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BUREAU OF PUBLIC ROADS

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CONSTRUCTING A MIXED-IN-PLACE SURFACE

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BITUMINOUS TREATMENTS USED ON ROADS OF INTERMEDIATE TYPE IN THE WESTERN STATES

Reported by J. T. PAULS, Senior Highway Engineer, U. S. Bureau of Public Roads

THE progress which western engineers have made and are making in improving their highways with the limited funds available should be of interest to the highway officials of the more densely settled areas. Low-cost bituminous treatments of soil, gravel, and broken-stone roads constitute, in a large measure, the methods adopted by the Western States for improving their important highways to meet the demands of modern traffic. Although the traffic carried by these roads seldom equals that of the main highways of the East, it probably approximates that of the secondary systems, and consequently some of the methods now used satisfactorily in the West may prove suitable in the East for roads of the secondary class.

The material contained in this paper was obtained by the writer during an inspection made in the early summer of 1929 in company with representatives of the Bureau of Public Roads, the asphalt industry, and highway officials of the States visited, which were Nebraska, Wyoming, Colorado, New Mexico, Arizona, California, Nevada, Oregon, Idaho, Washington, and Utah.

The purpose of the inspection was to obtain more complete information on the design, construction, maintenance, and behavior of the different types of bituminous treatments used in the Western States. As there is a considerable difference of opinion regarding various details of these types of improvement, it was considered desirable to visit a large number of projects representing a wide range of conditions and to obtain the views of highway officials familiar with this work.

The predominant types of bituminous treatments used in the West are:

1. Oil treatment of crushed stone and gravel roads by the mixed-in-place and plant-mixed methods.
2. Oil treatment of sandy soil roads by the mixed-in-place method.
3. Treatment of sandy soil roads with light oil by a method involving both penetration and mixing.
4. Surface treatment of bonded stone roads and oil-mixed surfaces.

The light oil, mixed-in-place treatment with crushed gravel and stone aggregate predominates in all the Western States except Oregon, and possibly Washington, where surface treatment is used extensively.

Plant mixing has been used to some extent, but its general adoption is doubtful for construction using light-oil mixes. However, this method is considered to have advantages in many cases over field mixing, particularly where the road to be surfaced has no aggregate in place or where the work is to be done by contract. The premix method in such cases does not cost much, if any, more than the road mix and, in addition, has the advantage of making possible better control of the mixed proportions.[1]

Surface treatments are being used extensively in northern California, Oregon, and Washington and are also gaining in favor in other States where climatic conditions are not particularly favorable to the light-oil-mixed type of surfacing. They are also coming into extensive use in the maintenance of oil-mixed roads.

Some oil mixing on fine sandy soil roads has been done recently in Nebraska and Wyoming. This work, however, has not been extensive and as yet has not passed the experimental stage, but should it prove successful a large field would be opened for its use in these States as well as in some of the others.

Treatment of soil roads with light oil by a method somewhat different from that used in Wyoming and Nebraska has proved successful in a few of the semiarid counties of California. This method is quite similar to that used in Illinois, in that very little mixing is done. More strictly, penetration, together with the kneading action of traffic, is depended upon to combine the oil and the soil.

THE MIXED-IN-PLACE TREATMENT OF CRUSHED GRAVEL AND STONE ROADS

ALTHOUGH the methods and equipment used in the surface mixing process must necessarily be flexible to meet local conditions, the same general principles are used regardless of the materials involved. The aggregate to be oiled is obtained either by scarifying the old base or by adding new material, or by both scarifying and adding new material. The bituminous material is spread in applications of about one-half gallon per square yard by pressure distributors until the desired amount has been spread. Disking immediately after each application is the general practice, and is a very effective means of preliminary mixing, greatly reducing the amount of blading required. If the road is being built without detouring traffic, disking also prevents the freshly applied oil from adhering to passing vehicles.

After the required amount of oil has been applied the materials are mixed with the aid of blade machines by repeated windrowing and spreading until all the aggregate is covered and the mix presents a uniform appearance. Areas which appear lean are given an additional application of oil and are then remixed. An excess of bitumen can be corrected by bringing additional aggregate into the mix. Upon the judgment of the engineer mainly rests the determination of the proper amount of oil. Uniformity of distribution is easily obtained with most of the present-day distributors of experienced operators.

METHODS ARE ADAPTED TO LOCAL CONDITIONS

Mixing may be modified to meet special conditions. As an illustration, one-half the road width may be built at a time, or mixing may be carried out full width and half depth, or the full section may be mixed as one unit.

[1] Since the above was written there has been developed a self-propelled mixer, which was used to a limited extent during the construction season of 1930, and which is intended to combine the advantages of field and plant mixing. This machine utilizes an elevator for picking up the aggregate from a windrow on the road and delivering it to a weighing device, from which it passes to the mixer, where it is mixed with the proper amount of road oil. The mixed material is discharged in a windrow behind the machine, where it is spread with a blade in the usual manner. This equipment, if it proves successful, will improve the control of the proportions of the mix and will eliminate other construction difficulties at present attendant on mixed-in-place construction. A photograph of this machine is shown on p. 191.

Mixed-in-Place Surface Constructed of Crushed Stone and 94 Per Cent Road Oil Cut Back with Kerosene

When the mixing process has been completed the mix is spread to uniform cross section for compaction, which may be effected either by rolling or by traffic, or by both. When heavy bituminous materials are used, it is generally advisable to roll the surface; but in the case of light-oil mixes, compaction by traffic seems to give the best results if the surface is lightly bladed or dragged and all irregularities are corrected during the compaction stage.

The use of side forms to obtain a thickened edge is not universal, as the cost is relatively high. On many projects the edges have been thickened either by building up the shoulders or by cutting a V-shaped trench along the sides just prior to spreading the mix.

Obviously the methods just described can not be employed during cold or wet weather, or when the aggregates contain an appreciable amount of moisture. Many projects, no doubt, have been constructed without particular attention being paid to this detail, the importance of which is now generally recognized.

When the existing road metal is of sufficient thickness it is a common practice to scarify the surface to obtain material for the mixing. When this is done it is generally necessary to add aggregate of some particular size to effect a better grading. The combined thickness of the base and the oil-mixed wearing surface varies, but usually is made not less than 6 inches. Adding graded aggregate preparatory to mixing generally results in greater uniformity with a correspondingly better oil-mixed surface than is obtained by scarifying the old stone surface, which, moreover, very often contains clayey material that is not considered desirable for oil-mixing. Loosening the old surface doubtless reduces the supporting value of the road.

Some of the States add clay binder in the construction of the stone surface to insure a better bonded surface. A surface in this condition they find less expensive to maintain than one less firmly bonded, such as is obtained where the fines are granular material rather than clay particles. For this reason clay is often advocated for binder when the metaled road is not to be oil mixed in the near future. When, later, oil mixing is resorted to, the best results are obtained by the addition of new aggregate, the grading of which should be as uniform as possible throughout the project.

CHARACTERISTICS OF BINDER AND AGGREGATE DISCUSSED

The following limits are typical and are considered satisfactory for the binder material in the aggregate to be oil mixed:

Cementing value, not less than 100 (Page cementation test).
Moisture equivalent, not more than 20 per cent.
Lineal shrinkage, not more than 5 per cent.

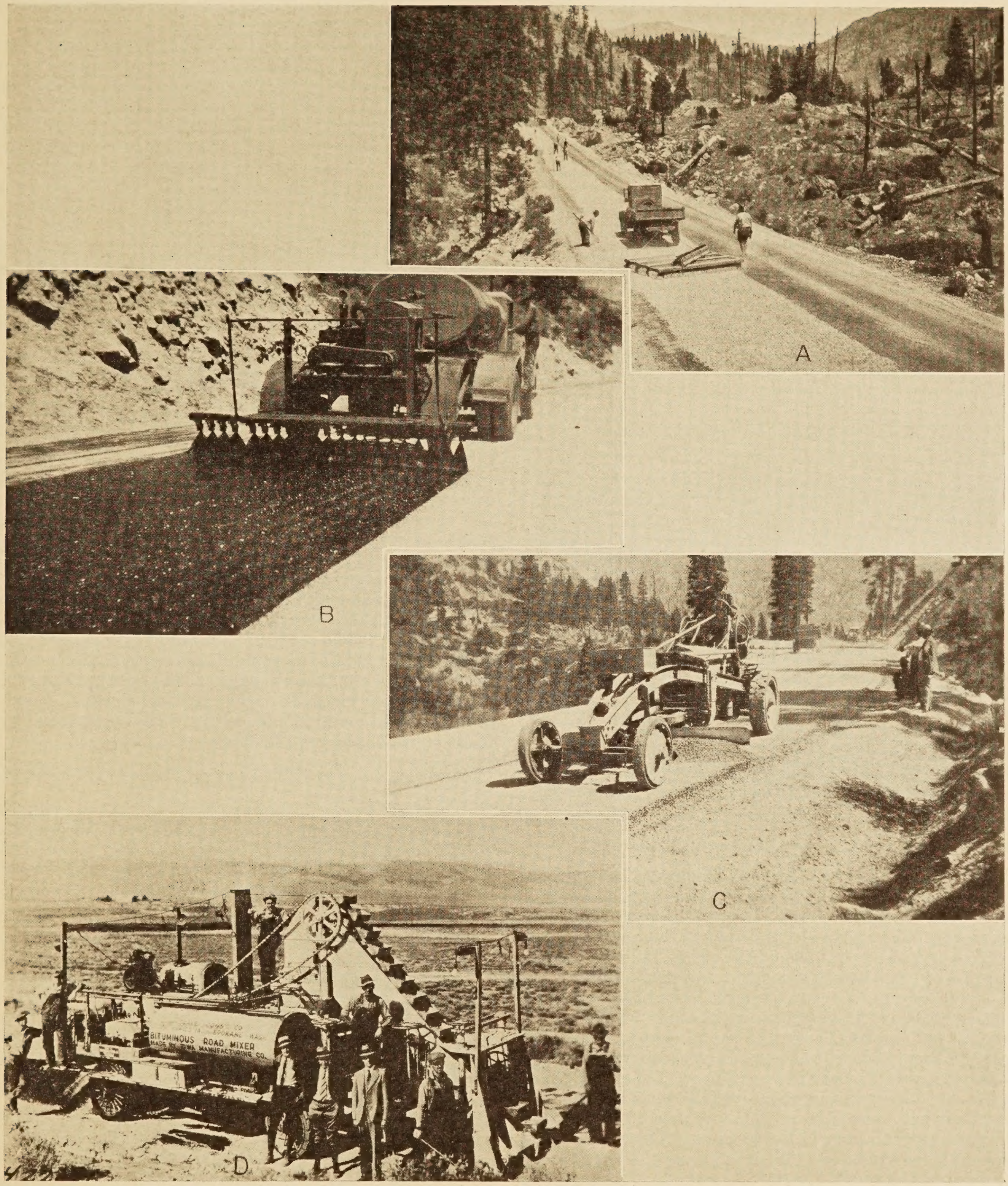
The grading of the aggregate for the oil-mixed surface should be such as to give high stability. With the use of light oil, lacking in body and adhesive properties, this is very important. With oils of this type it is necessary to use aggregate of small size. The maximum size used ranges from about 1 inch to three-fourths inch.

The tendency of the coarser particles of aggregate to become dislodged from the surface and be thrown to the edges was observed on many of the oil-mixed roads. Although this was due in many cases to an insufficient amount of oil, it seemed to be more noticeable on surfaces built with coarser aggregate. A smaller maximum size, of about one-half inch, might have reduced the segregation and raveling noted. However, the primary cause of such failures is believed to be the use of dry mixes.

Table 1 gives the grading of the crushed aggregate used on a large number of typical oil-mixed projects.

