ⅜ inch		1 to ⅜ inch.		
Pounds per square yard	35	35	50		50	35-45	35		35.		
Cost of double application		$2,696.23		$2,326.21	$2,620		$1,983.90	[5] $4,555.80			[6] $3,894.20
Seal coat:											
Date of application	November, 1927	October, 1929		August, 1929	October, 1930	May, 1926	July, 1929		August, 1929.		
Grade of tar	TC-4	TC-5		TC-4	TC-5	TC-3	TC-4		TC-4.		
Gallons per square yard	¼	⅓		0.3	0.3	0.3	0.3		⅓.		
Cover material:											
Type	Limestone	Limestone		Limestone	Limestone	Limestone	Limestone		Limestone.		
Size	1 to ⅜ inch	¾ to ⅜ inch		¾ to ⅜ inch	¾ to ⅜ inch	⅝ to ⅜ inch	1 to ⅜ inch		1 to ⅜ inch.		
Pounds per square yard	25	20			12 to 16	20	20		20.		

RE-TREATMENT

Project No.	11	12	13	14	15	16	17
First re-treatment:							
Date	August, 1930					1928	
Grade of tar	TC-5					TC-4	
Gallons per square yard	0.3					0.3	
Cover material—							
Type	Limestone					Limestone	
Size	¾ to ⅜ inch					1 to ⅜ inch	
Pounds per square yard	20					20	
Second re-treatment:							
Date						May, 1930	
Grade of tar						TC-5	
Gallons per square yard						⅓	
Cover material—							
Type						Limestone	
Size						¾ to ⅜ inch	
Pounds per square yard						22	

[1] Width of surface treatment 18 feet on all projects.
[2] Priming material used in mixed base.
[3] Second application also served as seal.
[4] Includes cost of seal application.
[5] Includes cost of crushed stone surface course.
[6] Includes cost of crushed stone and screenings surface courses.

TABLE 5.—*Typical specification and test values for the priming materials used*

Grade	TC-1		TC-2		TC-3 [1]		TC-4 [2]	
	Specification	Analyses	Specification	Analyses	Specification	Analyses	Specification	Analyses
Specific gravity at 77° F	1.10 to 1.18	1.13 to 1.17	1.10 to 1.18	1.14 to 1.15	1.10 to 1.18	1.13 to 1.15	1.10 to 1.18	
Water, per cent	2.0	0.5 to 2.0	2.0	1.1 to 1.7	2.0	1.5 to 2.0	2.0	
Free carbon, per cent	2 to 10	2.1 to 6.2	2 to 10	1.6 to 4.5	2 to 10	2.1 to 3.0	2 to 10	
Specific viscosity, Engler, 40° C	8 to 13	9.3 to 14.8	13 to 18	13.1 to 17.9	18 to 25	18.9 to 24.7	25 to 35	
Total distillate by weight, per cent:								
To 170° C	5.0	0.3 to 4.2	5.0	1.1 to 1.8	5.0	1.3 to 2.8	5.0	
To 300° C	40.0	25.8 to 37.4	35.0	23.9 to 29.8	35.0	24.8 to 31.4	40.0	
Softening point of residue,[3] ° C	[4] 65	50.0 to 64.5	[4] 65	58.0 to 60.0	65	51.5 to 64.0	65	

[1] This grade was used in the mixed base treatment on project 4.
[2] This grade was used in the mixed base treatment on project 5. Test values on TC-4 materials not available.
[3] Cube-in-water method.
[4] Specification limit was 60 prior to 1928 and 65 for 1928 and after.

During cool weather the primer was heated to a temperature of 100° to 150° F. as an aid in obtaining better penetration into the base. During warm weather it was applied at a temperature of 80° to 100° F. Whenever possible, traffic was prevented from passing over the primed base for a period of 24 to 48 hours. In some cases it was necessary to prime half of the base at a time. The lower photograph of Figure 2 is typical of the appearance of a primed base prior to the second application of tar material.

SECOND APPLICATION OF TAR

The next step in the construction of the surface-treated wearing surface is an application of a more viscous tar material, the function of which is to combine with the mineral aggregate cover to produce a thin well-bonded tar mat which will adhere to the primed base, and provide a wear-resistant and waterproof surface.

The material generally used was a hot application tar, heated to a temperature of 160° to 200° F. It was distributed after thorough penetration of the prime, in a single application at the rate of a third to a half gallon per square yard.

A cold application tar was used as a second application on project 13, where the long haul made it more convenient to use this grade of material. On projects 4 and 5 the type of tar used in the construction of the mixed bases was also employed for the second application or seal.

The kinds and amounts of second application hot tars (TH-1) materials, used on the various projects are given in Table 4 and typical specifications and test values in Table 6.

TABLE 6.—*Typical specifications and test values of the hot tar materials used*

	Specification	Analyses
Water	None.	None.
Float test at 32° C., seconds	[1] 90 to 150 [2] 120 to 170	[1] 109 to 131 [2] 121 to 169
Distillation by weight, per cent:		
Total to—		
170° C., not more than	1	0.0 to 0.7
235° C., not more than	10	0.5 to 9.1
270° C., not more than	15	8.2 to 17.4
300° C., not more than	25	12.7 to 23.5
Residue, by weight, per cent, not less than	75	
Specific gravity of total distillate at 25° C., not less than	1.03	
Softening point of residue[3] °C., not more than	75	53.3 to 73.0
Total bitumen soluble in CS_2, per cent	82 to 95	83.9 to 92.7

[1] Specification limits used up to and including 1927.
[2] Specification limits used after 1927.
[3] Cube-in-water method.

APPLICATION OF COVER MATERIAL

Following the second application of tar a cover of aggregate was applied in sufficient quantity to combine with the tar material to form a stable, nonskid, and wear-resistant mat.

The cover material was crushed granite or limestone of various gradations. On the majority of the projects it was 1 to ⅜ inch in size; on others it was 1¼ to ⅜ inch, ¾ to ¼ inch, and ⅝ to ⅜ inch. The amount of cover ranged from 35 to 50 pounds per square yard. Spreading was done by hand or with mechanical spreaders. Hand spotting and broom dragging followed spreading. The surface was then rolled, generally with a 5-ton roller, until the stone was thoroughly seated in the tar. The amount of rolling depended to some extent on the toughness of the cover material. The kind and quantities of cover used are given in Table 4. The following mechanical analyses are typical of the grading of the larger sized cover materials.

Passing 1¼ inch, retained on 1 inch, per cent	11	4
Passing 1 inch, retained on ¾ inch, per cent	63	28
Passing ¾ inch, retained on ½ inch, per cent	23	32
Passing ½ inch, retained on ¼ inch, per cent	2	29
Passing ¼ inch, per cent	1	7
Total	100	100

SEAL TREATMENTS APPLIED AFTER SOME MONTHS OF COMPACTION BY TRAFFIC

A seal treatment is generally applied to the surface at some interval following the original construction in order to further waterproof, bond, and smooth the surface.

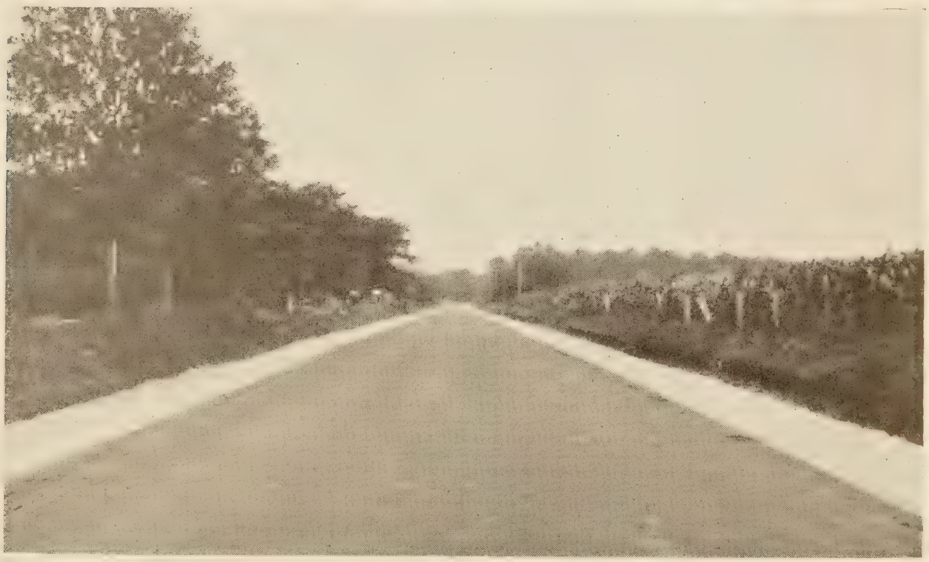
A seal treatment was applied, with one exception, to all the sections studied. The interval between the original treatment and the seal varied from three months to a year. A cold-application tar of either 18 to 25, 25 to 35, or 35 to 50 viscosity was used, except on project 8, where a hot-application tar was used. Both granite and limestone were used as cover material. The size was generally ⅜ to ¾ inch, although on a few of the older projects 1 or 1¼ to ⅜ inch material was used. The larger size was used in order to thicken the mat as well as to obtain a more effective early smoothing of the surface. The amounts and kind of material used are given in Table 4. Typical specifications and test results of the cold-application tars used for the second application on project 13 and those used in the seal treatments are given in Table 7.

Some of the older projects have received re-treatments. The materials and quantities used were similar to those used in the seal treatments except that on the more recent work there has been a tendency to use cold-application tar of a higher viscosity. Details of these re-treatments also are given in Table 4.

Mechanical operations common to surface treatment, seal, and re-treatment work are illustrated in Figure 3.

SATISFACTORY SURFACE TREATMENT ON PROJECT 11, OVER CLEAN SAND-GRAVEL ROAD. LOOSE MATERIAL ON UNTREATED ROAD STABILIZED BY HEAVY APPLICATION OF PRIMER

SURFACE TREATMENT BUILT OVER LOOSE SAND-GRAVEL BASE. SURFACE CONDITIONS ARE TYPICAL OF THOSE EXISTING ON THIS TYPE OF ROAD



SAND-CLAY-GRAVEL ROAD FOLLOWING APPLICATION OF THE TAR PRIME COAT PREVIOUS TO APPLYING THE SECOND APPLICATION OF TAR

FIGURE 2.—EXAMPLES OF SURFACE TREATMENT

160764—33——2

TABLE 7.—*Typical specification and test values of the cold application tars used in the second application, seal, and re-treatment*

Grade	TC-3		TC-4		TC-5		TC-6	
Used in	Seal		Seal		Seal and retreatment		Second application [1]	
	Specification	Analyses	Specification	Analyses	Specification	Analyses	Specification	Analyses
Specific gravity at 77° F	1.10 to 1.18	1.17	1.10 to 1.18	1.13 to 1.16	1.10 to 1.18	1.15 to 1.18	1.10 to 1.18	1.16 to 1.17
Water, per cent	2.0	1.0	2.0	0.9 to 1.9	2.0	0.8 to 1.9	2.0	1.5 to 1.9
Free carbon, per cent	2 to 10		2 to 10	3.9 to 4.3	2 to 10	1.8 to 6.5	2 to 10	
Specific viscosity, Engler, 40° C	18 to 25		25 to 35	26.1 to 34.3	35 to 50	35.0 to 48.4	50 to 65	56.6 to 62.0
Total distillate by weight, per cent:								
To 170° C	5.0	1.7	5.0	0.3 to 1.6	5.0	0.3 to 2.0	5.0	0.2
To 300° C	35.0	35.0	40.0	25.0 to 29.0	40.0	20.8 to 28.0	40.0	21.2 to 21.3
Softening point of residue [2], ° C	65		65	50.0 to 61.5	65	42.0 to 62.0	65	59.0 to 62.0

[1] Used on project 13 only. [2] Cube-in-water method.

DISCUSSION OF THE PROJECTS STUDIED

The cost of surface treatment, exclusive of the seal, on the projects studied ranged from about $1,500 to $2,700 per mile of 18-foot width, depending largely upon the availability of materials. Patrol maintenance cost from about $200 to $300 per mile per year, and seal and re-treatments from about $1,050 to $1,250 per mile.

ROUGHNESS INDICATOR USED TO GAGE RIDING QUALITIES OF SURFACES

The surface roughness of the projects as indicated by roughness indicator [3] readings varied considerably, not only between projects but between various portions of the same project. Readings were taken in June and December, 1931, with a roughness indicator installed on a Chevrolet sedan operated with 35 pounds tire pressure and at a speed of 25 miles per hour.

The results given in Table 8 show that lower readings were obtained in December than in June. This difference was probably due in large part to the greater resistance to movement at low temperatures of the hydraulic shock absorbers with which the car was equipped.

TABLE 8.—*Roughness indicator readings taken on the projects studied*

Project	Size of cover material used in seal and re-treatment	Average daily traffic	Average roughness factor per mile	
			June, 1931	December, 1931
	Inches	*Vehicles per day*		
1	¾ to ⅜	620	51	46
2	¾ to ⅜	540	87	54
3	¾ to 3/16	660	86	94
4	1 to ⅜	360	122	80
5	1¼ to ⅜	620	130	
6	¾ to ⅜	360	78	55
7	¾ to ⅜	170	79	59
8	¾ to ¼ [1] ¾ to ⅜	[2] 500	102	83
9	1 to ⅜	600	95	68
10	¾ to ⅜	610	67	59
11	1 to ⅜ [1] ¾ to ⅜	630	91	73
12	¾ to ⅜	160	79	54
13		100	140	
14	¾ to ⅜	150	159	
15	¾ to ⅜	110	132	
16	⅝ to ⅜ [1] 1 to ⅜	400	128	98
17	1 to ⅜	480	132	
18	1 to ⅜	220	109	130
19	1 to ⅜	220	129	92

[1] Re-treatment. [2] Estimate.

Experience with the roughness indicator has shown that the small surface irregularities obtained with a coarse stone cover tend to increase the readings, although the riding qualities of the road may not be affected. The instrument is sensitive to very small axle displacements and will measure roughness due to surface texture in addition to that due to the general contour of the road surface. In other words, its readings are a measure of the relative total roughness of the surface tested. Differences in the measurements which may be due to differences in cover material are not necessarily indicative of significant differences in riding quality.

[3] This device was described in PUBLIC ROADS, vol. 7, No. 7, September, 1926.

A study of the values given by the roughness indicator on the projects where ¾ to ⅜ inch cover was used in the seal treatments as compared with those on which 1 to ⅜ inch cover was used show considerably greater roughness for the larger aggregate. Six projects on which the smaller sizes aggregate was used gave an average reading per mile of 74 in June and 54 in December as against corresponding averages of 114 and 92 on four projects having the 1 to ⅜ inch aggregate. While this difference may not be due entirely to size of cover material, it is probable that this factor has had some influence.

Readings taken for comparison during February, 1932, on the newly constructed Mount Vernon Memorial Highway, which is considered to have somewhat better than average smoothness, were as follows:

(*a*) Bituminous concrete on clay-bound gravel base, 81.

(*b*) Bituminous concrete on reinforced concrete base, 59.

(*c*) Sheet asphalt on plain cement concrete base, 49.

SERVICE GIVEN BY TREATMENTS GENERALLY SATISFACTORY

The service behavior of the treatment was, in general, satisfactory although there was considerable variation not only between the various projects but between portions of an individual project.

The type of failure occurring most frequently on the projects was a cracking of the mat, usually confined to small local areas. This type of failure occurred over bases and subgrades having high plastic properties and seemed more pronounced on projects in the coastal area, where poorer drainage conditions no doubt tended to increase the plasticity of the subgrade and base materials. Light re-treatments were generally successful in repairing areas where failures of this sort occurred. Figure 4, A is a typical illustration of such a failure.

Detailed discussion of the base and subgrade materials, their effect on the behavior of the surface treatment and a description of tests for their control is given later in this report. (See pp. 14 to 20.)

The value of applying a tar primer previous to surface treatment has been demonstrated by these studies. The major functions of a primer are to bind, stabilize, and waterproof the top portion of the base and to develop a surface to which the superimposed mat will adhere. Examination of samples taken from the road showed that the primed base and the tar-treated mat were very firmly bonded and that the thickness of the wearing surface was increased by the depth of the tar-penetrated base. The depth of penetration varied considerably, because of the different types of base material treated, ranging from ⅜-inch on the well bonded topsoil and sand-clay bases to 1 inch or more on the more open gravel bases. The depth of penetration on the latter type of base was limited largely by the amount and consistency of the tar used.

HOT TAR PREFERABLE FOR SECOND APPLICATION

This study indicates that for surface treatments of this type the use of a hot tar for the second application gives better results than are obtained by the use of a cold tar. Under certain conditions there is a tendency for the cold application tar to penetrate into the primed base rather than to remain on the surface. When this occurs the cover stone is either pressed into the softened base or whipped off by traffic. This condition developed on projects 4 and 5 where the bases were of the mixed prime type. The cold tar used as second application material on these two projects penetrated into the mixed base and softened the top portion so that the cover stone was pressed into the base. As a result there was some shoving and loss of cover material on both projects. Figure 4, B illustrates this condition as it occurred on project 5. Laboratory examination of the mat on project 5 showed the top portion of the mixed base to be generally richer than the lower portion. A sample extracted from the base course in one location which is believed to be fairly representative of this project showed 7.4 per cent of bitumen in the top portion as compared with 4.0 per cent in the bottom portion.

On the majority of the projects studied hot tar was used for the second application. The hot tar gave satisfactory surfaces even where the base, as in project 11, was loose and open, or where the base was not so well compacted by traffic as was the condition on project 15. The greater viscosity of the hot tar prevents its penetration into the base and thereby provides a thicker film to hold the cover stone. Its greater adhesiveness adds immediate stability to the surface and little cover material is lost. It gives a more resilient surface than the cold application material. This property is especially desirable in treatments applied to flexible bases and also in regions where climatic conditions are unfavorable.

COLD APPLICATION TAR ADVANTAGEOUS FOR SEAL TREATMENT

The seal treatment is the final step in the construction of surface treatments of the type studied. It serves to close up the open texture and adds life and some additional road metal to the surface. Later re-treatments, similar to the seal treatment, are applied as maintenance measures, in order that the life and riding qualities of the road surface may be retained.

The materials used in the seal treatments and in the re-treatments were essentially of the same type. On the more recent work the tendency was to use a cold application of higher consistency than that of the tars formerly used. On the projects studied, the most viscous tar applied was the TC–5 having a specific viscosity of 35 to 50 at 40° C. Heavier grades, however, are now coming into use, particularly for re-treatment work.

Two important advantages in the use of cold application material over hot tar in these re-treatments are: (1) A more uniform texture of the surface is obtained, and (2) the cover aggregate can be readily dragged to give a smooth surface. Cold application tars also coat the cover material with a thinner film; and this condition tends to reduce subsequent bleeding and the formation of fat spots.

Hot tar was used in the seal and re-treatments on project 8 where the base was particularly plastic. To overcome this condition it was desirable to provide a thicker and more resilient surface than is ordinarily needed. In cases of excessive plasticity the use of hot tar is beneficial, as it prevents the disintegration of the surface by movement in the base course.

ANALYSIS MADE OF SAMPLES TAKEN FROM TEST HOLES

Samples of the surface mats were taken from a large number of test holes on the projects studied. The percentage and consistency of the bitumen extracted, and the grading of the mineral aggregates are given in Table 9. It was possible in many cases to make a clean separation of the tar mat and the tar-primed base; so that the analyses, extractions, and gradings could be made on each portion of the surface treatment. Where no satisfactory separation could be made, the entire thickness of the surface treatment was analyzed as one sample.

In the examination of the separated mats and primed bases, it was found that the percentage of bitumen extracted from the mats varied from 4.3 to 7.8, with an average of 5.8 per cent. That extracted from the primed bases varied from 2.8 to 6.3 per cent with an average of 4.8 per cent. In the cases where the entire thickness of the surface treatment was analyzed as one sample the percentage of extracted bitumen ranged from 3.3 to 6.9 per cent with an average of 4.6 per cent.

CONSISTENCY OF EXTRACTED BITUMENS DETERMINED BY FLOAT TEST AT 50° C.

While the consistencies of the extracted bitumens from the different projects covered a considerable range, it is of interest to note two points: (1) That, as would be expected, the consistency of the bitumen from the tar mats is much higher than that extracted from the primed bases; and (2) that the priming tar has stiffened considerably, as is shown by the float test results on the extracted bitumen. The float test at 50° C. was used as a measure of consistency. The thin fluid priming tar developed a consistency, as measured by this test, of 19 to 88 seconds, with an average of 59 seconds. These figures indicate a definitely higher consistency than that of the original material, which had a specific viscosity of not more than 18 at 40° C. The bitumens extracted from the tar mats had float test values of from 86 to 214, with an average of 134.

It should be recognized that the percentage of extracted bitumen does not give the exact amount of tar present in the road surface at the time of analysis. On extracting a tar aggregate, the free carbon present in the tar is left in the mineral aggregate and the true tar content is always greater than the value given by the extracted bitumen, the magnitude of the error depending on the amount of free carbon in the tar and on the amount of tar which can not be extracted.