SUITABILITY OF AGGREGATES FOR OIL MIXING AN IMPORTANT CONSIDERATION

Some of the Western States, particularly Arizona, have encountered some difficulty in applying the oil-mix treatment in certain areas, due to the fact that the aggregate contains a material known locally as caliche,



Examples of Road-Building Equipment Used on Intermediate Type Roads in the West. A—Brooming the Cover Stone on Surface Treatment Work. B—Attachable Spreader Equipment Used in California. C—Blading the Surface Treatment Cover. D—Portable Mixing Plant Recently Designed and Used on Mixed-in-Place Construction

Table 1.—*Grading of crushed aggregate used on typical oil-mixed projects*

State	Average mechanical analysis of road metal on typical oil-mixed projects; per cent by weight passing—							Oil used, per cent by weight	Oil required by formula [1]
	1-inch	½-inch	10-mesh	40-mesh	80-mesh	100-mesh	200-mesh		
Wyoming	95.7	59.9	39.3	23.7	15.2		6.7	4.1	3.0
	97.5	75.2	52.5	27.6	15.1		6.5	4.3	3.2
	98.0	82.1	63.9	33.5	18.7		7.2	4.8	3.5
	92.8	59.1	44.2	34.1	24.3		8.9	5.0	3.4
	99.0	78.5	53.9	22.0	11.1		5.1	3.9	3.0
	95.4	76.7	63.3	36.0	23.1		10.0	4.6	3.9
	91.3	59.0	42.1	26.8	18.0		4.9	3.2	2.5
	92.5	65.5	47.6	24.1	15.2		7.0	4.9	3.2
Average	95.3	69.5	50.8	28.5	17.6		7.0	4.4	3.2
New Mexico	99.8	71.3	59.3			14.0	7.8	4.0–5.2	3.5
	98.3	79.3	60.9			16.2	9.0	4.8–6.0	3.7
	98.7	69.8	47.3			6.1	3.3	3.9	2.7
	99.4	68.5	48.2			9.5	4.8	3.4	2.9
	98.4	88.8	74.1			9.3	4.8		3.3
Average	98.9	75.5	58.0			11.0	5.9		3.2
Idaho		48.6	34.0				6.4	4.2	2.9
		41.8	28.0				4.8	3.2	2.6
		47.7	34.7				5.9	3.2	2.8
		42.2	27.9				5.9	3.8	2.7
		55.1	35.3				4.6	3.5	2.6
		60.1	40.5				7.1	5.0	3.1
		40.0	30.1				5.9	3.0	2.8
		50.9	32.0				5.7	4.4	2.8
		56.4	39.1				4.4	4.9	2.7
		54.0	41.8				7.1	4.2	3.1
		57.7	48.8				7.5	4.2	3.3
		53.0	43.7				6.8	4.1	3.1
		56.0	40.4				5.2	4.4	2.8
		52.0	42.0				9.3	3.9	3.4
		48.2	40.4				5.0	4.3	2.8
		46.4	37.4				5.8	3.0	2.9
Average		50.6	37.3				6.1	4.0	2.9
Utah			38.3				10.3	4.4	3.5
			36.4				8.8	3.8	3.3
			25.9				6.0	3.3	2.7
			44.7				7.9	3.6	3.3
			33.5				5.7	3.2	2.8
			34.1				5.9	3.6	2.8
Average			35.5				7.8	3.7	3.1

[1] McKesson and Frickstad formula for estimating the amount of oil required. See text.

which is a calcareous clay or argillaceous limestone. Its presence is often not apparent, especially when it occurs in particles of small size. It has been found impracticable to apply the oil-mix treatment to aggregate containing any appreciable amount of this material.

TESTS DEVISED TO DETERMINE SUITABILITY

J. W. Powers, of the Arizona Highway Department, has devised a test to determine the suitability of an aggregate for oil mixing. His method is to mix the aggregate passing the 10-mesh sieve with sufficient oil to give a predetermined stain. The mixture is then compressed in a 3-inch ring, 2 inches deep, under a load of 2,000 pounds per square inch. The container and sample are then immersed in water and observed. The amount of swelling is indicative of the results which may be expected with the particular aggregate under consideration. Experience has shown that if no swelling of the mix occurs the aggregate will be satisfactory under all conditions and with all oils. A swelling of as little as one-sixteenth inch indicates that only mediocre success may be expected. With aggregate otherwise considered entirely unsuitable for mixing, swelling of as much as three-fourths inch is often obtained.

Preference on the part of the aggregate for the adsorption of water or of asphaltic residues is believed to indicate the probable behavior of an oil-mixed surface subjected to moisture. This principle, it is thought, accounts for the swelling of the material in this test.

Another test for the suitability of the fine aggregate has also been devised by Mr. Powers and is now being used by Mr. Hveem, of the California State Highway Department, in conjunction with research tests on aggregates for oil mixing.

The method of making this test is essentially to combine 10 grams of the fines passing the 200-mesh sieve with 50 cubic centimeters of the 60 to 70 per cent road oil, which has previously been heated to 130° F. Mixing is generally done with an electric mixer of the fountain type, a glass jar of about 250 cubic centimeters capacity being used for the container. The mixing is continued for five minutes, after which 100 cubic centimeters of water at 130° F. is added, followed by five minutes of additional mixing.

In this test unsatisfactory dust will separate from the oil and be deposited at the bottom of the jar, whereas a satisfactory material will remain coated in the oil.

VARIOUS LIGHT-OIL PRODUCTS USED

The petroleum products used in the oil-mix treatments of the West have come from a large number of fields, chiefly in California and Wyoming. So far neither service behavior nor laboratory tests have shown the source of the oil or the method of manufacture to have any important effect on this type of construction.

The various light-oil products coming from the refineries have been obtained by straight topping of the crude petroleum, as residues from steam distillations, and as by-products of the different cracking processes. The oil most widely used contains 60 to 70 per cent asphalt of 80 penetration, and has a specific viscosity (Engler at 122° F.) of 10 to 25, 25 to 50, and 50 to 80 for the light, medium, and heavy grades, respectively. The medium and high viscosity materials are preferred, as the more fluid materials do not produce mixes which are as well bonded as those produced by oils of greater viscosity. The heavier grades are commonly heated, particularly during cool weather, in order to promote ease of application.

SPECIFICATIONS AGREED UPON BY WESTERN STATE OFFICIALS

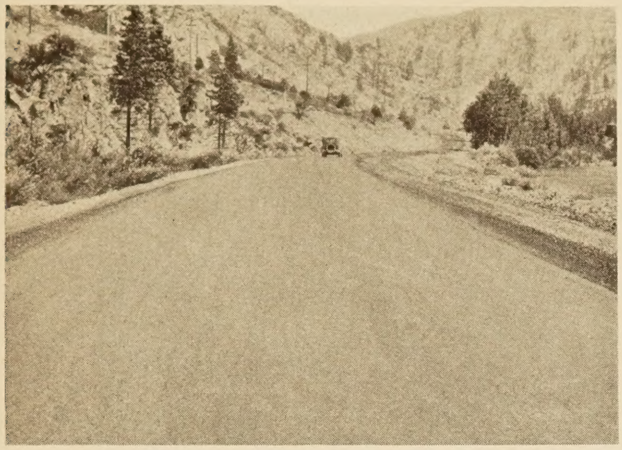
As a step toward standardizing and simplifying the requirements for road oils, a conference of highway officials of several Western States was held at Portland, Oreg., in February, 1930. It was then agreed to use the following specifications for road oils:

	Grade 0	Grade 1	Grade 2	Grade 3
Asphaltic residue of 80 penetration, per cent	30 to 40	50 to 60	63	95
Viscosity, Saybolt Purol at 122° F., seconds	15 to 40	40 to 80	200 to 300	
Float test at 50° C., seconds, minimum				250
Float test at 25° C., seconds, maximum			200	
Flash point, Pensky-Martens, °F., minimum	150	175	225	395
Water and sediment, per cent, maximum	2	2	2	
Water, per cent, maximum				½
Sediment, per cent, maximum				1
Bitumen soluble in CS_2, per cent, minimum	99	99	99	99
Bitumen soluble in CCl_4, per cent, minimum	99.65	99.65	99.65	99.65
Bitumen insoluble in 86° Baumé paraffin naphtha, per cent				6 to 27
Penetration of residue after loss on heating at 163° C. for 5 hours, minimum				125

Note.—Grade 0 and 1 to be used for dust palliative and prime applications, grade 2 for mixing, and grade 3 in surface treatment, generally as binder material applied hot.

USE OF HEAVIER OILS DESIRABLE IN MIXED-IN-PLACE CONSTRUCTION

It has been evident for some time, particularly on roads carrying fairly heavy traffic and on those where moisture and climatic conditions are not entirely favorable, that the use of a bituminous binder heavier than the light oils now used would give better results



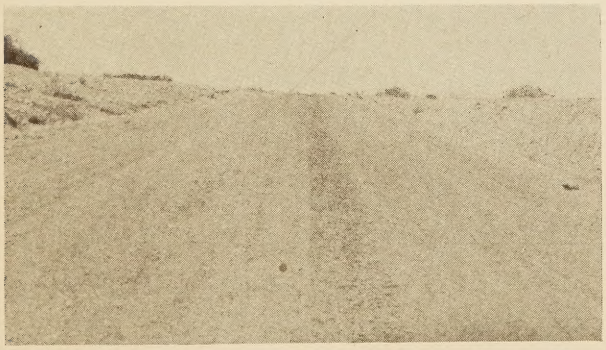
Typical Appearance of the Light-Oil-Mixed Roads of the West

in the mixed-in-place type of construction. With this in mind some experimental work using slow-drying emulsions and cut-back asphalts of the heaiver grades has recently been done in California.

EXPERIMENTS WITH SLOW-DRYING EMULSIONS SHOW PROMISE

The problem of developing an emulsion that would have a sufficiently retarded breaking point to permit mixing has not as yet been completely solved. Although material of this type is being made with a relatively slow break, experience shows that fine aggregate and dust accelerate the breaking of the emulsion. It has also been observed that the emulsion has a tendency to combine with the fines and leave the larger particles uncovered. This condition necessitates considerable rolling to incorporate these coarser particles and obtain a bonded mass.

Mixing an application of oil or water with the aggregate delays the breaking of the emulsion and makes it possible to obtain a better coating of the stone. Keeping the amount of fines in the aggregate to a minimum also reduces this difficulty. Although these recent changes in methods of construction and materials have in general improved the results obtained with this type of emulsion, further work along this line may well be done, as its use in the mixed-in-place type of treatment has not yet proved entirely satisfactory.



A Three-Inch Oil-Mix Road in Arizona. Early Failures Occurred Because the Aggregate Contained Caliche

CUT-BACK ASPHALTS ALSO USED SUCESSFULLY

Another material which has recently been tried out in mixed-in-place construction is cut-back asphalt. Both the 94 per cent grade of road oil and the 100 to 120 penetration asphalt material, cut back with kerosene, have been used. These materials seem to be entirely suitable for mixed-in-place construction. On the work so far completed the ease of construction and the excellent early appearance of the surfaces indicate that favorable results may be expected with this type of material. While its cost may be slightly higher than that of materials now in general use, it is believed that considerably better results may be obtained by using a heavier type of bitumen, as it offers greater resistance to raveling, particularly during freezing weather, and will withstand failure from moisture.

HEAVIER ROAD OILS NEEDED TO COMBAT WET WEATHER CONDITIONS

Experience has shown that oil-mixed surfaces in which the more fluid grades of road oil have been used fail rapidly under conditions of moist subgrade and wet weather. These road oils are not easily volatile under atmospheric conditions and stay in a fairly fluid condition in the surface mix. This fluidity and lack of great adhesiveness permit the water, moving up from the subgrade into the mix, to dislodge the oil surrounding the mineral aggregate in the lower strata, carrying the oil to the surface, where it gives the impression of

Typical Appearance of Bleeding on a Light Oil-Mixed Surface Caused Not by Excess Oil but by Moisture and Oil Rising to the Surface

bleeding or of an excessively rich mix. The waterlogged surface loses its stability and begins to shove and rut, since the action of traffic under these conditions tends to destroy the bond of the mix. This effect is due, no doubt, to the scrubbing and kneading action of traffic, which causes dislodgement of the oil from the surfaces of the stone particles.

Laboratory tests in conjunction with field observations indicate that road oils of high viscosity and high specific gravity resist the action of moisture better than the lighter materials, and also that a rich mix is more resistant to the action of moisture than a lean one. Although methods of construction or modifications of the materials may be devised for their more successful use, light oils are not at present proving satisfactory for mixed-in-place treatment under wet or freezing conditions. Consequently, there has arisen a great deal of interest in the use of heavier bituminous materials, such as cut-backs and emulsions, for this type of construction.