The consistency of the extracted bitumen represents the approximate consistency of the carbon-free constituents of the tar existing in the road surface at the time of the survey, except as the consistency may be affected by the slight loss of volatile materials occurring in the extraction process. This bitumen was recovered under a laboratory technique as careful as possible, and it is believed that there has been no undue hardening due to the procedure used. It is felt that the values as reported are reasonably accurate and comparable. The float test determination is well adapted to the testing of tars since it is little influenced by the presence of inert matter such as free carbon. Therefore, it is felt that the float-test values at 50° C. on the extracted

Table 9.—*Analysis of the bituminous mats and primed bases*

Identification			Description of sample	Mechanical analysis of the extracted aggregate, in percentage of total sample															Bitumen extracted	Float test at 50° C. of bitumen extracted	Condition [1] of wearing surface December, 1931
				Screen size							Sieve size										
Laboratory No.	Project No.	Hole No.		2 to 1½ inches	1½ to 1¼ inches	1¼ to 1 inch	1 to ¾ inch	¾ to ½ inch	½ to ¼ inch	¼ to No. 10	No. 10 to No. 20	No. 20 to No. 30	No. 30 to No. 40	No. 40 to No. 50	No. 50 to No. 80	No. 80 to No. 100	No. 100 to No. 200	Passing No. 200	*Per cent*	*Seconds*	
36198	1	35	Mat and primed base				3.5	8.1	14.4	16.7	12.6	6.5	5.6	5.3	6.4	2.7	6.4	7.7	4.1	45	Good.
35315	2	10	Mat					10.2	26.8	16.1	9.9	4.0	5.0	4.4	5.4	2.0	5.1	5.0	6.1	139	Do.
35315	2	10	Primed base					4.9	8.5	12.4	15.6	9.9	10.5	9.7	10.4	3.3	6.6	5.4	2.8	19	
36130	3	13	Mat				11.1	19.1	21.5	16.9	7.9	2.6	3.1	2.1	3.3	1.2	3.1	3.8	4.3	125	Pitted.
36130	3	13	Primed base					2.9	12.1	12.4	16.4	9.7	11.2	7.3	8.2	2.2	6.1	7.0	4.4	45	
35306	4	1	Mat and primed base						6.0	13.2	17.1	6.7	7.7	7.5	13.5	5.4	10.8	8.3	3.8	46	Lean.
35307	4	2	do					1.1	3.1	8.5	18.5	9.8	10.5	9.5	12.6	4.9	9.3	8.4	3.8	42	Spongy and cracked.
35308	4	3	Mat and primed base, upper portion.					1.8	5.4	7.0	13.4	6.6	8.6	8.8	15.0	6.3	13.7	9.8	3.6	34	Good.
35279	4	3	Mat and primed base, lower portion.				2.3	2.0	3.5	6.5	12.0	6.9	8.4	7.7	14.4	6.8	13.7	12.2	3.6	37	
36194	5	34	Mat and primed base, upper portion.							6.0	14.7	11.4	13.8	13.9	15.0	3.7	7.3	6.8	7.4	27	Do.
36195	5	34	Mat and primed base, lower portion.						.7	3.6	12.1	12.2	14.5	15.3	18.4	4.1	7.6	7.5	4.0	21	
35309	6	4	Mat					5.3	29.0	20.6	10.0	3.5	4.3	3.2	5.1	2.0	4.9	6.9	5.8	214	Do.
35309	6	4	Primed base					1.0	3.3	5.5	21.9	10.7	11.8	8.6	10.9	3.2	8.2	12.1	2.8	80	
35310	6	5	Mat					12.2	30.7	23.5	9.0	2.1	2.5	1.8	3.1	1.2	3.0	4.2	6.7	194	Do.
35310	6	5	Primed base				1.1	3.8	3.9	6.8	25.5	9.7	9.5	7.2	8.9	2.2	6.7	9.7	5.0	72	
35311	6	6	Mat					9.4	35.4	24.4	6.9	2.2	2.5	1.9	3.2	1.4	3.3	4.5	4.9	134	Do.
35311	6	6	Primed base					.3	6.5	9.7	17.8	8.5	7.4	7.3	11.0	6.0	8.1	11.8	5.6	88	
35312	7	7	Mat				6.0	8.2	35.8	20.3	5.4	2.0	2.3	1.8	3.0	1.2	2.6	3.6	7.8	93	Do.
35313	7	8	do					2.9	30.9	25.2	10.5	2.9	3.3	2.3	4.1	1.8	3.9	5.2	7.0	104	Do.
35313	7	8	Primed base		3.6	0	3.4	3.2	4.9	6.6	14.6	8.2	10.2	8.6	11.5	4.7	6.4	10.5	3.6	48	
35314	7	9	Mat				9.2	14.7	22.5	18.7	7.6	2.9	2.2	2.1	4.0	1.6	3.9	5.0	5.6	86	Wavy.
35314	7	9	Primed base				1.9	7.9	8.2	9.3	15.0	6.3	4.9	5.1	10.2	3.8	9.8	12.2	5.4	34	
36133	8	11	Mat				5.1	22.6	28.4	12.2	5.2	1.9	2.1	1.8	3.5	1.4	4.3	5.2	6.3	200	Rough and wavy.
36133	8	11	Primed base					1.0	4.8	6.2	15.5	6.1	6.7	6.4	13.9	3.4	13.7	16.0	6.3	61	
36135	9	15	Mat and primed base					8.9	14.2	8.7	10.7	5.4	7.2	6.0	10.6	2.7	8.1	12.7	4.8	107	Good.
36156	10	24	do				4.1	16.6	18.8	12.3	5.4	2.2	3.9	4.3	8.2	3.3	5.7	8.3	6.9	199	Do.
36153	11	23	Mat						8.6	22.2	19.0	15.2	5.0	3.8	6.3	2.4	5.7	7.1	4.7	110	Do.
36153	11	23	Primed base				7.9	4.2	11.0	9.7	12.3	6.1	7.5	6.1	9.7	3.8	8.1	10.2	3.4	68	
36174	12	30	Mat and primed base			3.6	12.6	14.3	12.5	7.7	5.2	4.5	5.0	5.3	8.0	2.5	6.1	7.5	5.2	54	Do.
36140	13	18	do			8.4	6.1	14.1	18.6	12.4	7.4	3.0	3.9	3.4	6.3	2.0	4.9	6.0	3.5	74	Wavy.[2]
36143	14	19	Mat					4.9	32.0	27.5	8.8	1.5	1.9	1.3	2.6	1.5	4.8	7.9	5.3	93	Slightly wavy.[2]
36143	14	19	Primed base				6.7	5.2	16.2	10.5	7.6	3.0	3.7	3.5	8.9	4.5	11.6	14.0	4.6	63	
36146	16	20	Mat					5.0	31.7	25.5	10.7	2.9	2.9	1.9	3.4	1.4	3.2	6.5	4.9	115	Good.
36146	16	20	Primed base					1.6	13.2	14.7	9.8	3.6	5.0	5.4	14.7	4.4	10.7	11.4	5.5	77	
36171	17	29	Mat and primed base			13.7	9.0	9.9	9.5	5.1	6.1	4.6	4.7	5.0	9.6	3.4	7.2	7.8	4.4	163	Do.
36161	18	26	do	20.6	13.8	11.4	6.1	5.0	5.9	3.4	4.2	3.4	4.7	5.3	5.2	1.2	2.8	3.7	3.3	300	Do.
36165	18	27	do				9.7	14.3	18.8	16.2	9.2	3.3	3.5	3.1	5.8	1.6	3.9	5.9	4.7	167	Rutted.
36168	19	28	do					6.9	15.7	16.4	12.5	6.9	6.0	5.3	7.1	2.4	4.9	10.0	5.9	117	Good.

[1] Conditions where samples were taken.

[2] Base corrugations not removed before treating.

bitumens, representing the pure bitumens of the tars, may be considered as comparable to the consistency of the tars in the road surfaces at the time of extraction even though the free carbon is lacking.

NO UNDUE HARDENING OF TAR MATS SHOWN

If the consistencies of the extracted bitumen as given by the float test at 50° C. are compared with the specific viscosity or float test at 32° C. on the material at the time of construction it will be evident that considerable hardening has taken place. While it is no doubt true that the tar on the top surface of the road exposed to light and oxidation may be quite hard, the consistency of the tar extracted throughout the entire mass of the surface mat did not indicate in general any detrimental hardening on those projects which used a hot tar for the second application and a lighter cold tar for seal. In the float test at 50° C. the resultant tar extracted from the wearing suface, not including the primed base, gave results ranging from 86 to 214 seconds. In general the older projects showed higher float test values at 50° C., indicating the effect of longer weathering in hardening the bituminous material. On only one project was the consistency of the extracted bitumen greater than the consistency requirement for tar materials which are generally used in the initial construction of penetration macadam. This fact would seem to indicate that the tar in the mats at the time of the survey was still live and plastic.

CRUSHING OF COVER MATERIAL INDICATED BY ANALYSIS

The gradings of the aggregates extracted from the bituminous mats showed considerable crushing of the cover material to have occurred. It will be observed in Table 9 that the percentages passing the ¼-inch screen and the No. 200 sieve are relatively high, compared with the typical grading of the cover stone used on the majority of the projects.

The preponderance of coarse aggregate on project 18, as shown by the grading of sample No. 36161, may be explained by the fact that on one portion of this project the base was covered with coarse stone before the application of the surface treatment. Sample No. 36165 is the sand-clay portion which did not receive the stone veneer treatment.

On only a few projects was it possible to obtain samples of the mat separated from the primed base. The cases where such samples were obtained offer a means of estimating the extent to which crushing of the cover material occurred. Granite was used on projects 2, 6, and 7; and samples taken from these projects gave percentages passing the ¼-inch screen ranging from 50.0 to 66.2, with an average of 58.7. The two samples taken from projects 14 and 16, on which limestone was used as a cover material, gave percentages of 36.9 and 36.7, respectively. From these limited data it is evident that there was considerable crushing of both materials, although the limestone was apparently more resistent than the granite.