Table 2 gives the analyses of typical oils obtained from different fields and by different processes of manufacture used in the mixed-type of construction in the West and also the results of the Hubbard-Field stability tests on specimens molded from mixtures of these oils and sheet-asphalt sand.

Table 2.—*Test results on bituminous materials and Hubbard-Field stability values on sand mixtures*

B. P. R. No.	28825	28836	28855	30574	30941	31750	32591	32583	32584	32622	32553
Field	California	California	California	California	Texas		Wyoming	California	California	California	Wyoming
Process of manufacture	Topped residue	Topped residue	Topped residue	Topped residue		Cracking-plant residue	Cracking-plant residue	Cracking-plant residue	Cracking-plant residue	Fluxing	Fluxing
Type	70 to 80 road oil	70 to 80 road oil	70 to 75 road oil	60 to 70 road oil	No. 65 road oil	60 to 70 road oil	70 to 80 road oil	70 to 80 road oil	70 to 80 road oil	100 to 120 asphalt cement, cut back	94+ road oil, cut back
ANALYSIS											
Specific gravity, 25°/25° C	0.967	0.961	0.974	0.966	0.960	1.094	1.045	0.999	0.991	0.970	0.993
Flash point, ° C	107	143	99	68	85	163	189	144	122	79	105
Specific viscosity, 50° C., Engler	65.9	41.4	65.5	29.0	55.5	52.2	74.1	69.8	31.2	78.9	78.2
Loss, 163° C., 5 hours, 50 grams, per cent	8.64	5.48	9.82	15.42	13.46	4.83	1.92	3.65	5.58	13.28	13.13
Float test on residue, 50° C., seconds	32	23.8	36	37.4	44	22.8	43.4	54.8	39.6	75.8	91
Bitumen soluble in CS_2, per cent	99.95	99.91	99.94	99.92	99.88	98.91	99.63	99.80	99.77	99.79	99.97
Bitumen insoluble in 86° Baumé naphtha, per cent	9.89	7.50	12.21	13.18	19.27	26.03	21.73	13.96	13.68	8.05	17.04
Per cent residue of 100 penetration	70.14	66.05	67.15	62.7	65.9	69.5	74.4	73.7	72.1	75.3	78.0
Residue:											
Penetration at 25° C	85	88	103.5	104	113	103	98	93	113	103	98
Penetration at 0° C	12	15	19	22	38	13	16	17	21	19	26
Softening point, ° C	46.3	46.5	44.8	44.3	47	41.5	44.4	45.6	43.9	44.2	45
Ductility at 25° C., centimeters	110+	110+	110+	106.5	75	110+	110+	110+	110+	110+	110+
Ductility at 1.5° C., centimeters	6.8	5.2	11.9	7.0	6.0	6.2	(1)	4.7	5.0	7.0	5.5
Stability,[2] Hubbard-Field, at 25° C.:											
After 1 day at 60° C.—											
Per cent of bitumen volatilized	5.93	4.27	6.28	5.84	6.46	1.82	2.20	1.38	2.95	7.18	7.03
Stability, pounds	655	512	683	712	863	615	978	863	755	925	1,238
After 5 days at 60° C.—											
Per cent of bitumen volatilized	8.83	5.15	10.71	9.86	11.35	4.38	3.08	2.83	4.86	12.33	13.38
Stability, pounds	795	555	925	805	983	675	1,188	1,075	880	1,575	2,362
After 10 days at 60° C.—											
Per cent of bitumen volatilized	9.82	8.78	11.20	11.26	13.25	5.56	3.40	3.89	6.65	14.85	16.21
Stability, pounds	1,112	712	1,175	1,125	1,135	875	1,188	1,563	1,400	2,362	3,125

[1] Snapped.
[2] The cylinders for the stability test were made with Potomac River sand of the following grading:

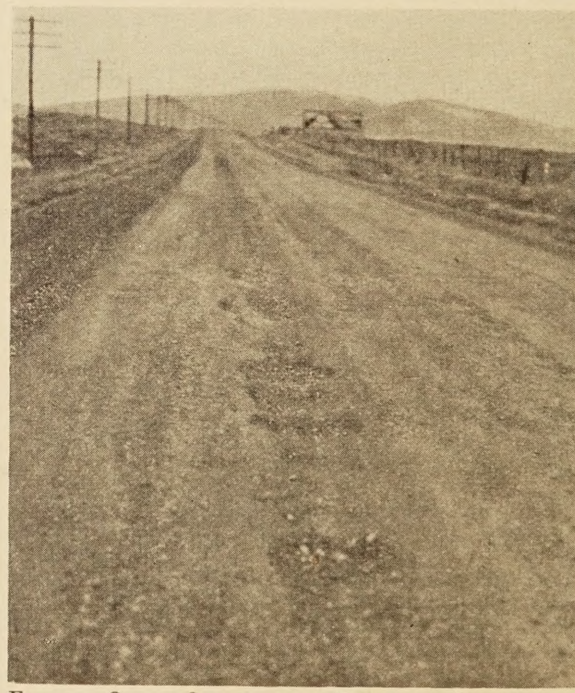
Passing	10	20	30	40	50	80	100	200
Retained	20	30	40	50	80	100	200	---
Per cent	11.0	10.4	18.2	18.7	23.4	6.9	9.5	1.9

Eight per cent of bituminous material was used throughout. Materials were mixed and molded at room temperatures and subjected to a temperature of 60° C. in a Freas oven for the period stated. Specimens were tested for stability at 25° C.

CUT-BACK ASPHALTS SHOW RELATIVELY HIGH STABILITY

While there have been no recognized tests for determining the relative efficiency or binding power of the various oils that have been used in the oil processing, recent tests, of which those recorded in Table 2 are a part, have been made in the bureau's laboratory, using the Hubbard-Field stability test as a criterion. These tests indicate that there is a wide difference in the stability and the rate of hardening of these various road oils in fine-graded mixtures. The comparatively high stability obtained with the two cut-backs indicates that this type of material should prove more resistant to the destructive action of water, surface raveling, and displacement than the oils now in common use.

These two cut-backs represent a type of bituminous material which has only recently been used in the West, but which has been extensively used in the East for both surface treatment and cold mixing. In the Eastern States gasoline and similar distillates have generally been used as fluxing media. It was thought that the use of gasoline in cut-backs for mixed-in-place work would result in a too rapid stiffening of the road mix, thus preventing thorough covering of the stone and rendering the compaction of the finished surface more difficult. Therefore, after experimental work in the laboratory, two grades of cut-back, using a less volatile solvent, such as kerosene, were suggested and



Failure Often Occurs from Raveling During the Dry Season Following the Action of Moisture on the Mix During the Wet Season

Early Raveling Develops When Insufficient Oil is Used in Construction. This Mix Contains About 25 Per Cent More Oil Than Called for by McKesson and Frickstad Formula

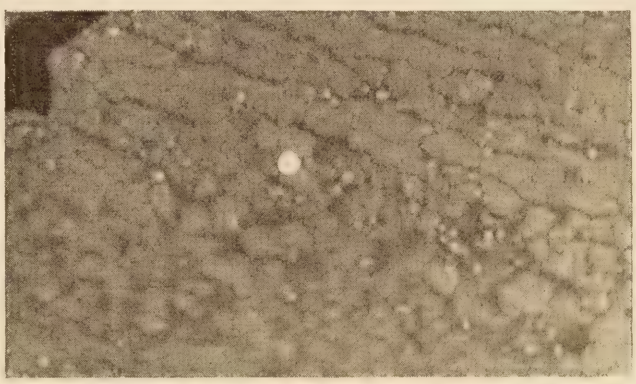
are being tried out in the West.[2] These two cutbacks are a 94+ per cent road oil, which is similar to a 150 to 200 penetration asphalt cement, and a 100 to 120 penetration oil asphalt. When cut back with 20 to 25 per cent of kerosene as the fluxing medium they give a product having a specific viscosity (Engler at 50° C.) of 70 to 80. The evaporation of the kerosene is not too rapid to interfere with the covering of the stone and subsequent compression, and the finished pavement develops a stability which could not be obtained with the usual light oil used in this type of construction.

PROPER AMOUNT OF OIL AN IMPORTANT CONSIDERATION

The amount of oil necessary for a particular job depends largely on the grading and character of the aggregate. The more fine material present, particularly of the size passing the 200-mesh sieve, the more oil is required. In all cases sufficient oil should be used to coat all the particles and partially fill the voids. The use of less than this amount results in early raveling and failure of the surface. Allowance must also be made if the aggregate is of the character that absorbs oil. This is particularly true when the aggregate contains an appreciable amount of soft limestone.

Several methods are in general use for determining the amount of oil required. The most common of these are the stain-test formulas, such as the McKesson and Frickstad formula and its modifications, and the "cut-and-try" method. The latter involves the determination of the requisite amount of oil on a short portion of the road as a guide in conjunction with the grading of the aggregate, determined periodically for the remainder of the project. Some engineers depend on the cut-and-try method, using the stain and formula, or both, as guides during the work. In any case, good judgment and considerable experience are necessary to determine the proper amount of oil to be used.

The tendency now is to use more oil than formerly, and considerably better results are being obtained. On the early work in many of the States the amount of oil used was determined by the stain tests, and the formula was developed primarily on the basis of experience in southern California. It has since been found that considerably more oil is required in areas with colder climates. In some of the States, and with certain types of mixture, it is frequently found necessary to use as much as 50 per cent more oil than is called for by the stain test or by the McKesson and Frickstad formula.[3]



Typical Failure of a Light-Oil-Mixed Surface During Dry Weather Following the Action of Moisture

Table 1, previously referred to, gives the amounts of oil actually used in a number of projects and the amounts which would have been used had the formula been followed.

T. E. Stanton, materials and research engineer of the California State Highway Commission, has recently developed a formula by which he believes the required percentage of oil can be accurately determined.

[2] Materials of this type were first used on the experimental road which extends westerly from the California-Nevada State line for a distance of about 10 miles along the Truckee River. This project was conducted cooperatively by the division of highways, California Department of Public Works, and the Bureau of Public Roads.

[3] $P=0.015a+0.03b+0.17c$, where P=the percentage of oil required, a=the percentage of aggregate retained on the 10-mesh sieve, b=the percentage of aggregate passing the 10-mesh and retained on the 200-mesh sieve, and c=the percentage passing the 200-mesh sieve.

Constructing a Mixed-in-Place Surface. Applying Bituminous Material, Disking, and Mixing

The formula is based on the surface area of the aggregate as determined by sieve analysis and modified by surface characteristics. For materials of average grading and average surface characteristics the following simplified formula is proposed for use in the field:

$$P = 0.020\,a + 0.045\,b + 0.180\,c$$

Where P = percentage of oil required, a = percentage retained on the 10-mesh sieve, b = percentage passing the 10-mesh and retained on the 200-mesh sieve, and c = percentage passing the 200-mesh sieve.

For very fine mixes, such as 100 per cent passing a ¼-inch sieve, it is recommended that the coefficient of c in this formula be changed to 0.150, whereas for coarse mixes, with only 50 per cent passing a ¼-inch sieve and only 4 to 5 per cent passing the 200-mesh sieve, the term should be increased to 0.20 c.

Another matter which should be considered in determining the amount of oil to be used is the moisture in the aggregate. If the moisture present, which is generally appreciable, is not taken into account, extractions and stain tests may indicate high oil content when in reality the mix is lean. An error in judgment may occur if the appearance of the mix is used as the guide in determining the amount of oil to use, as a small amount of moisture will invariably give the appearance of more oil than is actually present.

ONE-AND-ONE-HALF TO THREE INCH SECTIONS USED FOR MIXED-IN-PLACE SURFACES

The thickness of oil-mixed surfaces has been found to range from 1½ to 3 inches, but in the majority of the cases examined it was 2 inches. Washington seems to be the only State using the 1½-inch section, and this may be explained by the fact that this type of construction is regarded in Washington as a temporary improvement, later to be strengthened by surface treatments or to be replaced by some higher type of construction. Washington also primes the base before constructing the mixed mat. This procedure no doubt improves the base condition and also serves to strengthen the wearing surface. With the exception of Washington, however, there appears to be a growing tendency to regard 3 inches compacted as the minimum thickness for a satisfactory mat.

Light-Oil-Mixed Surface Rapidly Failing on Account of Insufficient Oil. Note Coarse Aggregate Thrown to the Edges

VARIOUS MAINTENANCE METHODS USED

Maintenance methods used on oil-mixed surfaces depend not only on the condition of the road but also on the policy of the engineers in charge. The general practice is to use one or more of the following methods: (*a*) Repairing holes and breaks as they develop by using premixed material; (*b*) enriching the surface periodically by light applications of road oil; (*c*) scarifying and remixing with additional oil; and (*d*) applying surface treatments consisting of hot application materials or emulsions and covering with crushed stone or gravel.

100 TO 120 PENETRATION ASPHALT CUT BACK WITH KEROSENE. SMOOTHING OF THE MIX PRIOR TO COMPACTION

The practice of surface treating the oil-mixed surface in order to provide greater wear resistance and to reduce the maintenance cost seems to be gaining in favor. This treatment provides an inexpensive method for improving oil-mixed roads to meet more adequately the needs of increased traffic.

The application of additional light oil to enrich the mix is used quite extensively in southern California, but does not seem to be much in favor elsewhere. The main objection to this treatment is the raveling and peeling which occurs under traffic during the period of drying. This method of maintenance seems to be of doubtful value except where traffic can be detoured for a time while the surface is hardening.

LIGHT OIL-MIXED SURFACES DEFECTIVE IN MOIST CLIMATES

Northern California, Oregon, and Washington favor surface treatment rather than the light-oil-mixed type, particularly in sections where wet subgrades or moist and freezing weather conditions prevail. It has been the experience of these States that light-oil-mixed surfaces do not prove satisfactory under these conditions. Water from the subgrade seems to rise freely to the surface, carrying with it the oil from the mix below. As this process continues the mix becomes unstable and rapidly rolls and displaces under traffic. The loss of stability seems to be aided by the action of the water on the light oil as this material appears to lose much of its body and adhesive qualities.

The early behavior of the mix when acted on by moisture gives the appearance of richness; that is, it bleeds and tends to shove and become wavy. After some time the surface mat breaks, raveling occurs, and failure soon develops. Until recently excess oil was believed to be responsible, and this misunderstanding tended to keep the quantity of oil used at a minimum.

The oil-mixed type of surface is far from being waterproof. The amount of oil used is generally sufficient only to coat the mineral aggregate without an excess to decrease the voids materially. Furthermore, the compaction is not sufficiently thorough. These two conditions render the pavement porous, with a tendency to become water-logged.

COST DATA DISCUSSED

Such data as are available indicate that the cost of the oil-mix treatment, exclusive of the cost of the aggregate, ranges from $1,000 to $2,000 per mile for an 18-foot width of 2 to 3 inches compacted depth. This figure does not include the cost of the base stone, which varies considerably, depending chiefly on the cost of the aggregate in place. For a large amount of this work under a range of conditions the cost for a 5 to 6 inch compacted crushed gravel or stone course ranges from $3,500 to $4,500 per mile.

Although definite figures on the cost of maintenance of oil-mixed roads are very limited, such data as are available indicate that the treatment is economical in comparison with untreated macadam.

The cost of surface maintenance of 600 miles of untreated macadam in Idaho during 1928 was $285 per mile, exclusive of material replacement, while on 200 miles of the oil-treated surface it was $294 per mile. The traffic on the former was 100 to 200 vehicles per day and on the latter from 100 to 1,200.

The annual maintenance cost in Wyoming during 1928, on a considerable mileage of treated roads, averaged $330 per mile.

The New Mexico Highway Journal for May, 1929, gives the following summary in proving the contention that oil-treated roads are cheaper than those which are untreated:

> Gravel and crushed stone roads in New Mexico constitute 1,450 miles. Approximately 1,000 miles now require 4 inches of material to restore them to their original thickness. It has been found that the untreated roads lose approximately 1 inch of material per year.

	Untreated	Oiled
Original cost per mile of construction	$2,860	$3,800
Annual maintenance cost includes:		
Interest on investment, at 6 per cent	171	228
Replacement of material lost	715	
Maintenance	350	250
Total annual cost	1,236	478

CONCLUSIONS

The results of this survey lead to the following conclusions regarding the use of the mixed-in-place method with gravel or stone aggregate.

1. In sections where conditions are suitable, such as arid and semiarid regions, the light-oil-mixed treatment is proving satisfactory and economical and will undoubtedly continue to be used extensively.

2. Light oil does not give a sufficiently well bonded surface to prevent raveling under heavy traffic, particularly in cold weather, nor does it withstand the action of moisture.

3. For unfavorable conditions a heavier asphaltic oil, or a soft asphalt cement cut back with a distillate, such as kerosene, naphtha, a combination of both, or a suitable asphalt mixing emulsion, should be used. A surface treatment using a hot application material or emulsion on either the light-oil mix or on the untreated macadam may be used to obtain more satisfactory results.

4. An insufficient amount of oil has been used on much of the work up to this time, resulting in many failures and high maintenance cost. The fact that a bituminous mix has the greatest resistance to deterioration when its bitumen content is the maximum allowable, as judged from the stability required, seems to have been ignored generally on bituminous work in the West. It seems, indeed, that the attempt has been made to use the minimum amount possible.

5. Very little shoving and corrugating occurs. When such defects are found they are generally due not to excess oil but to moisture or subgrade conditions.

OIL TREATMENT OF EARTH AND SANDY SOILS

94 Per Cent Road Oil Cut Back with Kerosene Mixed in Place with Blow-Sand Soil

"BLOW-SAND" ROADS TREATED IN WYOMING AND NEBRASKA

OIL treatment of earth and sandy soils by the mixing method has not been tried to any large extent in the Western States. Some work of this type has recently been done in Wyoming and Nebraska. The soil in both cases is a very fine grained and poorly graded material commonly called blow sand.

The method of construction consists of mixing in two layers to produce a final compacted depth of about 4 inches. A light road oil was used on the work in Wyoming, while in Nebraska both a light road oil of 60 to 70 per cent asphalt and a heavier material of 94 per cent asphalt and 100 to 120 penetration asphalt cut back with a slow drying distillate of the kerosene type were used.[4]

Sufficient time has not elapsed since this construction to allow conclusions to be drawn regarding its success. The sandy soil is very unstable, and for that reason the light oil may not add sufficient stability. By the use of the heavier material much greater bond is obtained, as well as a much better road surface.

[4] During the summers of 1929 and 1930 the division of bridges and highways, Nebraska Department of Public Works, and the Bureau of Public Roads conducted cooperative experiments, using these materials in the treatment of road surfaces composed of fine sandy soils.

The following table gives the typical grading of the soils which were oil mixed in Wyoming and Nebraska:

	Wyoming Project 198	Nebraska Project 313A
	Per cent by weight	*Per cent by weight*
Passing 10-mesh sieve	99.7	100.0
Passing 20-mesh sieve		98.8
Passing 30-mesh sieve		96.8
Passing 40-mesh sieve	93.8	87.7
Passing 50-mesh sieve		65.9
Passing 80-mesh sieve	75.9	21.4
Passing 100-mesh sieve		10.9
Passing 200-mesh sieve	19.8	1.4

The amount of oil used in this construction was about 7 per cent on the Wyoming work and 7 to 8 per cent on the Nebraska job. As shown by the grading of the soil, the Wyoming material should require more oil, because of the large amount of material passing the 200-mesh sieve. This is borne out by the early behavior, which shows the surface tending to ravel and dissipate under traffic. In this case additional oil will no doubt have to be added and mixed into the surface.

SOIL ROADS TREATED IN CALIFORNIA

Treatment of soil roads with light oils, similar to those used on crushed stone and gravel roads, by a method which is a combination of penetration and mixing has been used on a large scale in Fresno County and other counties of California and has proved highly satisfactory. These soils vary from those that are almost all sand to a red loam. Although the more sandy material has given the best results, oil treatment of the more plastic material has also been successful. In general, where the soil lacks granular material, sand or gravel is first mixed into the surface.

The following table gives the analysis of a typical soil on which these treatments are made:

	Per cent by weight
Retained on 10-mesh sieve	0. 0
Passing 10-mesh, retained on 20-mesh	. 1
Passing 20-mesh, retained on 30-mesh	2. 5
Passing 30-mesh, retained on 40-mesh	4. 3
Passing 40-mesh, retained on 50-mesh	9. 0
Passing 50-mesh, retained on 100-mesh	37. 0
Passing 100-mesh, retained on 200-mesh	23. 3
Passing 200-mesh	23. 8

METHOD OF CONSTRUCTION DESCRIBED

Progressive construction covering a period of about two years is required in order to build a satisfactory oil-surfaced soil road. The construction treatments, four or five in number, are applied during the summer months of the first two years, the procedure being as follows:

The road surface is bladed to the cross section desired, material for about 1 inch of soil being left in windrows at the edges. A light oil of about 60 to 70 per cent asphalt content is then applied at the rate of three-fourths gallon per square yard and covered with the soil bladed in from the windrows. As soon as the traffic begins to break through the first treatment the surface is scarified to a depth of 2 or 3 inches and a second treatment similar to the first is applied. Similar treatments are added during the following year until the oiled mat has sufficient thickness and richness to carry the traffic, after which only light treatments are required every two or three years.

An Oil-Treated Road in Fresno County, Calif.

More than 2,000 miles of these roads have been built in Fresno County alone. They are in excellent condition and have the appearance of sheet asphalt. Many of them carry traffic in excess of 2,000 vehicles per day.

The good behavior of these roads is probably due largely to the dry and warm climate and to the fact that the soil is largely sandy. In Illinois, where there has been considerable oiling of the soil roads, the results have not been so favorable, probably because of a combination of conditions such as moisture in the soil, the moist and cold climate, and less granular and well-graded soil.

SURFACE TREATMENT

The fact that the heavier bituminous materials used in surface-treatment work are only slightly affected by moisture and that this treatment forms a nonporous surface mat which largely prevents the escape of the air under the surfacing, and thereby tends to prevent the rise of moisture from the subgrade, is probably responsible for the good behavior of this type.

Light Blading of Cover on Surface-Treatment Work Used Quite Generally in the West

The present attempt to use heavy asphaltic oils or soft asphalt cements of both the cut-back and emulsion types is motivated by the desire to obtain not only a more stable and wear-resistant surface but also one that will resist the action of moisture.

Surface treatments are used not only on crushed-stone and crushed-gravel macadams but also on old and new oil-mixed surfaces. Several types of surface treatment differing primarily only in thickness and methods of construction are used, depending largely on the surface to be treated.

"ARMOR COAT" TREATMENT USED IN CALIFORNIA

In California the so-called "armor coat" is used extensively. It is constructed essentially in accordance with the following outline:

1. Thoroughly sweep the old surface and prime with one-half gallon per square yard of 50 to 60 fuel oil.
2. Apply hot about one-eighth to one-fifth gallon per square yard of 95 per cent grade road oil.
3. Cover with three-fourth to one-half inch crushed stone or gravel at the rate of 50 to 60 pounds per square yard.
4. Blade and roll lightly.
5. Apply about three-eighths gallon per square yard of the same grade of road oil.
6. Cover with one-half to one-eighth inch crushed stone or gravel at the rate of about 20 to 30 pounds per square yard.
7. Roll lightly.

On some of the older work a prime application of 60 to 70 road oil was used. This material was not entirely satisfactory, as it hardened very slowly, during which time the surface picked up greatly under traffic. A prime application is not so necessary on a well-bonded oil mix or on some other types of bituminous surfacing, but should be used on an untreated macadam to tie the treatment to the base, as well as to harden and bond it. A fairly hard asphalt cement cut back with a distillate of the kerosene type which penetrates well and is fairly quick drying, or a fluid residual from certain types of cracking-plant process, should prove highly satisfactory for this purpose.

Light tar of 8 to 13 viscosity is being used extensively in the East, but is not available in the West.

VARIOUS PRODUCTS USED FOR SURFACE TREATMENTS

Emulsions made of heavy road oils and high-penetration asphalt cements are coming into rather extensive use on surface treatment work. This is true not only in California but in Oregon and Washington as well.