ABOVE: DISTRIBUTOR APPLYING HOT APPLICATION TAR TO THE PRIMED BASE

BELOW: APPLYING MINERAL AGGREGATE WITH MECHANICAL SPREADERS RESULTS IN A MORE UNIFORM DISTRIBUTION THAN BROADCASTING WITH HAND SHOVELS

ABOVE: DRAGGING COVER MATERIAL WITH A WIRE BROOM DRAG FOLLOWING SPREADING OF STONE COVER. THIS OPERATION SHOULD ALWAYS BE USED TO IMPROVE THE RIDING QUALITIES OF THE SURFACE

BELOW: ROLLING THE SURFACE TO PREVENT DISPLACEMENT AND LOSS UNDER TRAFFIC

FIGURE 3.—MECHANICAL OPERATIONS IN SURFACE TREATMENT WORK

There was little indication of detrimental effects due to the crushing of the cover material. It should be noted, however, that the projects studied were of relatively recent construction. It is believed that excessive crushing of cover material will eventually affect the stability of the surface and that, with due regard to economy, tough, durable stone should be used in surface treatment and re-treatment work. Both the granite and the limestone were considered satisfactory as cover materials; and yet, judging by the crushing which occurred, it is obvious that a more resistent stone should be used if a satisfactory surface is to be retained without too frequent re-treatment.

In some cases the cover stone was spread by hand and in others by mechanical spreaders. Under average conditions considerably better results can be obtained by the latter method and, whenever practicable, mechanical spreaders should be required. In order to insure a uniform texture and a smooth riding surface it is essential that hand spotting and brooming be required when hot application tars are used, and that dragging be required in the case of cold applications.

RESULTS OF SOIL TESTS INTERPRETED

The theory of stability of soil mixtures was discussed in the publication Reports on Subgrade Soil Studies,[4] page 38. In this discussion the soil is represented as consisting of large aggregate and mortar, just as are mixed bituminous and concrete paving materials, the function of the large aggregate being to furnish strength and hardness to the road slab and that of the mortar to bind the large aggregate particles into a stable mass.

[4] Reprint of PUBLIC ROADS, vol. 12, Nos. 4, 5, 7, and 8, June, July, September, and October, 1931.

The large aggregate, which is that fraction of the soil retained on the No. 10 sieve, should be hard and tough enough to resist crushing under traffic and can be present in amounts up to at least 50 per cent of the total soil mixture. The soil mortar consists of a clay binder, a silt filler, and a sand-fine aggregate. The character and proportions of these materials must be such that—

(*a*) They have the cohesion required to bind the particles of both coarse and fine aggregate together adequately;

(*b*) They do not shrink in amounts sufficient either to crack the road slab or to cause the occurrence of small fissures between particles of aggregate, which may facilitate the entrance of water into the interior of the slab;

(*c*) They do not swell on wetting an amount sufficient to push the particles of aggregate out of the positions which they have assumed during the consolidation of the surfacing material.

As a matter of fact the same soil colloids which furnish the cohesion also cause volume change and softening in the presence of water. In practice, therefore, the object is to obtain the highest cohesion possible without jeopardizing the integrity of the slab structure by detrimental volume change or softening of the binder clay.

QUALITY OF CLAY BINDERS INDICATED BY PLASTIC AND CAPILLARY PROPERTIES

In untreated roads the binder should be capable of expanding an amount just sufficient to close the surface pores, thus preventing the water from penetrating and softening the interior of the road surface. When the expansion of the binder exceeds that required to close the sand pores, the sand grains are likely to become unseated, reducing the stability of the mixture. When the binder does not expand sufficiently to close the sand pores, water may enter and soften the road surface. It follows that the amount of binder required to produce a stable mixture depends upon the expansion properties of the binder. Binders which are only slightly expansive may be used in an amount sufficient to fill the pores of the sand almost completely. As the expansive properties of the binder become greater, the amount used without danger of unseating the sand grains must of necessity become smaller and smaller.

Of two soils which have an equal tendency to shrink or expand the one having the greater cohesion should be the better binder. Of two soils having equal cohesion, that having the less tendency to shrink or expand should be the better binder, since a greater amount of it can be used than of the more expansive soil.

The facts outlined above may be summarized in the statement that the suitability of a clay binder is dependent on its cohesive, expansive, and shrinkage properties. The cohesion of soils is related to their plasticity; the shrinkage and expansion of soils depend upon the capillary properties. It follows that the character of soil mortars may be determined in the laboratory by constants which throw light on the plastic and capillary properties of the clay binders. These constants are the liquid limit, plastic limit, plasticity index, shrinkage limit, shrinkage ratio, centrifuge moisture equivalent, and field moisture equivalent.

SUBGRADE SOIL CONSTANTS DEFINED

Complete information on the significance of these constants, their use in practice, and their determination has been published in PUBLIC ROADS and is contained in Reports on Subgrade Soil Studies, referred to above.

In the present discussion the description of the soil constants is limited to that required for an understanding of their use in the work covered by this report.

(1) *Liquid limit.*—The liquid limit is defined as the moisture content of the soil at which small shocks will just cause it to flow. It is the maximum moisture content of plastic soils when in the plastic state, and is indicative of the maximum capillary capacity of all soils, plastic or nonplastic. At the liquid limit the cohesion is practically equal to zero.

(2) *Plastic limit.*—The plastic limit is defined as the minimum moisture content at which the soil can exist in the plastic state.

(3) *Plasticity index.*—The plasticity index is the difference between the liquid and plastic limits. It is an expression of the range of moisture contents through which plastic soils remain plastic and consequently cohesive. The plasticity index, in other words, indicates the amount of water, in excess of that represented by the plastic limit, which must be added in order to reduce the cohesion of the soil to practically zero, its state at the liquid limit. It may, therefore, be considered as a qualitative measure of the cohesive property of the soil.

(4) *Shrinkage limit.*—For practical purposes the shrinkage limit is the maximum moisture content of the soil when it has attained the minimum volume during the drying process. It indicates elastic properties of soils, high values indicating high elasticity.

The shrinkage limit indicates minimum porosity produced by maximum capillary pressure due to evaporation. A high shrinkage limit indicates high porosity under maximum capillary pressure. Shrinkage limits of 30 or more are characteristic of elastic soils.

In binders elasticity is not detrimental since the important quality of binders is cohesion and not supporting power. The shrinkage limit, however, has an important bearing on the qualities of binders, because of its relation to the field moisture equivalent. The more nearly the shrinkage limit approaches the field moisture equivalent the less the volume change of the soil under field conditions. A shrinkage limit equal to or greater than the field moisture equivalent indicates no volume change under field conditions.

(5) *Shrinkage ratio.*—When a soil loses moisture by evaporation above the shrinkage limit it shrinks proportionately to the amount of moisture loss. The shrinkage ratio expresses the percentage of soil shrinkage in terms of the percentage of moisture loss. Thus, a shrinkage ratio of 1.8 signifies that above the shrinkage limit a loss of moisture equal to 1 per cent of the weight of the dry soil will cause the soil mass to shrink 1.8 per cent of the volume of the dry soil.

(6) *Centrifuge moisture equivalent.*—The centrifuge moisture equivalent is defined as the percentage of water retained by the soil when compressed by a centrifugal force equal to 1,000 times the force of gravity for one hour.

Generally, except in certain silt soils and in soils which waterlog, the centrifuge moisture equivalent is less than the liquid limit. The centrifuge moisture equivalent indicates the affinity of a soil for water as a result of its capillary properties. The lower the centrifuge moisture equivalent of a soil, the less is its ability to take up moisture by capillarity. For soils with equal liquid limits, the less the centrifuge moisture equivalent the less is the ability of the wet soil to take up capillary moisture and the lower will be the capillary rise.

Centrifuge moisture equivalents which exceed liquid limits without water-logging indicate extremely high capillarity. Centrifuge moisture equivalents with water-logging indicate impermeability caused by gluey colloids.

Field moisture equivalent.—The field moisture equivalent is defined as the amount of water which a soil will absorb when its moisture content is gradually increased by adding water. As water is added to a soil powder, cohesive or glue-like properties are developed and continue to increase until a certain amount of moisture, depending upon the character of the soil, is absorbed, and a maximum cohesion is developed. With the increasing cohesion the soil grains are more and more restrained from separating. Moisture can enter the soil only by separating the particles; and when the cohesive force exceeds the capillary force tending to cause the separation, no more moisture can enter and the field moisture equivalent is reached. This constant is, therefore, an index of the cohesive properties of the soil.

The addition of moisture in excess of the field moisture equivalent, by means of manipulation, reduces the cohesion until the liquid limit is reached, at which the cohesive properties virtually disappear. The field moisture equivalents of expansive soils which have no cohesion are equal to the liquid limits.

If the liquid limit is greater than the field moisture equivalent the following relations hold true: The greater the difference between field moisture equivalent and liquid limit, the greater is the plasticity of the soil, the greater is the resistance of damp soil to the entrance of capillary moisture, and the less is the tendency of the soil to expand in the presence of moisture.

CONSTANTS OF AVERAGE OR STATISTICAL SOILS USED AS BASIS OF COMPARISON

These constants serve to furnish information on the three important properties of binder clays, their cohesion, their water-retentive or expansive properties, and their shrinkage properties. They do not give quantitative measurements of cohesion, shrinkage, and expansion. Their value lies in the fact that the magnitudes of the constants and their quantitative relations to one another are associated with the characteristics of soil groups whose properties have become known qualitatively through their performance in service.

To facilitate the use of the constants it is necessary to have—

(*a*) A basis of comparison by means of which it is possible to obtain some quantitative conception of the degree to which these three properties are present in a binder clay;

(*b*) A knowledge of the relations between soil performance and the presence of these properties in different degrees.

The basis used for comparison is the set of relationships which was found to exist between the average clay contents and the average soil constants of more than 5,000 soil samples. An "average" or "statistical" soil may be defined as a hypothetical soil having constants conforming to these averages. Table 10 gives the soil constants of statistical soils for varying percentages of clay.

TABLE 10.—*Soil constants of statistical soils*

Percentage of clay	Liquid limit	Plasticity index	Shrinkage limit	Moisture equivalent: Centrifuge	Moisture equivalent: Field
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1	13	0	17	9	9
2	14	0	17	10	10
3	14	0	17	10	10
4	15	1	17	11	11
5	15	1	17	11	11
10	18	3	16	13	14
15	23	6	16	17	19
20	28	9	15	20	22
25	35	13	15	25	26
30	42	18	14	30	29
35	49	22	14	35	31
40	56	26	13	40	34
45	62	30	13	45	35
50	69	34	12	50	37
55	76	39	12	55	39
60	83	43	12	60	41
65	90	48	11	65	42
70	97	52	11	70	44
75	104	56	11	75	46
80	111	61	10	80	47
85	118	65	10	85	48
90	125	69	10	90	50
95	132	74	9	95	51
100	139	78	9	100	52

In this table we find that the average or statistical soil having a clay content of 50 per cent has physical constants as follow:

Liquid limit	69
Plasticity index	34
Shrinkage limit	12
Shrinkage ratio [5]	2
Centrifuge moisture equivalent	50
Field moisture equivalent	37

Comparisons may be made with soils having the same clay content but different constants. A soil with a similar clay content but with a higher plasticity index, say 45, is suggestive of clay more active than the average with respect to plasticity, volume change, etc., the higher plastic properties being due mainly to the presence of gluey colloids. Likewise, a soil with a similar clay content but with a lower centrifuge moisture equivalent, say 40, suggests a clay of lower water retentive properties than the average.

STATISTICAL RATIOS USED TO EXPRESS RELATION OF ACTUAL TO STATISTICAL SOILS

It is convenient in practice to express the relationships of constants of a given soil to those of the average soil as a ratio termed the average or statistical ratio. Thus the average ratio of the plasticity index of 45, referred to above, is $\frac{45}{34}$, or 1.32, and the average ratio of the centrifuge moisture equivalent of 40, also referred to above, is $\frac{40}{50}=0.80$.

In the case of natural soils, in which the active portion of the soil tested comprises a large part of the entire soil sample, the soil constants as such are usually capable of indicating clearly the soil characteristics. In graded mixtures, however, the clay binder may be but a small fraction of the portion of the soil tested. In such cases the use of the ratios to supplement the constants may be required in order to disclose the character of the clay.

Without these average ratios it would be necessary to perform the very painstaking and costly operations of separating the clay contents from the soil samples

[5] The average shrinkage ratio is obtained by substituting the average specific gravity of soils, 2.65, and the statistical shrinkage limit (Table 10) in the formula:

$$\text{Shrinkage ratio}=\frac{100\times\text{specific gravity}}{100+\text{shrinkage limit}\times\text{specific gravity}}$$

and testing them separately in order to determine the character of the clay. Since a knowledge of the mechanical analysis without a knowledge of the character of the clay binder is inadequate to determine the efficiency of the soil for use either as road surfaces or as bases for surface-treated roads, the importance of the average ratios will be readily understood.

GROUP CLASSIFICATION OF SOILS SERVES AS KEY TO PERFORMANCE

Because of the fact that the presence of certain soil constituents indicates the important soil properties, it has been found possible to arrange the various soils in groups which are indicative of their performance. The characteristics of the uniform soil groups are discussed in the following paragraphs.[6]

Group A–1.—Well-graded material, coarse and fine, excellent binder. Highly stable under wheel loads, irrespective of moisture conditions. Functions satisfactorily when surface-treated or when used as a base for a relatively thin wearing course.

Group A–2.—Coarse and fine materials, improper grading or inferior binder. Highly stable when fairly dry. The more plastic soils of this group are likely to soften at high water content caused either by rains or by capillary rise from saturated lower strata when an impervious cover prevents evaporation from the top layer, or to become loose and dusty in long continued dry weather.

Group A–3.—Coarse material only, no binder. Lacks stability under wheel loads but is unaffected by moisture conditions. Not likely to heave because of frost or to shrink or expand in appreciable amount. Furnishes excellent support for flexible surfaces and also for relatively thin rigid pavements.

Group A–4.—Silt soil without coarse material, and with no appreciable amount of sticky colloidal clay. Has a tendency to absorb water very readily in quantities sufficient to cause rapid loss of stability even when not manipulated. When dry or damp, presents a firm riding surface which rebounds but very little upon removal of load. Likely to cause cracking in rigid pavements as a result of frost heaving, and failure in flexible pavements because of low supporting value.

Group A–5.—Similar to Group A–4, but furnishes highly elastic supporting surfaces with appreciable rebound upon removal of load even when dry. Elastic properties interfere with proper compaction of macadam during construction and with retention of good bond afterwards.

Group A–6.—Clay soil without coarse material. In stiff or soft plastic state absorbs additional water only if manipulated. May then change to liquid state and work up into the interstices of macadams or cause failure due to sliding in high fills. Furnishes firm support essential in properly compacting macadams only at stiff consistency. Deformations occur slowly and removal of load causes very little rebound. Shrinkage properties combined with alternate wetting and drying under field conditions are likely to cause cracking in rigid pavements.

Group A–7.—Similar to Group A–6, but at certain moisture contents deforms quickly under load and rebounds appreciably upon removal of load, as do soils of Group A–5. Alternate wetting and drying under field conditions leads to even more detrimental volume changes than in the case of Group A–6 subgrades. May cause concrete pavements to crack before setting and to crack and fault afterwards. May contain lime or associated chemicals productive of flocculation in soils.

[6] See Reports on Subgrade Soil Studies, pp. 17 to 49.

As the characteristics of the mortar change from those of the A–1 subgrade, the mortar may become an A–2 material of one of several varieties. Increase in sand content, for instance, would produce a friable variety approaching the A–3 material; increase in clay content would produce a plastic variety approaching the A–6 or A–7 materials; and increase in the silt content would produce a highly capillary variety approaching the A–4 or A–5 material.

Without surface treatment the A–1 material should prove satisfactory on both wet and dry subgrades; the plastic A–2 may serve well on dry subgrades; the friable fairly well on wet subgrades; and the capillary variety is likely to fail in either case. The cohesionless A–3 and the highly elastic A–5 soils are unsuited for road surfaces. The A–4, the A–6, and the A–7 soils are likely to be satisfactory as untreated road surfaces only in dry weather.

EFFECTS OF SURFACE TREATMENTS DISCUSSED

Bituminous surface treatments provide (*a*) cohesion which serves to bind the top particles of the base together, (*b*) a mat which resists abrasion and protects the base from the suction, thrust, or other shocks produced by traffic, and (*c*) an impervious top which prevents the entrance of surface water into the base and the evaporation of capillary moisture from the base.

The wear-resistant mat and the cohesive action of the bituminous surface treatment are beneficial for bases comprised of all groups of soils.

The ability of surface treatments to prevent surface water from entering the soil bases is especially advantageous to those group A–6 and A–7 soils which are so impervious that capillary moisture can not enter from below in detrimental amounts. Under such conditions, these soils make excellent bases for surface treatments.

The increase of capillary moisture in the soil slab due to the prevention of evaporation may have several important effects: (*a*) It may soften the more plastic varieties of clay binder and thus make unstable the soil slabs which contain the amounts of this type of clay required for stable untreated surfaces; (*b*) it may provide additional cohesion for holding together the grains of over-sanded mixtures which become very loose in dry weather when untreated; (*c*) it may cause loss of stability in bases composed of the highly capillary varieties of A–4 soils.

It is thus evident that the amount of clay necessary to bind an untreated road may be excessive if the road is treated, the rise of capillary moisture causing the base to soften and fail. The occurrence of failures over plastic bases and subgrades on some of the projects covered by this study is attributable to this phenomenon.

The present tendency is to use less clay in new construction and, on previously untreated roads to modify the plasticity of the mortar by the addition of granular material or by some other suitable means, prior to application of the surface treatment.

Materials belonging to the various soil groups may be used successfully as bases for surface treatment under the following conditions: A–1 materials on dry or moderately wet subgrades; plastic and capillary A–2 materials on dry subgrades and friable A–2 materials on both wet and dry subgrades; well drained A–4, materials not subjected to frost action and certain impervious varieties of the A–6 and A–7 subgrade materials. A–1 materials on very wet subgrades and A–2 plastic and capillary materials on either very wet or moderately wet subgrades are likely to prove troublesome because of softening of the clay binder.

Because it increases the capillary moisture content, and because this in turn produces additional cohesion, a surface treatment may not only stabilize the surface of a soil road, but may also, in the case of materials having but little cohesion, exercise a stablizing benefit throughout the entire depth of the road base and a part of the subgrade beneath. This fact explains why many materials, not suited for soil roads without treatment, perform satisfactorily when surface-treated.

The grading of the soils which contained kaolin as the clay binder and which were found to furnish highly stable untreated road surfaces in Georgia was as follows:

Material retained on the No. 10 sieve, not more than about 50 per cent; the soil mortar, that fraction passing the No. 10 sieve, consisting of clay, 5 to 10 per cent; silt, 10 to 20 per cent; total sand, 70 to 85 per cent; and coarse sand, 45 to 60 per cent. Average effective size approximately 0.01 millimeter and uniformity coefficient greater than 15.

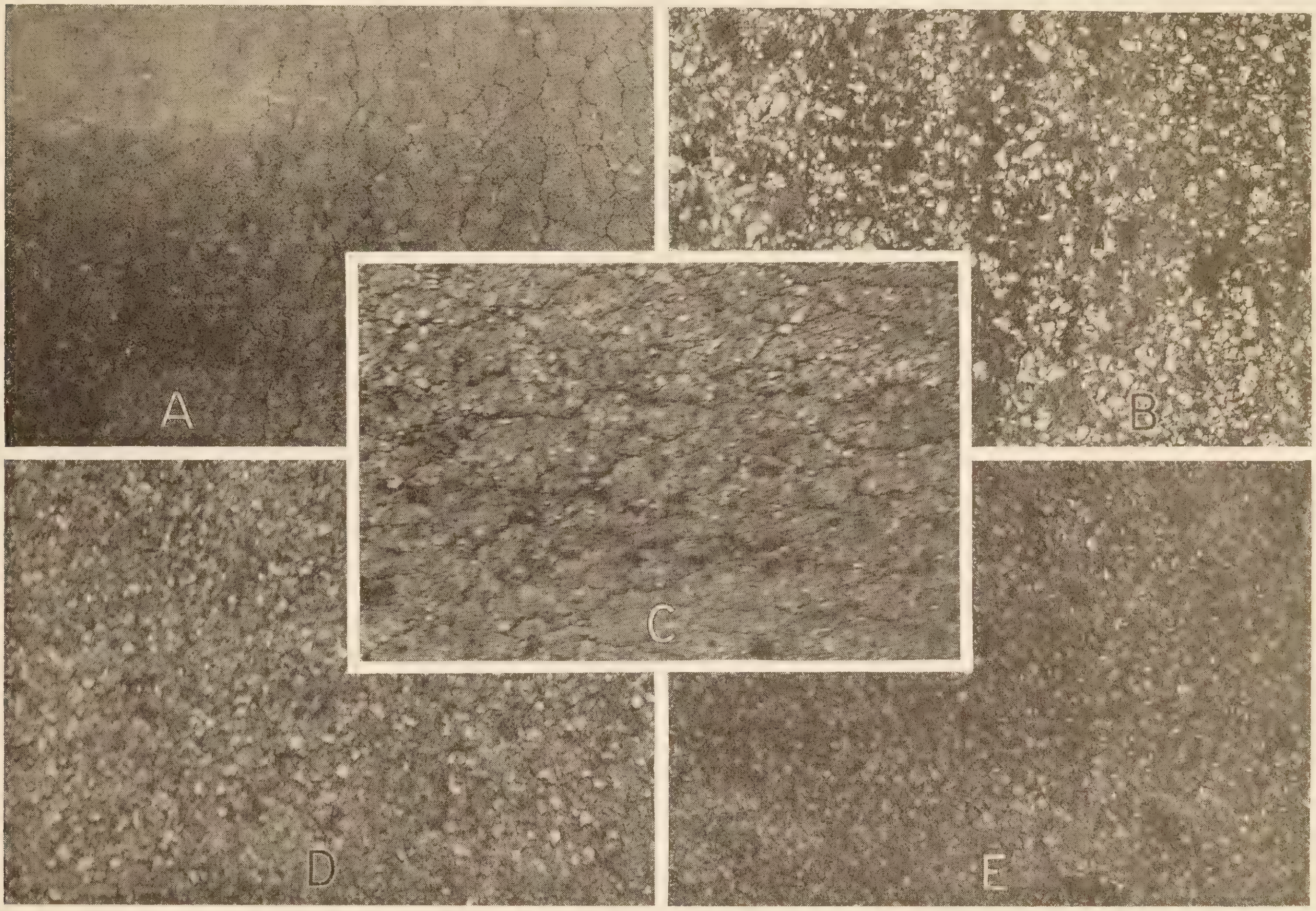


Figure 4.—Examples of Surface Texture on Tar-Treated Projects

A, Characteristic Failure on Sand-Clay-Gravel Base of High Plasticity under Unfavorable Drainage Conditions