In Oregon the practice in surface treating is to use a prime application of light oil or gas-oil tar. Otherwise, the light type of surface treatment used is quite similar to the "armor coat" treatment used in California.

Equipment Used in Southern California for Long-Haul Delivery of Oil

"MULTIPLE LIFT" METHOD USED IN OREGON

Oregon has more recently been using what is termed a "multiple lift" type of surface treatment when a thickness greater than that obtained by the common treatment is desired. A thickness of 2½ inches or more can be obtained by this method. One advantage of this process is that the thickness of the surface mat can be varied to suit the traffic and base conditions on a particular project. The steps involved and the materials used are as follows:

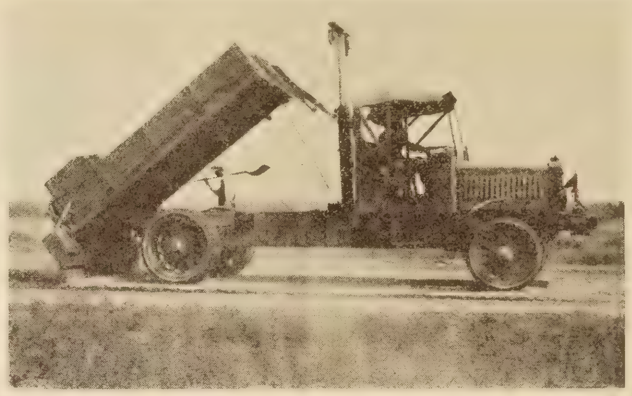
1. Thoroughly sweep the existing road surface.
2. Apply a tack coat of about 0.15 gallon per square yard of 95 per cent road oil, hot.
3. Cover with 50 to 60 pounds per square yard of 1½ to ¾ inch crushed aggregate.
4. Smooth by blading lightly and roll.
5. Apply about one-third gallon per square yard of the same type oil.
6. Cover with about 30 pounds per square yard of three-fourth to one-half inch crushed aggregate.
7. Smooth as before and roll.
8. Apply about one-fourth gallon per square yard of the same oil.
9. Cover with about 30 pounds per square yard of one-half to one-eighth inch crushed aggregate.
10. Smooth as before and roll.

Sometimes the final treatments, items 8, 9, and 10, are repeated to give a better sealed surface. Greater thickness is obtained by increasing the number of "lifts"; that is, by doubling or trebling the treatments given under items 3, 4, and 5.

The cost of a 2½-inch mat constructed in this manner is rather high. This fact is due to some extent to the many steps involved in the construction. To obtain the same thickness of mat, a mixed-in-place method of construction would be more practical and probably more economical. However, the heavy bituminous material would have to be designed for cold application and mixing.

METHOD INVOLVING PARTIAL EMULSIFICATION USED IN OREGON

Oregon has recently devised a method of partially emulsifying the hot oil for surface-treatment work,



Detachable Spreader Used in Applying Cover Material on Surface-Treatment Work

particularly for treatments using heavy oil. The plan is to combine water and an emulsifying agent, such as soap, with the hot oil at the instant it strikes the stone. This is accomplished by means of a second spray bar attached so that a spray of water is directed against the oil spray. About 10 per cent of water is required. The use of this method results, it is said, in better covering and penetration of the aggregate.

WASHINGTON PRACTICE DISCUSSED

In Washington surface treatment is used not only on the crushed gravel and stone macadams but to a large extent on such oil-mixed surfaces as are built. The treatment is similar to the light treatments used in Oregon and California, with the exception that two successive prime applications of light oil are applied. Here, as in other sections where light oil has been used

Surface-Treated Gravel Macadam Road near Crater Lake, Oreg.

for priming the base, considerable peeling and raveling has occurred under traffic during the hardening of this material. This difficulty was overcome in many instances by mixing the excess primer with fine material bladed in from the shoulders. Light blading of this material over the surface of the roadway has corrected many of the irregularities prior to the application of the heavier surface-treatment oil.

The riding qualities of the surface-treated roads in general compare favorably with those of the mixed-in-

(Continued on p. 208.)

THE MOST RECENT METHODS ADOPTED FOR THE USE OF TAR, BITUMEN, AND ASPHALT IN ROAD CONSTRUCTION

REPORT OF AMERICAN ENGINEERS TO THE SIXTH INTERNATIONAL ROAD CONGRESS

By A. W. DEAN, Chief Engineer, Massachusetts Department of Public Works; R. H. BALDOCK, Maintenance Engineer, State Highway Commission of Oregon; G. H. HENDERSON, Chief Engineer, State Board of Public Roads of Rhode Island; PREVOST HUBBARD, Chemical Engineer, The Asphalt Institute; and CHARLES H. MOOREFIELD, State Highway Engineer, South Carolina

INTRODUCTION

BECAUSE the title assigned to this report contains terms which are not expressed in exact conformity with common practice in the United States, a brief statement of the significance of these and other similar terms from the American standpoint should be made in order to prevent misunderstanding on the part of representatives from other countries.

Bitumen as here used is a generic term, including that portion of tar, petroleum, and asphalt products which is soluble in carbon disulphide.

The adjective "bituminous" is equivalent to the expressions "containing bitumen" or "with bitumen." Thus, a bituminous mixture is a mixture containing bitumen in the form of tar, petroleum, or asphalt, and a bituminous treatment is a treatment made with bitumen in the form of tar, petroleum, or asphalt.

Tar is a bituminous product which yields pitch when partially evaporated or fractionally distilled, and is condensed during the destructive distillation of organic materials, such as coal, oil, lignite, peat, wood, etc. The great bulk of tar used for highway purposes in the United States is obtained from the destructive distillation of coal, although a portion is produced by the destructive distillation or cracking of gas oils in the manufacture of carbureted water gas.

Asphalt is a semisolid or solid cementitious material inherently black to dark brown in which the predominating constituents are natural bitumens occurring as semisolids or solids in nature or obtained by refining petroleum.

Rock asphalt is rock naturally impregnated with asphalt.

Asphaltic road oils are liquid products of various degrees of viscosity containing asphalt which may be recovered by evaporation or distillation.

Cut-back asphalts are semisolid or solid asphalts dissolved or rendered fluid by admixture with petroleum distillates, which are frequently but not necessarily of a highly volatile nature.

BITUMINOUS TREATMENT OF EARTH ROADS

The two widely different types of natural soil roads, namely, clay and sand, are susceptible to entirely different types of treatment with bituminous materials. As might be expected, intermediate types of a sand-clay nature are susceptible to a variation in treatment between the two extremes.

CLAY ROADS

Where the subgrade and surface of an existing soil road is a plastic clay, conditions are least favorable for obtaining permanently satisfactory results with bituminous treatment, and too much should not be expected from such treatment. Nevertheless, where a suitable type of bituminous material has been used judiciously on clay roads a distinct improvement in comfort of travel and in traffic-carrying capacity during adverse weather conditions has been effected at a reasonable cost. Such work is perhaps best typified by the large mileage of bituminous-treated clay roads in the States of Illinois and Minnesota.

During dry weather these roads, while capable of carrying heavy loads, become exceedingly dusty, and during long spells of wet weather, particularly in the winter and early spring, the natural soil becomes so soft and slippery as to either eliminate traffic or restrict it to light loads and create considerable hazard. Because the natural soil is highly absorptive and retentive of water, the bituminous surface first constructed is apt to break up during protracted spells of wet weather, and in order to effect any permanent improvement repeated surface treatments are required, with the expectation that as the old surfaces become broken up by traffic and ground into the underlying soil a bituminous soil mixture of appreciable thickness is gradually produced which is more water resistant and stable than the natural soil. Such retreatments are usually made in the spring, and frequently additional treatments are given in the fall. The thicker the layer of soil and oil mixture eventually produced the greater becomes the load-supporting value of the road during unfavorable weather conditions.

General experience has indicated that in order to obtain progressive improvement in the condition of clay roads by bituminous surface treatment the oil should possess high penetrating nonemulsifying characteristics but need not necessarily develop highly cementitious qualities after application. Asphalt which may be present in the oil should develop as such rather slowly, so that sufficient opportunity is afforded for thorough blending of the oil with the soil before the mixture sets up. For this reason, what are known as slow-curing oils are generally preferred. Application of such material is usually made by means of a pressure distributor after the road has been properly shaped with a road machine during compaction under traffic. The oil is first heated to between 150° and 190° F. (66° and 88° C.) usually by means of a jet of live steam. The oil as applied, therefore, often contains a small amount of water, which is not considered objectionable. Single applications are usually made at a rate of not over one-half gallon per square yard when the surface is fairly dry. A slightly moist condition is, however, to be preferred to a dusty bone-dry condition, which tends to make the oil ball up and not distribute itself uniformly. The slow-curing highly penetrative oil is absorbed by the soil to such an extent that no mineral cover is ordinarily required. From two to seven days may be required to secure thorough absorption, during which time it is advisible to eliminate traffic from the treated surface. If for any reason the surface is tacky and likely to pick up when traffic is admitted, it should be covered with a very light layer of soil bladed in from the sides of the road.

In certain cases a fairly viscous asphaltic oil is purposely used to produce a tacky surface, which is then covered with a light coating of gravel or stone chips similar to the stabilizing course later described for sand-clay treatment.

By treatment with oil alone the road is made practically dustless until the bituminous surface becomes cut up under traffic during wet weather, and the resistance of the road to rapid deterioration in wet weather is somewhat increased.

It has been found that repeated annual or semiannual treatments of the same nature work additional improvements, and for this reason attempts have been made with some degree of success to hasten such results by means of a number of treatments applied at relatively close intervals, each treatment but the last being harrowed into the soil and mixed in place with a road blader by methods similar to those later described in connection with mixed-in-place gravel roads. Thorough mixing of oil with the fine clay soil by this means is, however, rather difficult to secure, and the mixed-in-place method has not proved as promising for clay as for other types of road material.

SAND ROADS

Where the natural soil is practically pure sand its method of treatment with bituminous material will to a large extent depend upon the grading and character of the sand grains. If it is of such nature that it would prove satisfactory for use in sheet-asphalt construction it is also well adapted for use in the construction of what has been termed "the sand-asphalt road."

The sand-asphalt road is the ultimate development of bituminous-surface-treated and mixed-in-place oil-sand roads, made possible by the excellent quality of the sand itself. In this class of work, which has been extensively constructed in Massachusetts, Delaware, and North Carolina, a premixed base or foundation is first constructed with a mixture composed of approximately 93 per cent of the natural sand and a 7 per cent paving grade of asphalt cement, heated and combined at a paving plant such as is used in the preparation of sheet-asphalt mixtures. No mineral filler is ordinarily used in the foundation mixture. In North Carolina the compacted base usually has a thickness of 3 inches and is laid between temporary or permanent plank forms which have been staked in place prior to preparation of the subgrade. After thorough compaction by rolling the surface of the base is given a squeegee coat of hot asphalt cement and then covered with a 2-inch thick wearing course of sheet-asphalt paving mixture made with the same sand, to which mineral filler is added prior to combining it with the asphalt cement. Where natural drainage conditions are good this type of pavement has proved quite satisfactory under reasonably heavy traffic.

In the Cape Cod region of Massachusetts excellent results have been obtained with repeated bituminous-surface treatment of natural sand soil roads. The modern methods employed in this work call for use during the first two years of a road oil which yields approximately 45 per cent of asphalt by the evaporation test. One-third gallon per square yard of this oil is applied the first year and this treatment repeated during the second year. During both years the road is bladed or dragged at frequent intervals to maintain a smooth, uniform cross section. At the end of the second year a bituminous carpet has been produced which is usually quite hard. During the following year a more highly asphaltic oil containing 60 per cent asphalt is applied at the same rate per square yard, and during the fourth and fifth years an 85 per cent asphalt oil is used. The fifth treatment is made at a rate of one-fourth gallon per square yard. At the end of five years the bituminous surface has been built up to a point where it no longer requires annual treatment.

Some sand soils are not suited to either of the types of treatment above described, and first require modification by admixture with clay or clay soils before treatment.

SAND-CLAY ROADS

Sand-clay roads, of which thousands of miles have been constructed, particularly in the southeastern section of the United States, are composed of natural or artificial mixtures of sand and clay in such proportion as to produce a wearing course vastly superior to either all clay or all sand. Such mixtures usually consist of from 65 to 85 per cent of sand, from 9 to 25 per cent of clay, and from 5 to 20 per cent of silt. Topsoil is a natural mixture of sand and clay found in surface deposits and is frequently used for this purpose just as it is stripped from the fields. While vastly superior to the average graded earth road, an untreated sand-clay or topsoil road becomes softened during prolonged wet spells and is very dusty in dry weather.

During the past few years considerable attention has been directed to means of improving such roads by surface treatment with bituminous materials so as to create a better year-round wearing surface and increase their traffic-carrying capacity. It has been found that in order to secure satisfactory results from such treatment the existing road surface requires careful advance prepartion, which consists of shaping and compacting where necessary to produce a true well-bonded surface. In Florida a thin stabilizing layer of fine pea gravel is sometimes worked into the surface during such preparation. The treatment itself consists of the following steps:

1. Thorough sweeping to remove all loose particles and dust, in so far as possible, without disturbing the bonded surface.
2. Application of a prime coat of tar or asphaltic oil of sufficiently low viscosity to penetrate the upper portion of the old road. This priming material is applied at the rate of from one-fifth to one-third gallon per square yard, depending upon the absorptive capacity of the road surface, and is intended to harden and moisture-proof the soil and provide a surface to which the heavier asphaltic or tar product later applied will adhere.
3. Application of an asphaltic or tar product of relatively high viscosity in sufficient amount to retain a later application of fairly coarse mineral aggregate. This material, which is frequently asphalt cement of between 150 and 200 penetration, is applied by means of a pressure distributor at a temperature of 250° to 325° F. (121° to 163° C.) and at a rate of from 0.3 to 0.5 gallon per square yard, depending upon the surface texture of the primed base and the size of mineral aggregate used for cover.
4. Application of mineral aggregate cover consisting of broken stone or slag passing a 1-inch or 1¼-inch screen, which, after brooming and rolling, combines with the second application of bituminous material to produce a thin wearing course knitted to and overlying the old sand-clay road which thereafter serves as base.

5. Where winter conditions are likely to be severe an additional light application of cut-back asphalt may be applied and covered with fine mineral aggregate to thoroughly seal the surface if after a few months' traffic the bituminous mat previously constructed does not possess the desired degree of waterproofing. This practice is regularly followed in South Carolina, the seal coat being applied before the first winter of service.

The serviceability of the bituminous-surface treatment above described is dependent upon careful and intelligent maintenance applied promptly as required. The patrol system of maintenance is almost essential, as the surface should be under constant observation to detect and correct defects as they develop and prevent deterioration of adjacent areas due to progressive disintegration which takes place very rapidly if the original trouble is not promptly eliminated. It has been found that retreatment of bituminous surfaces on this type of road will be required at intervals of two, three, or four years, and may consist of a light seal or enriching treatment or of a heavier treatment to thicken or smooth up the original wearing course. South Carolina makes a practice of using the first-mentioned type of retreatment on old treatments that are still smooth, but uses a mixed-in-place treatment with as little as one-fourth gallon of bituminous material and 25 pounds of crushed stone per square yard on old treatments that have become roughened. In South Carolina and Florida many bituminous-surface-treated sand-clay roads which have been in service for three or four years are successfully carrying traffic of considerably over 1,000 vehicles per day and in some instances in excess of 2,000 vehicles per day.

SURFACE-MIXED GRAVEL AND BROKEN-STONE ROADS

The extraordinary easy-riding quality of a well-constructed and properly maintained gravel road has been widely noted and commented upon by engineers as well as the traveling public. Most of these gravel roads are at their best when the gravel is moist but not saturated with water. If they could be kept permanently in this condition their traffic-carrying capacity would be much higher and the cost of maintenance would be greatly reduced. The same has been noted of what have been termed "traffic-bound broken-stone roads," composed of small-size broken-stone fragments, together with fines produced at the crushing plant, and constructed in the same manner as gravel roads, being compacted by traffic accompanied by frequent blading with a road machine. For best results the proportion of coarse to fine fragments should be such as to produce a dense aggregate when compacted.

Although perhaps not generally recognized, the basic principle of the use of bituminous material in what has been termed the "surface-mixed" or "mixed-in-place" gravel and broken-stone road appears to be the substitution of bituminous material for that amount of water which would produce the most satisfactory condition for the particular untreated aggregate. This class of construction has been most extensively adopted by California, but other States, including Oregon, Idaho Arizona, New Mexico, and Nevada, have closely followed the California method in less extensive work, and modifications of this method have been used to some extent in Wisconsin and Minnesota.

In the treatment of an existing traffic-bound gravel or broken-stone road sufficiently thick to eliminate the necessity of using additional mineral aggregate the method of treatment as practiced in California is briefly as follows:

The old road is first scarified to a uniform depth of from 3 to 4 inches and then harrowed, after which an asphaltic oil of from 60 to 70 per cent asphalt content is applied to half the width of the road at a temperature of from 150° to 200° F. by means of a pressure distributor, the rate of application being approximately 1½ gallons per square yard. The treated surface is immediately harrowed to prevent the oil from being picked up by the mixing equipment. Power or tractor-drawn graders are used for mixing by starting the grader at the center and working the bituminous-treated aggregate in a windrow, first to the edge and then back to the center of the road. This operation is continued until the mixture is of uniform color and texture, after which it is bladed into place. The other half of the road is then treated and mixed in the same manner, after which compaction is secured under traffic during blading in order to maintain a smooth, even surface. After compaction the road has the general appearance of a well-bonded asphaltic concrete pavement, although the mixture is not as hard and firmly bonded as in the case of a hot-mixed asphaltic concrete. Maintenance consists of blading with a road machine similar to the maintenance of an ordinary gravel road, light scarifying being sometimes necessary to maintain a smooth surface. In some cases the oil-mixed road is given a surface treatment of bituminous material when it is in good condition, in the same manner and with the same class of product as would be used in the surface-treatment water-bound macadam.

Analyses of samples taken from surface-mixed roadways show that wide variation in grading of mineral aggregate may be tolerated so long as the correct amount of bituminous material is used for the particular aggregate. As a guide to determining when the proper amount of bituminous material has been used, that portion of the treated aggregate which passes a sieve having 2-millimeter openings is subjected to a stain test. California has found that mixtures which produce a light yellowish brown stain in which the impression of the individual sand particles may be distinguished and which is not blurred or blotched give the most satisfactory results. Where too little oil is used the mixture is apt to ravel under traffic and the use of much excess is apt to cause distortion under traffic. In the former case the remedy is to apply additional oil, which is harrowed and mixed into the scarified road. If an excess of oil has been used the trouble may be corrected by scarifying the road and adding additional aggregate of the same character as originally used.

Idaho, under more severe climatic conditions, has found it desirable to incorporate a somewhat greater proportion of oil than has California and frequently uses as much as a gallon and a half of oil per square yard to a 2-inch thickness of mineral aggregate. Idaho's experience has indicated that the surfacing material which is to be treated should be limited to a maximum size of 1 inch and should carry not less than 45 per cent of material passing the ¼-inch screen in the case of screened gravel and not less than 55 per cent of the smaller size for crushed gravel or crushed rock. Aggregates containing as high as 70 to 80 per cent of this fine aggregate have been satisfactorily treated.

In the case of new construction or when a surface-mixed wearing course is to be laid on an old gravel road, good practice calls for purchasing the mineral aggregate in two sizes, with the ¼-inch screen as the dividing line. These sizes may then be combined on the road in any desired proportions.

In some cases the mixture of gravel or broken stone with the asphaltic oil has been made at a paving plant and then laid on an oil road or prepared foundation. If this is done the bituminous-treated aggregate can best be placed by means of road machines and should be compacted by traffic, accompanied by frequent blading. The use of a roller for compaction does not give the same satisfactory results as in the case of the hot-mixed asphaltic concrete, and traffic compaction is therefore greatly to be preferred. The apparent advantage of machine mixing over mixing in place would seem to be insurance of greater uniformity of mix, but service results so far have not definitely indicated that the difference is sufficiently great to justify any material increase in cost due to plant mixing.

BITUMINOUS TREATMENT OF WATER-BOUND SURFACES

Ordinary gravel and water-bound macadam roads have been successfully surface treated with a great variety of bituminous materials, including nonasphaltic distillate, dust-laying oils, fluid and viscous residual tars and asphaltic road oils, cut-back asphalts, emulsified asphalts, and soft asphalt cements. All of these products are ordinarily applied by means of a pressure distributor, those of relatively high viscosity being preheated to such degree of fluidity as to permit securing the desired uniformity of application. For purposes of dust laying only the very fluid products which can be distributed cold are applied at a rate barely more than sufficient to saturate the dust particles on the road surface. Such applications have to be made at rather frequent intervals.

For the purpose of producing an impervious bituminous mat or carpet on the road surface, either fluid cut-back products, emulsified asphalts, or viscous residual products are used. Such work may be classified under single and double treatments, depending upon whether one or two treatments are used to produce the original mat surface. While the former has been most widely employed, it is believed that the double-surface treatment is ordinarily productive of a more durable mat, which justifies the slightly higher cost.

An unusual method of developing an emulsified asphalt application is used in Oregon, consisting of the installation of a separate water tank and spray bar on the pressure distributor, so that the asphalt and water with soap solution are distributed together from two separate spray bars on one distributor.

DOUBLE-SURFACE TREATMENT

Double-surface treatment usually involves use of a light fluid tar or road oil primer, preferably followed by application of a soft asphalt cement of from 150 to 300 penetration. It is particularly applicable to surfaces from which the dust can not be completely removed prior to treatment, as the priming material saturates such dust particles, penetrates the upper portion of the road, and puts it in condition which permits the heavier asphaltic product to adhere in much the same manner as has been described for the surface treatment of sand-clay roads. The priming material should be applied only in sufficient quantity to be absorbed by the road surface within from 24 to 48 hours, so that it will not pick up under traffic. It should not be covered with mineral aggregate, but should receive directly the treatment with soft asphalt cement or very heavy asphaltic oil. The former is preferable from the standpoint of its better ability to retain the coarse aggregate which is applied for final cover. For this purpose, ¾-inch stone, free from dust, should be used and thoroughly compacted by rolling. If dust is present it is apt to sift over the asphalt-treated surface and prevent the large stones from adhering firmly.

Surface treatments in general will not make an old rough surface smooth, and it is therefore necessary to bring the road to a true, uniform contour before applying the treatment as described. This is ordinarily done before the priming material is applied, but excellent results have been obtained in the State of Washington by means of two applications of priming material, the first made as previously described and the second consisting of a 60 to 70 per cent asphaltic road oil applied at the rate of 0.2 gallon per square yard, which is then covered with crushed stone or gravel from one-half inch to dust, applied at the rate of 50 to 60 cubic yards per mile. This treatment is then worked over the road with a grader so as to true up the surface with a mixture of the aggregate and asphaltic oil. The heavier asphaltic product, consisting of a 95 per cent asphaltic road oil, is then applied at the rate of 0.35 gallon per square yard and covered with three-fourth to one-eighth inch mineral aggregate.

Where the old road is very rough a retread treatment, such as later described, is to be preferred unless the old road is first scarified and reshaped.

SINGLE-SURFACE TREATMENT

In the single-surface treatment of a previously untreated water-bound surface the bituminous material is expected to perform two functions, namely, to penetrate the surface to some extent and at the same time to hold a substantial cover of mineral aggregate. If a road oil is sufficiently fluid to serve the first purpose it does not possess sufficient viscosity or body to perform the second as satisfactorily as does a soft asphalt cement, and the mineral aggregate cover is therefore likely to be displaced by traffic and pick up and spatter vehicles for some time after treatment. Residual bituminous products which behave in this manner are, unfortunately, being quite widely used, with the result that for a matter of several days and often a week after treatment the road is in an unsatisfactory condition from the standpoint of the user.

The use of a soft asphalt cement for single treatment of previously untreated water-bound surfaces is also unsatisfactory, because it does not penetrate and attach itself to the surface, which, if at all dusty, is apt to produce a condition which will allow traffic to completely remove the mat over sections of the road area and deposit it on other sections, which then become soft and mushy. The resulting road is apt to be very rough and uneven.