B, Surface Condition Typical of the Two Mixed Base Projects, 4 and 5, Where Cold Tar Materials TC–3 and 4 Were Used for Second Application. Photo Shows Cover Stone Embedded in the Softened Primed Base Rather Than Being Held by a Tar Film

C and D, Project 8, Illustrating the Effect of Mica in the Base. Base Materials Identical in Character Except for the Mica Present. Figure C Represents the Surface Whose Base Contained an Appreciable Amount of Mica and Figure D the Surface Whose Base was Free from Mica

E, Project 7, Hole 7. Good Surface Conditions over A–7 Soil under Favorable Drainage Conditions

KAOLIN REPRESENTATIVE OF GOOD BINDER CLAYS

It will be readily understood that the two important requirements of binder clay, to wit, appreciable cohesion and no detrimental volume change, are the requirements also of good pottery clay. The cohesion is required to hold the molded pieces together during the burning and the absence of volume change is required to prevent cracking of the heated pieces. It is, therefore, not surprising to learn that kaolin (hydrous silicate of aluminum), an excellent China or porcelain clay, seems to satisfy both the practical and theoretical requirements of good binder clay, according to experience with untreated topsoil roads in Georgia.

The character of kaolin when compared with that of other soils is disclosed by its statistical ratios, which are as follows:

Liquid limit	1. 07
Plasticity index	1. 00
Shrinkage limit	2. 77
Centrifuge moisture equivalent	1. 23
Field moisture equivalent	1. 06

Table 11, which contains the ratios of a limited number of typical soils, assists in revealing the significance of the ratios of kaolin binders. From these values it can be seen that the liquid limit of kaolin, like that of the A–6 and A–7 clays, is equal approximately to that of the statistical soils. It is apparent that kaolin will

TABLE 11.—*Ratios of test constants of typical soils to those of statistical soils*

Soil	Ratio to statistical soil					Subgrade group
	Liquid limit	Plasticity index	Shrinkage limit	Moisture equivalent		
				Centrifuge	Field	
Florida sand	0.73	--------	0.94	0.45	1.45	A-3
California sand	1.43	--------	1.00	.30	1.70	A-3
New Hampshire silt	.76	--------	1.67	.79	.96	A-4
Missouri silt	.84	0.67	1.71	1.07	1.04	A-4
Oregon silt	1.82	1.60	2.06	2.25	2.06	A-5
Maryland silt	2.71	2.21	6.71	2.94	3.57	A-5
Virginia clay	1.08	1.51	1.10	2.04	.67	A-6
Texas clay	1.12	1.48	.92	1.88	.81	A-6
Minnesota gumbo	1.05	1.31	1.31	1.40	1.31	A-7
Mississippi clay	1.00	1.34	.90	1.43	1.11	A-7

not lose stability until it takes up as much moisture as that required to soften the fine-grained cohesive soils.

The typical silts listed in Table 11 have plasticity index ratios less than the liquid limit ratios, while the clays have plasticity index ratios greater than the liquid limit ratios. This fact indicates that clays have relatively much greater cohesion than silts. The plasticity index ratio of kaolin, however, just about equals the liquid limit ratio. It follows that the cohesive properties of kaolin are somewhat greater than those of silts but not as great as those of the clays and gumbos.

With this moderately high cohesion, kaolin has an exceptionally high shrinkage limit ratio which, combined with the low field moisture equivalent ratio, suggests negligible shrinkage properties. Its centrifuge ratio of 1.23 indicates water retentive properties smaller than those of the A–5, A–6, and A–7 soils.

STATISTICAL RATIOS EXPLAIN PERFORMANCE OF MATERIALS USED ON PROJECTS

Tables 12 and 13 give the statistical ratios of the materials used as subgrades and bases on the various projects studied. The clay contents used in these tables are based upon that portion of the sample passing the No. 40 sieve, which is the portion used in determining the soil constants. These clay contents are important only in determining the statistical ratios, and should not be confused with those given in Tables 2 and 3, which are the true clay contents of the soil mortar (material passing the No. 10 sieve).

An examination of Tables 12 and 13 will help to explain the behavior of the surface-treated roads observed in the survey. It should be borne in mind that the properties of good binders are represented by those of kaolin; and that bituminous surface treatments permit a much wider range in soil properties than is practicable in untreated roads.

According to these tables seven base samples have relatively high plasticity index ratios (greater than 1, that of kaolin). They are 6369 and 6206, project 1; 6064 and 6063, project 2; 6195, project 3; 6062, project 7; and 6197, project 14.

With the high plasticity indices, 5 of these samples, 6369, 6064, 6195, 6206, and 6063, have field moisture equivalent ratios less than 1.06, that of kaolin. Three of these 5 samples, 6369, 6064, and 6195, were taken from portions of roads which had developed defects. The clay contents[7] of samples 6369 and 6064, were, respectively, 21 and 22 per cent, while the clay content of the third sample, 6195, was 13 per cent. The surface defect in project 3 (base sample 6195) is pitting, and this may be due to the character of the surface treatment rather than to the characteristics of the base material. The clay contents of the 2 surfaces representative of good results—samples 6063 and 6206—were, respectively, 14 and 15 per cent.

Samples 6062 and 6197, which also had high plasticity indices, were taken from sections reported as having wavy surfaces. Field moisture equivalent ratios greater than 1.06, that of kaolin, indicate that these soils have relatively high moisture absorptive properties.

[7] Clay contents of soil mortar, that fraction passing No. 10 sieve, Tables 2 and 3.

TABLE 12.—*Ratios of test constants of soils tested to those of statistical soils having the same percentage of clay on projects having sand-clay-gravel base*

Identification				Ratios to statistical soil having same percentage of clay						Condition of wearing surface
Project No.	Laboratory No.	Hole No.	Course	Clay content[1]	Liquid limit ratio	Plastic index ratio	Shrinkage limit ratio	Centrifuge moisture equivalent ratio	Field moisture equivalent ratio	
				Per cent						
1	S-6369	36	Base	26	0.94	1.36	1.20	0.65	0.88	Badly cracked.
	S-6206	35	do	23	1.00	1.36	1.33	.78	1.00	Good.
	S-6194	35	Subgrade	15	.74	.50	[2] .94	1.00	.84	
2	S-6063	10	Base	22	.97	1.30	1.27	.86	1.04	Do.
	S-6057	10	Subgrade	16	.79	0	1.13	.47	.90	
	S-6064	12	Base	27	.89	1.20	1.21	.67	.81	Cracked.
	S-6059	12	Subgrade	12	.95	0	[2] 1.31	.50	1.25	
7	S-6060	7	Base	46	.75	.90	1.38	.65	.75	Good.
	S-6054	7	Subgrade	49	.90	.85	2.58	.69	1.14	
	S-6061	8	Base	20	.43	.22	[2] 1.93	.60	.50	Do.
	S-6055	8	Subgrade	44	.75	.83	1.23	.77	.91	
	S-6062	9	Base	11	.95	1.33	1.13	.79	1.13	Wavy.
	S-6056	9	Subgrade	27	.76	.93	1.14	.67	.78	
11	S-6203	23	Base	6	1.31	0	[2] 1.65	.83	2.08	Good.
	S-6173	23	Subgrade	32	.75	.79	1.50	.88	.83	
13	S-6196	18	Base	8	1.35	0	[2] 1.71	.58	2.15	Wavy, base corrugations not removed before treatment.
	S-6170	18	Subgrade	19	1.04	.75	1.60	1.42	1.41	
14	S-6197	19	Base	12	1.25	1.75	[2] 1.50	1.00	1.50	Slightly wavy, base corrugations not removed before treatment.
	S-6171	19	Subgrade	31	1.02	.61	2.36	1.19	1.38	
15	S-6199	21	Base	10	1.44	0	---------	1.69	2.00	Good.
	S-6200	21	Subgrade	21	.90	.78	1.53	1.10	1.09	
16	S-6198	20	Base	13	.90	0	[2] 1.44	.87	1.12	Do.
	S-6172	20	Subgrade	31	1.00	1.06	1.86	1.19	1.14	
	S-6201	22	Base	10	1.22	0	[2] 1.50	.77	1.50	Slightly cracked.
	S-6202	22	Subgrade	11	1.32	0	[2] 1.81	1.21	1.80	

[1] Based on mechanical analysis of material passing No. 40 sieve.
[2] Soils which have no significant shrinkage limit. Shrinkage limit computed for purpose of comparison.