Probably the most satisfactory class of materials for single-surface treatment are cut-back products of sufficient fluidity to penetrate the road surface and containing a distillate which is not so readily volatile as to leave the bituminous base before penetration is secured. Emulsified asphalts have also given good results in single bituminous treatments where the original surface is not excessively dusty.

Dust is perhaps the greatest enemy to successful surface treatments, and good practice calls for its removal, so far as possible, by thorough sweeping prior to application of bituminous material.

RETREAD TREATMENT

Retread construction has been adopted with a number of variations in different parts of the country, particularly in connection with the treatment of old gravel or macadam surfaces where something more durable than surface treatment is required at a lower cost than would be involved in the construction of a bituminous-macadam wearing course.

In Pennsylvania and a number of other States a mixed-in-place method has been extensively used with excellent results. In this method the old road is first scarified, reshaped, and consolidated with the addition of new stone or gravel if necessary to increase its thickness. If, however, the old road is of suitable thickness and of uniform cross section it is merely swept to remove all excess dust and loose material. After preparation of the old road a layer of crushed stone of from 1¼ to ¾ inch diameter is spread to a depth of 2 inches and is then treated with refined tar or cut-back asphalt at the rate of from one-half to three-fourths gallon per square yard. The applied material is then worked back and forth with a blader until it has become thoroughly mixed and worked to a true, uniform cross section, and has begun to set. This may require from four to five days. At the end of this period a seal coat of the bituminous material is applied at the rate of one-fourth gallon per square yard, and lightly covered with stone chips. Traffic is permitted to operate continually during the entire construction. Compaction will, of course, be hastened by use of a roller immediately following the blader, rolling being continued until after the seal coat of bituminous material has been applied and covered with stone chips.

The State of Indiana has developed a radically different method under the name of "retread" which, in certain respects, is quite similar to asphalt macadam, but uses less bituminous material. The old road is prepared to serve as foundation in the same manner as previously described, and upon the base is spread 2 to 1¼ inch stone for a depth of from 2 to 3 inches, loose, as desired. This course is lightly rolled and then treated with about 0.4 gallon per square yard of a cut-back asphalt containing a fairly slow drying distillate. The surface is then bladed with the blade so set that only the upper portion of the treated stone is moved and only the bitumen-coated stone pushed in front of the blade. After blading to proper cross section the road is rolled once with a 10-ton roller, and after being subjected to traffic for a few days is then rolled very thoroughly. The texture of the surface at this stage is rather open, and application of one-half to five-eithths inch stone chips is therefore made in sufficient quantity to fill the surface voids. These chips should be clean and free from dust and should be used only in sufficient quantity to accomplish the purpose of filling surface voids. The second application of the cut-back asphalt is then applied at the rate of 0.2 gallon per square yard and the bitumen-coated chips bladed or dragged with a sled drag, after which they are rolled into the surface. Some two weeks later a third application of the cut-back asphalt is made at the rate of approximately 0.15 gallon per square yard, covered sparingly with one-half inch stone chips, and the road finished off by thorough rolling. The total quantity of bituminous material, amounting to three-fourths gallon per square yard, is less than half the quantity of bituminous cement used in the construction of a bituminous-macadam pavement of the same thickness, but excellent results have been secured by this method where carefully constructed and carefully maintained. Maintenance should start immediately after completion of the surface, and in some cases it has been found desirable to reseal the surface after a period of one or two years, using from one-fourth to one-half gallon per square yard of cut back asphalt and 30 to 40 pounds per square yard of ¾-inch stone chips.

Because of the fact that the retread method uses a small quantity of bituminous cement and does not tend to shove under traffic, it is possible to gradually build up or reinforce an old road by successive retread treatments at suitable intervals.

SURFACE TREATMENT OF BITUMINOUS MACADAM, ASPHALTIC CONCRETE, BRICK, AND PORTLAND CEMENT CONCRETE

For bituminous-surface treatment of pavements higher than the water-bound type a rapid-drying cut-back asphalt containing a highly volatile distillate is most commonly used, application being made by means of a pressure distributor. By using a cut-back or emulsified asphalt it is possible to control distribution so as to obtain a very thin carpet, which is particularly desirable in the treatment of old asphalt macadam or asphaltic concrete pavements from which the seal coat has been worn away but which otherwise are in good condition. One-half-inch stone or slag chips make an excellent cover material for such treatment and are generally to be preferred to sand. When the old surface is at all rough, however, a retread or mixed-in-place treatment with the same materials is preferred. In certain cases, where an old sheet-asphalt pavement is so badly cracked as to require seal coat, a relatively fine sand may be used to advantage over a very light squeegee coat of the cut-back asphalt, the advantage of the sand in this case being that it helps to fill the cracks in the underlying surface.

The construction of a thin bituminous mat on old brick and concrete roads, while occasionally successful, has not proved sufficiently dependable to warrant its very extensive adoption, and such surfaces are usually covered with an asphalt wearing course of asphalt macadam, asphaltic concrete, or sheet asphalt, constructed in the usual manner after truing up the old surface with binder course or asphaltic concrete mixture which is frequently prepared with a cut-back or emulsified asphalt and laid cold.

BITUMINOUS MACADAM

Bituminous macadam pavements have perhaps reached a higher degree of perfection in the States of Massachusetts and Rhode Island than elsewhere, although excellent pavements of this type are constructed in other sections of the country. The bituminous macadam, while one of the simplest types to construct, is more susceptible to abuse from careless workmanship or use of improper methods than are most of the other types of bituminous pavements, for the reason that if almost every principle of construction is violated it is still possible to produce a pavement of reasonably good appearance immediately after completion, in which the defects will not develop until after it has been subjected to traffic for a considerable period of time. When properly constructed the pavement has a long life even under heavy traffic conditions, as has been repeatedly demonstrated by the experience of the two States above-mentioned.

Where the bituminous macadam is to be constructed upon a gravel or broken stone foundation, particular attention should be paid to remedying poor subgrade conditions. In Rhode Island it has been the practice to lay a blanket course of sand or fine gravel from 4 to 6 inches in depth over areas of bad mucky soil prior to constructing the foundation course of coarse gravel or stone varying in size from 8 inches downward. Thorough consolidation of newly constructed foundations prior to laying the base course and wearing course is essential to securing a lasting uniformity of contour of the finished pavement, and it has been found advisable to allow such foundations to season under traffic prior to laying the wearing course.

The construction of adequate shoulders and side supports is also of vital importance, as the edges of the wearing course are more susceptible to displacement and deterioration than any other portion of the roadway. Constructing the foundation wider than the wearing course is also desirable, in order that loads transmitted from the surface at the sides may be more evenly distributed over the subgrade.

The construction of the pavement calls for considerable care in certain details. Hard trap rock is the preferred mineral aggregate, ranging from 2½ to 1½ inches in size. In any event the individual size of fragments should be reasonably uniform, so as to uniformly distribute voids in the course to be penetrated. A larger size should be used for the softer varieties of rock. After spreading and initial compaction the surface should be carefully examined to discover segregated areas containing an excess of fine material, and in such areas the material should be removed and replaced with suitable aggregate.

The asphalt cement, emulsified asphalt, or refined tar used for first application should be applied uniformly over the surface, preferably by means of a pressure distributor. A battery of as many as three large pressure distributors has been successfully used in the construction of wide roads, so that the whole width of the surface may be treated at one time. In such case one distributor spreads along one side of the road over one-third its width and is followed by the second distributor, which is so operated as to make a neat joint with the first application. The third distributor follows the second in like manner and carries the application to the other side of the road. The bituminous material should, of course, be applied at such temperature that uniform penetration of the broken-stone course is secured. If for any reason during original application uncovered streaks are produced, such places should be covered by means of hand pouring pots prior to application of the keystone.

Just sufficient keystone should be spread over the first application to permit rolling. After initial rolling enough additional keystone is added to fill the surface voids. Hand or machine operated brooms are of distinct value in spreading the keystone uniformly and are used to remove all excess prior to application of the bituminous seal coat. The keystone should be free from dust and of approximately ¾-inch average diameter. Asphalt makes the most durable seal coat and is applied by means of a pressure distributor at the rate of approximately one-half gallon per square yard. This seal coat is covered with clean stone chips thoroughly rolled into the surface. The total amount of bituminous material used in the construction of the most durable asphalt macadam pavements averages approximately 1 gallon per square yard for each inch of thickness. When an asphalt cement is used for seal coat on a properly constructed bituminous macadam, maintenance is reduced to a minimum and retreatment or replacement of seal coat should not be required for many years.

Some engineers who have specialized in this type of construction do not believe it possible to overroll a bituminous macadam after the bituminous material has been applied, and place such stress upon obtaining ultimate compaction as to require continuous backrolling for several days after the pavement is completed.

HOT-MIXED PAVEMENTS

Types.—The three principal types of hot-mixed asphalt pavements are: Coarse aggregate asphaltic concrete, fine aggregate asphaltic concrete, and sheet asphalt. The asphaltic concretes are ordinarily laid to a finished thickness of 2 inches over a substantial foundation, and a coarse aggregate asphaltic concrete, without mineral filler, is extensively used in the construction of foundations from 3 to 6 inches thick, commonly known as "black base." Sheet asphalt is laid to a finished thickness of 3 inches, including a 1½-inch binder course and a 1½-inch wearing course. If a total thickness of 2½ inches of sheet asphalt is desired, the wearing course and not the binder should be reduced to 1-inch thickness. The design and construction of hot-mixed asphalt pavements have been so thoroughly covered in paving literature that it seems unnecessary in this report to attempt to discuss many of the details which are of recognized importance in securing satisfactory results.

The method of preparation, laying, and compacting of all three types is essentially the same, although the composition varies, as shown below.

1. Coarse aggregate asphaltic concrete consists of a mixture of broken stone, broken slag, or gravel (usually passing a 1¼-inch screen and retained on a ¼-inch screen), sand, mineral filler, and asphalt cement. The coarse aggregate predominates and usually runs to from 55 to 65 per cent of the total mixture. Asphalt varies from 5 to 8 per cent, and the remaining 30 to 40 per cent consists of sand and mineral filler.

2. Fine aggregate asphaltic concrete is essentially a sheet-asphalt mixture containing from 25 to 35 per cent of ½ to ¼ inch stone chips and from 7 to 9½ per cent asphalt cement.

3. Sheet-asphalt binder course mixture is a coarse aggregate asphaltic concrete containing no mineral filler and as a rule carries from 4 to 5½ per cent asphalt cement, the aggregate being so graded as to produce a reasonably dense mixture but not carrying such a high percentage of fines as to create a smooth sealed surface when compacted. Sheet-asphalt wearing course mixture is composed of sand, mineral filler, such as limestone dust passing a sieve of 200 mesh, and asphalt cement. The character of the individual constituents and the proportions in which they are combined should be so controlled as to produce a mixture which, when compacted, will contain not over 5 per cent and preferably not less than 2 per cent voids and at the same time possess sufficient stability to prevent shoving or displacement under traffic.

STABILITY OF MIXTURES

During the past few years considerable attention has been devoted to developing a physical test which will measure the stability or resistance to displacement of compressed sheet-asphalt paving mixtures, and one of these methods, known as the stability test, is coming to be quite extensively used as an aid to design and control of such mixtures. Many interesting facts have been learned from the stability test which may be frequently applied to pavement work as a substitute for the old arbitrary specifications and rule-of-thumb methods.

Thus it has been found that between two sands of identically the same grading and general appearance under the microscope one may be capable of producing mixtures of high stability, while the other may produce mixtures of relatively low stability only. This is evidence that in the past the importance of exact grading limitations has been greatly overestimated. It has been found that, starting with a given sand, the stability of the mixture is increased by the addition of successive increments of mineral filler up to a certain critical point, after which further addition of filler produces a decrease in stability. The point of maximum stability for combinations of any given sand and mineral filler will approximate the point at which the further addition of filler begins to increase the percentage of voids in the total aggregate.

It has been found that considerable difference in stabilizing and void-filling characteristics exists between different fillers, depending not only upon their relative fineness but upon their general composition and surface texture. It has been shown that the addition of asphalt to the total aggregate, in quantity more than sufficient to fill the voids, will greatly lower the stability of the mixture. From the standpoint of resistance to water action, it is undesirable to design a mixture with an aggregate containing an extremely low percentage of voids, because in such mixtures the film of asphalt is too thin, and where possible the mixture should therefore be designed to carry at least 9½ or 10 per cent of asphalt.