TABLE 13.—*Ratios of test constants of soils tested to those of statistical soils having the same percentage of clay on projects having topsoil or sand-clay base*

TOPSOIL BASE PROJECTS

Identification				Ratios to statistical soil having same percentage of clay						Condition of wearing surface
Project No.	Laboratory No.	Hole No.	Course	Clay content [1]	Liquid limit ratio	Plastic index ratio	Shrinkage limit ratio	Centrifuge moisture equivalent ratio	Field moisture equivalent ratio	
				Per cent						
4	S-6043	1	Base	12	0.80	0	[2] 1.25	0.36	1.12	Lean.
	S-6044	1	Subgrade	29	.70	.81	1.21	.72	.71	
	S-6045	2	Base	17	.64	.43	1.00	.78	.75	Spongy and cracked.
	S-6046	2	Subgrade	40	.88	.85	2.08	1.00	1.06	
	S-6047	3	Base	11	.74	0	[2] 1.19	.50	1.00	Good.
	S-6048	3	Subgrade	21	.72	.89	1.20	.71	.78	
6	S-6049	4	Base	22	.50	.50	.87	.50	.57	Do.
	S-6050	5	do	28	.51	.50	1.21	.64	.57	Do.
	S-6051	5	Subgrade	29	1.05	1.00	2.07	1.21	1.21	
	S-6052	6	Base	23	.41	.18	.93	.35	.50	Do.
	S-6053	6	Subgrade	39	.87	.80	2.15	.90	1.09	
8	S-6165	14	Base	17	.76	.57	1.06	1.00	.95	Rough and wavy.
	S-6190	33	do	23	.63	.45	1.27	.78	.79	Badly cracked.
	S-6205	33	Subgrade	25	.77	.85	1.67	.92	.81	
	S-6191	33	do	29	1.18	1.44	1.64	1.31	1.21	
9	S-6166	15	Base	17	.56	.43	[2] .94	.78	.70	Good.
	S-6167	15	Subgrade	48	.78	.82	1.58	.77	1.05	
	S-6168	16	Base	19	.67	.50	1.13	.68	.73	Slightly cracked.
	S-6169	16	Subgrade	34	.87	1.00	1.36	.85	.90	
10	S-6174	24	Base	20	.86	.89	1.27	1.00	.95	Good.
	S-6175	24	Subgrade	21	1.59	1.44	2.67	1.81	1.96	
	S-6176	25	Base	26	.94	.86	1.67	1.04	1.12	Cracked.
	S-6204	25	Subgrade	19	1.56	1.50	2.40	1.32	1.86	
12	S-6186	30	Base	19	.70	.50	1.00	.89	.86	Good.
	S-6188	30	Subgrade	34	.98	.90	2.07	.82	1.16	
	S-6187	31	Base	30	.93	.89	1.64	.93	1.03	Slightly cracked.
	S-6189	31	Subgrade	14	2.41	0	2.94	2.13	3.06	
17	S-6184	29	Base	19	.67	.75	1.07	.89	.73	Good.
	S-6185	29	Subgrade	45	.85	.80	1.92	.73	1.03	
18	S-6180	27	Base	29	.73	.63	1.50	.97	.86	Rutted.
	S-6181	27	Subgrade	19	1.48	1.50	2.40	1.26	1.77	
19	S-6182	28	Base	30	.64	.56	1.21	.77	.69	Good.
	S-6183	28	Subgrade	32	1.27	1.16	2.29	1.25	1.53	

SAND-CLAY BASE PROJECTS

Project No.	Laboratory No.	Hole No.	Course	Clay content [1]	Liquid limit ratio	Plastic index ratio	Shrinkage limit ratio	Centrifuge moisture equivalent ratio	Field moisture equivalent ratio	Condition of wearing surface
				Per cent						
2	S-6058	11	Base	16	0.75	0	[2] 1.31	0.47	0.90	Good.
3	S-6195	13	do	19	.85	1.25	1.07	.68	.82	Pitted.
	S-6164	13	Subgrade	11	.84	0	1.25	.86	.80	
5	S-6192	34	Base	38	.74	.75	1.77	.63	.85	Good.
	S-6193	34	Subgrade	15	.65	0	[2] 1.13	.29	.89	
18	S-6177	26	Base	19	.85	.88	1.27	1.05	.95	Do.
	S-6178	26	Subgrade	34	.98	1.05	1.86	.91	1.06	
	S-6179	26	do	15	1.48	0	[2] 2.38	1.12	1.89	

[1] Based on mechanical analysis of material passing No. 40 sieve.
[2] Soils which have no significant shrinkage limit. Shrinkage limit computed for purposes of comparison.

Their clay contents were, respectively, 9 and 11 per cent.

The high field moisture equivalent ratios (greater than 1.06) of base samples 6203, project 11; 6196, project 13; 6199, project 15; 6201 and 6198, project 16; and 6043, project 4, combined with plasticity indices of zero suggest the presence of detrimental expansive properties due in part to the absence of cohesion. These samples have clay contents of 11 per cent or less. However, three of the six surfaces represented by these samples are reported as being in good condition.

Seven subgrade samples (Nos. 6054, project 7; 6171, project 14; 6175 and 6204, project 10; 6189, project 12; 6181, project 18; and 6183, project 19) listed as A–5 soils, indicated potential elastic properties high enough to cause their shrinkage limits to exceed 30.

In the case of samples 6183 and 6054 the relatively high plasticity indices of 22 and 29, respectively, indicate cohesive properties tending to reduce the elasticity of the material in service. It is interesting to note that the road surfaces laid on the subgrades from which these two samples were taken remained in good condition. The road surfaces laid on four of the five subgrades represented by the other A–5 soil samples referred to developed defects.

There is nothing in the test results on base samples 6045, project 4; 6165 and 6190, project 8 and 6168, project 9, to account for the defects developed by the surfaces represented by these samples.

The data regarding the desirable properties of soil mortars and subgrade soils is not comprehensive enough to permit the drawing of hard and fast specifications. Added to the information which has been previously collected regarding these matters, the preceding discussion becomes quite indicative. The following is suggested for bases to be surface treated:

1. Binder clays having high plasticity, indicated by plasticity index ratios greater than 1, with normal expansive properties, indicated by field moisture equivalent ratios less than 1.06, should not be present in base mortars in amounts exceeding 20 per cent.

2. Highly expansive clay binders indicated by field moisture equivalent ratios greater than 1.06 are likely to prove troublesome, whether the plasticity is high or low.

3. The less plastic subgrades of the A–5 groups are likely to prove troublesome in surface-treated roads.

4. Binder clays having plasticity index ratios of 1.00 or less and field moisture equivalent ratios not exceeding 1.06 can be used in varying amounts successfully.

For example, as is shown in Table 2, sand-clay-gravels with clay up to 15 per cent functioned well with surface treatments, whereas those on which the treatments cracked contained slightly more than 20 per cent.

The excellent performance of the base represented by sample 6060, project 7, with 36 per cent of clay, may have been due more to good drainage conditions than to good grading of soil material. In this connection, however, it should be recalled that when enough fine material is present to make A–7 soils impervious, they lose stability primarily as a result of water entering from the top. Consequently, as illustrated by the Minnesota gumbos, they are stabilized by surface treatments preventing the entrance of water from above. It is, therefore, possible that soils with either a very large or very small amount of clay may function well when surface-treated, whereas, a soil containing a moderate amount may cause softening and loss of stability.

A number of the sand-clay-gravel base projects were built of river-washed material containing only from 4 to 13 per cent of clay. The surfaces on these projects were generally in better condition than those built on bases having considerably larger percentages of clay binder. The river-bed sand-clay-gravel contained a high percentage of material larger than 2 millimeters, as much as 71 per cent in one instances, and exceeding 50 per cent in 4 cases.

The sand-clay and topsoil bases which are shown in Table 3 to have given good service had clay contents varying from 9 to 26 per cent. The clay contents of the faulty bases varied from 12 to 26 per cent. It is thus apparent that the clay content alone is not a criterion of the service value of the base materials.

PROPERTIES OF SUBGRADE AND BASE MATERIALS IMPORTANT IN SURFACE TREATMENT

It is evident from the foregoing discussion that the behavior of surface treatments depends upon the character of the base and subgrade materials. The suitability of the underlying material is largely dependent upon the character and quantity of the binder. The suitability of an untreated road as a base, or new base construction for surface treatment, is often indicated by its behavior under traffic. An untreated surface which tends to ravel in dry weather will probably be more satisfactory after treatment than one which remains well bonded. This is contrary to early opinions on this subject; but experience has shown that where a given clay is used as a binder a less amount is desirable in bases for surface treatment than is required for an unsurfaced road of the same material. The clay required for stability in the latter tends to become plastic after surface treatment, because the surface mat prevents evaporation and causes the base to yield under traffic; and this leads to weakening and failure of the mat.

The maximum amount of clay binder permissible in the base depends largely upon the fine materials and particularly on the character of the clay itself. Because of the presence in base materials of certain soil constituents which determine to a large extent the behavior of the base, it is possible to apply soil analysis not only to the subgrade soils but to the base course material as well.

Unsatisfactory base materials were used on several of the projects studied, with resulting failure of the surface. In some cases also the constructed base courses were composed of materials inferior to the natural soil in the road. Analyses of the materials before construction would not only have prevented the use of this unsatisfactory material but would have brought out the possibility of using the natural soil or would have indicated the best method of treating it to make it satisfactory.

For example, sand admixtures are likely to prove beneficial to base materials when highly plastic clay with a plasticity index ratio greater than 1.00 is present in amounts exceeding 20 per cent. This same type of clay, in moderate amounts, may prove beneficial in stabilizing elastic bases which have little or no plasticity and have field moisture equivalent ratios greater than 1.00 The same type of clay may be advantageously used in considerable amounts to stabilize highly elastic A–5 soils.

ADAPTABILITY OF VARIOUS SOIL GROUPS FOR SURFACE TREATMENT SUMMARIZED

The performance which may in general be expected from soils of the various uniform groups, when used as bases for surface treatment, is outlined in the following paragraphs:

Group A–1.—Materials would be highly satisfactory but are seldom encountered. There is also the possibility of softening on very wet subgrades.

Group A–2.—Materials range from friable to plastic. The less plastic materials are satisfactory. The more plastic materials are unsatisfactory, except under dry conditions, but are often used. The presence of micaceous materials tends to decrease greatly the stability of the base material. Some suitable treatment for reducing the plasticity of the material or stabilizing bases having the more plastic characteristics should be applied. A large percentage of the bases studied come under this group.

Group A–3.—Materials are highly satisfactory for surface treatment. In the construction of a bituminous mat on this material a large amount of primer will probably be necessary to stabilize the surface of the base. The sand-gravel materials obtained from runs and river beds and used on some of the projects, such as project 11 and parts of projects 13 and 16, are of this group, as are the topsoils used on project 4 and part of project 6.

Group A–4.—Material is not satisfactory for surface treatment except under favorable moisture conditions. Since material is deficient in sand, stabilizing by mixing a fairly light tar with it, or laying a thin surface cover of coarse graded aggregate, would probably be more practicable than adding a large amount of sand or other fine granular materials, which would be required as an admixture. The topsoil on part of project 10 is of this class. This material was not given any special treatment and the surface mat has developed some cracks.

Group A–5.—Materials may not be satisfactory for surface treatment because of detrimental elasticity. Stabilizing by mixing a light tar with the surface would probably be as satisfactory as employing a thick top course of stone or other suitable material.

Groups A–6 and A–7.—Materials generally lose stability as a result of water entering from above. Surface treatments which prevent this entrance of moisture produce fairly satisfactory results. A thin top course of sand added to the surface would greatly improve the material for surface treatment. The A–7 soil, found extensively in the Piedmont area, is a light red-colored material. The base material on part of project 7 is of this type.

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No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

TECHNICAL BULLETINS

No. 55T . . Highway Bridge Surveys. 20 cents.

No. 265T . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS CIRCULARS

No. 62MC . . Standards Governing Plants, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects. 5 cents.

No. 93MC . . Direct Production Costs of Broken Stone. 25 cents.

No. 109MC . . Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails, Flood Relief, and Miscellaneous Matters. 10 cents.

MISCELLANEOUS PUBLICATION

No. 76MP . . The results of Physical Tests of Road-Building Rock. 25 cents.

REPRINT FROM PUBLIC ROADS

Reports on Subgrade Soil Studies. 40 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They can not be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio. (1927.)

Report of a Survey of Transportation on the State Highways of Vermont. (1927.)

Report of a Survey of Transportation on the State Highways of New Hampshire. (1927.)

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio. (1928.)

Report of a Survey of Transportation on the State Highways of Pennsylvania. (1928.)

Report of a survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States. (1930.)

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in PUBLIC ROADS may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

JANUARY 31, 1933

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION						APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal-aid allotted	Percentage completed	Mileage: Initial	Mileage: Stage[1]	Mileage: Total	Estimated total cost	Federal-aid allotted	Mileage: Initial	Mileage: Stage[1]	Mileage: Total		
Alabama	2,350.9	$ 4,648,723.85	$ 2,324,361.84	27	150.5	77.0	227.5	$ 893,223.37	$ 446,611.66	10.3	28.1	38.4	$ 3,315,399.04	Alabama
Arizona	1,213.9	3,173,325.89	1,374,568.02	65	125.5	154.5	280.0	9,644.06	1,928.81				128,133.66	Arizona
Arkansas	1,953.7	3,421,030.81	1,612,737.68	62	91.9	40.3	132.2	1,080,612.73	540,119.86	55.5		55.5	1,448,409.36	Arkansas
California	2,459.2	8,278,470.13	2,486,231.74	68	135.6	41.3	176.9	2,193,130.53	201,821.92	70.9		70.9	52,050.49	California
Colorado	1,781.3	2,479,420.76	1,117,579.88	66	100.9	22.7	123.6	712,809.12	320,764.04	46.6		46.6	805,464.56	Colorado
Connecticut	289.8	4,775,965.40	1,870,572.75	63	51.5		51.5	274,024.48	84,250.20	4.5		4.5	17,881.35	Connecticut
Delaware	374.4	538,564.15	101,900.00	55	14.3	17.2	31.5	218,276.10	41,300.00	9.8		9.8	33,025.44	Delaware
Florida	661.0	5,863,099.75	2,795,408.63	54	157.7		157.7	297,518.00	148,758.99	10.6		10.6	1,241,804.16	Florida
Georgia	3,176.8	5,624,315.89	2,276,808.32	57	161.9	174.5	336.4	500,491.90	219,482.10	22.5	26.9	49.4	84,696.48	Georgia
Idaho	1,539.0	2,415,174.17	983,277.00	72	121.7	122.5	244.2	598,446.86	185,127.72	16.5	16.7	33.2	75,427.89	Idaho
Illinois	3,069.7	20,636,314.07	8,115,405.14	79	636.0	33.0	669.0	1,498,259.44	471,696.98	62.4		62.4	126,899.36	Illinois
Indiana	2,004.5	8,514,308.55	3,931,048.24	91	319.8	3.0	322.8	1,725,082.44	184,013.84	87.4		87.4	123,082.17	Indiana
Iowa	3,519.1	5,384,285.39	993,885.38	91	261.1	40.0	301.1	359,559.81	23,060.00	25.0	1.2	26.2	11,498.31	Iowa
Kansas	3,792.7	4,458,185.58	1,680,581.32	66	265.8	122.6	388.4	1,077,611.14	89,018.71	102.0	12.1	114.1	349,958.22	Kansas
Kentucky	1,879.6	4,714,099.88	1,717,805.82	54	211.1	118.2	329.3	134,410.69	40,800.00	2.8		2.8	153,098.85	Kentucky
Louisiana	1,603.7	6,347,853.95	2,831,064.79	57	47.1	28.3	75.4	924,128.64	371,437.65	5.9		5.9	8,644.29	Louisiana
Maine	818.9	2,343,014.91	495,125.28	66	70.2	.3	70.5	113,343.37	41,181.46	.2	1.9	2.1	72,743.65	Maine
Maryland	827.4	1,140,554.27	427,636.61	88	48.5	3.2	51.7	574,970.90	29,400.00	21.8		21.8	32,060.11	Maryland
Massachusetts	867.1	4,654,918.21	1,187,127.43	60	63.2	4.9	68.1	158,206.29	30,000.00	3.4		3.4	30,738.38	Massachusetts
Michigan	2,289.7	7,206,955.82	2,935,734.95	66	290.2	103.0	393.2	1,262,075.91	420,725.00	88.1	1.4	89.5	120,096.19	Michigan
Minnesota	4,318.9	4,645,947.47	133,628.91	84	149.7	139.5	289.2	114,649.27	100.00	1.3	.4	1.7	47,190.24	Minnesota
Mississippi	1,828.0	5,714,491.86	2,814,065.33	61	204.9	74.9	279.8	673,667.22	320,828.04	19.2	4.2	23.4	3,605,579.07	Mississippi
Missouri	3,180.8	2,901,425.33	671,445.44	75	125.8	11.0	136.8	1,337,847.95	281,719.71	68.0		68.0	307,560.13	Missouri
Montana	2,730.3	7,219,244.17	4,048,652.81	55	551.8	244.8	796.6	667,451.08	375,119.26	78.6	11.9	90.5	195,371.64	Montana
Nebraska	4,275.9	5,727,947.49	2,693,488.24	42	162.1	130.7	292.8	62,693.01	23,086.84	8.4		8.4	298,699.33	Nebraska
Nevada	1,343.5	1,635,594.70	745,167.04	85	29.7	118.3	148.0	349,536.98	10,444.96	9.1	9.3	18.4	60,955.22	Nevada
New Hampshire	430.1	911,667.00	391,047.21	71	24.8	3.5	28.3	88,104.15	35,241.66		.6	.6	112,615.99	New Hampshire
New Jersey	629.2	6,215,931.90	2,132,266.20	60	64.2		64.2						65,234.22	New Jersey
New Mexico	2,221.3	2,934,756.32	1,343,845.14	64	168.9	86.3	255.2	274,939.21	129,753.60	10.8	5.2	16.0	267,392.19	New Mexico
New York	3,497.0	17,355,694.40	5,314,545.00	48	455.7	28.3	484.0	2,338,808.60	872,085.74	51.3	3.6	54.9		New York
North Carolina	2,259.3	3,084,111.93	1,538,594.73	41	346.2	23.6	369.8	1,734,589.62	868,977.3	227.9	.3	228.2	1,584,117.25	North Carolina
North Dakota	5,188.8	4,610,632.97	1,942,330.22	52	390.5	444.9	835.4	915,977.20	298,951.00	68.6	253.3	321.9	222,492.47	North Dakota
Ohio	2,996.3	7,898,433.27	2,240,055.09	77	198.7	69.6	268.3	2,409,334.00	461,688.63	32.7	6.4	39.1	233,614.00	Ohio
Oklahoma	2,405.7	3,940,027.91	1,931,830.12	79	187.9	48.5	236.4	2,839,958.50	583,587.00	159.3	38.3	197.6	434,169.17	Oklahoma
Oregon	1,605.5	3,859,713.97	1,598,090.97	55	115.6	81.3	196.9	532,222.22	194,254.87	13.4	15.8	29.2	109,262.95	Oregon
Pennsylvania	3,136.1	11,790,658.36	3,617,335.39	63	431.1	14.1	445.2	1,753,304.53	571,988.81	58.4		58.4	26,339.82	Pennsylvania
Rhode Island	269.8	959,110.79	298,191.64	27	21.8	4.3	26.1	199,761.94	74,618.00	2.8	.2	3.0	24,931.99	Rhode Island
South Carolina	1,353.4	3,513,090.82	1,326,892.73	54	162.5	157.2	319.7	77,398.09	10,787.67		3.4	3.4		South Carolina
South Dakota	4,157.9	4,116,695.40	1,826,707.28	76	275.6	252.3	527.9	357,389.43	59,470.74	65.4		65.4	55,377.27	South Dakota
Tennessee	1,678.7	5,019,033.23	2,508,498.53	31	161.0	61.5	222.5	700,835.12	350,417.54	22.6	5.7	28.3	549,329.74	Tennessee
Texas	7,800.0	17,322,985.27	6,984,132.52	62	738.8	439.2	1,178.0	5,244,063.51	1,459,443.93	247.9	103.8	351.7		Texas
Utah	1,248.9	1,646,827.64	695,811.63	70	94.0	79.4	173.4	389,214.72	116,975.97	24.8	15.6	40.4	211,909.93	Utah
Vermont	384.6	524,908.90	61,754.29	63	27.8		27.6						16,037.73	Vermont
Virginia	1,944.0	4,173,434.50	1,850,900.30	57	202.6	41.3	243.9	1,161,242.97	493,230.78	41.2	32.5	73.7	310,231.84	Virginia
Washington	1,326.4	2,433,262.83	798,612.10	42	104.0	1.1	105.1	946,662.00	160,000.00	12.0	4.5	16.5	94,532.16	Washington
West Virginia	913.1	3,577,911.03	1,336,621.05	64	125.1	8.4	133.5	32,291.00	16,145.50				194,006.53	West Virginia
Wisconsin	2,738.6	6,567,626.26	1,380,806.56	78	173.6	96.1	269.7	52,061.50	21,500.00		.9	.9	63,391.59	Wisconsin
Wyoming	2,037.4	3,275,883.26	1,220,583.53	80	268.3	186.8	455.1	29,783.45	1,244.51	5.0	4.4	9.4	4,053.27	Wyoming
Hawaii	78.4	2,176,281.06	1,179,014.06	45	60.1		60.1	290,788.83	219,999.72	5.9		5.9	749,436.92	Hawaii
TOTALS	105,055.3	252,371,911.47	95,883,774.88	62	9,347.3	3,953.4	13,300.7	40,180,451.88	11,903,160.78	1,880.8	608.6	2,489.4	18,074,944.62	TOTALS
Construction completed		141,875,000	59,555,000											
Balance uncompleted		110,497,000	36,329,000											

[1] The term stage construction refers to additional work done on projects previously improved with Federal-aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

U. S. GOVERNMENT PRINTING OFFICE: 1933