It has been found that a variation of 10 points penetration in the asphalt cement produces but little effect upon the stability of the mixture as compared with normal variation in percentage and character of mineral filler and normal variations in character of sand. With some aggregates a variation of as much as 1 per cent of asphalt may produce five times as great an effect upon the stability of the mixture as will a 10-point variation in penetration of the asphalt.

PAVING PLANT AND CONSTRUCTION DETAILS

Uniformity of plant output is essential to high-class construction, and perhaps the most important detail to observe in this connection is to insure thorough premixing of the constituents of the dry aggregate before adding the asphalt cement. Unless this principle is put into practice, no amount of mixing after the asphalt has been added to the aggregate will secure the desired uniformity of output.

The use of a drum mixer of several tons capacity has been found to produce just as satisfactory mixtures as can be made by the pugmill type. In connection with the latter it has sometimes been found advantageous to change the blades so as to force the mixture around the circumference of the mixer rather than to toss it from the ends toward the center.

No matter how carefully a mixture is designed, it will not develop its inherent stability unless it is thoroughly compacted. Thorough compaction is therefore the first fundamental in connection with construction. While the same degree of compression can probably be obtained by rollers of varying design and weight, modern practice tends to favor use of a heavy 3-wheel roller for initial compaction of both sheet asphalt and asphaltic concrete paving mixtures, because maximum uniform compression is most easily obtained by this type of roller. In the case of sheet asphalt or fine aggregate asphaltic concrete, final rolling should be performed with a tandem roller in order to obtain a smooth uniform surface.

Smoothness or easy-riding quality of a newly finished asphalt pavement is almost, if not quite, as important as thorough compaction, and an increasing amount of attention is being paid to this detail. Finishing machines similar to those used in Portland cement concrete construction are being successfully used in the construction of hot-mixed-asphalt pavements in different sections of the country, and the State of California now requires the use of a finishing machine in its standard specifications. It seems quite probable that such machines will be very widely used in the future.

Spreading boxes for uniformly spreading bituminous-pavement mixtures or aggregates which are to be treated with bituminous materials have been used with such excellent results in some localities as to give promise of much wider adoption in the future. Spreading devices attached to the rear end of trucks, which have been developed in connection with the construction of State highways in Washington and Oregon, have proved especially satisfactory for applying thin layers of fine material aggregates over seal coats or surface treatments. When so used the trucks are slowly backed over the treated surface, the run-out from the rear end supplying sufficient cover to prevent the truck wheels from picking up the bituminous material on the road surface.

ASPHALT-BLOCK PAVEMENTS

Asphalt blocks are composed of a fine aggregate asphaltic concrete and are made in a variety of sizes, the one most generally used for paving highways being 12 inches long, 5 inches wide, and 2 inches deep. Where weight is an important consideration, as in the case of bridge floors, a smaller block, 8 inches long, 4 inches wide, and 1½ inches deep, is sometimes used. Asphalt blocks are usually laid upon a Portland cement mortar bed spread over the foundation, and it is of course important that the mortar be struck off so as to produce a uniform contour, true to grade and of uniform density. The asphalt blocks should be laid immediately upon the moist mortar, with close joints and uniform top surface. The blocks should be laid so as to make the lateral joints as tight as possible and the longitudinal joints broken by a lap of approximately 4 inches.

As soon as practicable after laying the blocks and making the necessary corrections the surface of the pavement should be swept clean and hot asphalt applied with a squeegee or machine distributor over the entire area. This is a rather recent innovation, as most of the older asphalt-block pavements were constructed merely with a sand filler. The application of asphalt is covered with a clean layer of thin coarse sand or stone screenings passing a ¼-inch screen before traffic is admitted.

On grades too steep for the ordinary smooth surface, asphalt blocks should be laid with recessed joints, thereby affording protection against slipping of horses and skidding of motor vehicles. In such cases the foundation and mortar bed are laid in the usual manner. The asphalt blocks are then laid upon the mortar bed one row at a time, with a ½-inch wooden strip between each course. The wooden strips are next removed and the joints filled with grout composed of 1 part Portland cement to 1½ parts of sand. Before the grout has taken its initial set it is scraped out of the transverse joints by means of a special tool to a depth of about one-half inch. This results in the formation of recessed joints one-half inch in width and about one-half inch in depth.

ROCK ASPHALT

The two principal classes of rock asphalt, namely, bituminous limestones and bituminous sandstones, are used in considerable quantities in the construction and maintenance of pavements. The former is usually enriched by the addition of an asphaltic flux and laid and compressed while hot, according to the usual methods for laying hot-mixed asphalt paving mixtures.

The bituminous sandstone, most of which is obtained from Kentucky, is, on the other hand, almost invariably laid cold. This product as marketed usually carries from 5½ to 9½ per cent of a soft bitumen coating a sharp grain silica sand, with very little, if any, extremely fine mineral particles present. When used in original construction it is usually laid to a compacted depth of 1½ inches. The product is crushed to pass a ¾-inch screen, with 80 per cent or more passing a ¼-inch screen. Where the bituminous limestone is to be cold laid it is crushed to pass a ¼-inch screen, and after compression is seal coated with material passing a ⅛-inch screen. When laid on gravel or broken stone foundations a bituminous primer should preferably be applied to the foundation surface, as described for other types of construction. The cold-laid rock asphalt can best be compressed during warm weather. In cold weather it is very difficult to secure satisfactory compaction. Cold-laid rock asphalt is frequently used in patching old bituminous pavements, for which purpose it shows up to best advantage.

COLD-MIX AND COLD-LAID BITUMINOUS PAVING MIXTURES

Cut-back and emulsified asphalts and cut-back refined tars have beeen extensively used in the preparation of bituminous concrete mixtures without preheating the aggregate. Such mixtures have been satisfactorily used for many years for the maintenance of bituminous pavements under the designation of "cold-patch mixtures" and are laid and compressed without preheating. In some cases it is advisable to cure the mixture by exposure to the air in piles for 24 to 48 hours before use in order to allow most of the volatile constituents to evaporate. These mixtures have also been used to some extent in the construction of cold-laid pavements.

There are a number of patented or proprietary mixtures which are prepared with cold or preheated sand with the idea of making a synthetic product of characteristics similar to the natural bituminous sandstones but of more uniform composition. These mixtures have been used for maintenance and construction in the same manner as described for rock asphalt. The asphalt used as a binding material in such mixtures is usually of softer consistency than would ordinarily be used in the preparation of a mixture containing similar aggregate which is to be laid hot. An interesting modification of this type which is intended to duplicate sheet asphalt is prepared by mixing a sheet-asphalt aggregate composed of sand and mineral filler with hard pulverized asphalt and a flux at such temperature that the hard asphalt will not actually be fluxed during the mixing process. Such mixture can be transported and handled cold, but is heated, immediately prior to laying, to the usual temperature for sheet-asphalt mixtures, at which temperature the fluxing process becomes complete. By this method it is claimed that an asphalt plant can be kept in continuous operation throughout the year, as against the usual 90-day period, the material being prepared and stocked for later transportation and use. Moreover, the contractor laying the pavement does not have to use as expensive equipment as though he were making the complete mixture.

Another somewhat similar process involves the incorporation of a hard pulverized asphalt with any of the usual mineral aggregates for asphaltic concrete or sheet-asphalt construction and then mixing same with a flux below the usual fluxing temperature. Such mixtures are laid without preheating, the fluxing operation gradually taking place after the material has been laid and compacted.

Some of the products above described may be considered as still in the experimental stage of development. As a general proposition, no fine aggregate mixture can be laid and compressed cold to secure the same desired density as required for a hot-laid mixture, unless the bituminous binder is of such soft consistency as not to immediately produce the firm bond secured in a hot-laid mixture. This is particularly true of the fine aggregate mixtures.

Perhaps the most extensively used and successful type of cold-laid mixture is produced by first coating a dry aggregate, consisting of commercial broken stone, with a petroleum distillate, such as kerosene, and then mixing it with hot asphalt cement of about the consistency used in bituminous-macadam construction. No attempt is made to use a graded aggregate for this purpose, as it would be difficult to spread and compress. Such products are made with aggregates of at least two different sizes to produce two mixtures which are laid separately. The coarser mixture is laid so as to duplicate quite closely the first course of a bituminous macadam, the advantage being that assurance is obtained that all of the individual stone fragments are uniformly coated with a relatively thick film of asphalt. After compression a much finer aggregate mixture is spread and compacted on the first course to produce a seal coat. Many pavements of this type have been in service for a considerable period of time and have proved satisfactory under fairly heavy traffic.

(Continued from p. 199.)

place types. The use of mechanical spreaders in applying the cover material and the method of smoothing the cover with blade graders before rolling have not only reduced the cost of construction but have greatly improved the riding qualities as well.

RESULTS OF SURVEY SHOW IMPORTANCE OF LOW-COST CONSTRUCTION

This general survey has shown that the bituminous treatments of low-cost roads, such as crushed gravel, crushed stone, and soil roads, are in general proving satisfactory, and that this work represents a large portion of the construction carried on in the Western States. Limited funds with great mileages prohibit to a large extent the construction of any of the so-called permanent and more expensive types. As this condition will probably continue for many years, it is reasonable to expect that in the future these States will continue to be engaged largely in the construction and improvement of the types now being built and in the development of such other relatively low-cost types as may prove suitable.

There is no objection on the part of the Western States to some increase in the cost of construction, provided such increase results in a decreased cost of maintenance. This is particularly true of those States which depend largely upon Federal-aid funds. Since the Government does not aid in maintenance, it is becoming more important, as the amount of road building increases, to keep the cost of maintenance, rather than that of construction as low as possible. To accomplish this end it can be expected that greater attention will be given to the use of types, methods, and materials best adapted to meet given conditions.

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ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.
Report of the Chief of the Bureau of Public Roads, 1928.
Report of the Chief of the Bureau of Public Roads, 1929.
Report of the Chief of the Bureau of Public Roads, 1930.

DEPARTMENT BULLETINS

No. *136D. Highway Bonds. 20c
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
*463D. Earth, Sand-Clay, and Gravel Roads. 15c.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
*670D. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691D. Typical Specifications for Bituminous Road Materials. 10c.
*724D. Drainage Methods and Foundations for County Roads. 20c.
1216D. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1279D. Rural Highway Mileage, Income, and Expenditures 1921 and 1922.
1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

No. 331C. Standard Specifications for Corrugated Metal Pipe Culverts.

TECHNICAL BULLETIN

No. 55. Highway Bridge Surveys.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.
*93M. Direct Production Costs of Broken Stone. 25c.
109M. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails, Flood Relief, and Miscellaneous Matters.

MISCELLANEOUS PUBLICATIONS

No. 76. The Results of Physical Tests of Road-Building Rock.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *914Y. Highways and Highway Transportation.
937Y. Miscellaneous Agricultural Statistics.
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 Connecticut.

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

Report of a Survey of Transportation on the State Highways of Vermont.

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

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

Report of a Survey of Transportation on the State Highways of Pennsylvania.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.

Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.

Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.

Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced-Concrete Slabs Under Concentrated Loading.

Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

*Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

NOVEMBER 30, 1930

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE			Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
Alabama	2,178.0	$ 2,024,368.94	$ 953,400.88	70.9	26.8	97.7	$ 2,680,852.64	$ 1,318,156.05	120.4	4.2	124.6	$ 5,282,541.96	Alabama
Arizona	887.9	3,523,989.75	2,635,686.93	111.5	130.8	242.3	777,954.08	758,765.79	39.7	11.7	51.4	2,399,674.92	Arizona
Arkansas	1,785.8	6,579,858.69	3,086,243.22	197.0	50.4	247.4	1,128,328.37	558,744.83	23.4	13.5	36.9	2,780,139.73	Arkansas
California	1,930.9	7,909,854.10	3,383,099.64	192.5	14.0	206.5	1,625,079.50	699,558.45	2.6	19.0	21.6	4,427,520.40	California
Colorado	1,242.2	4,693,681.85	2,509,007.51	162.4	75.7	238.1	635,746.03	357,034.94	26.5	24.1	50.6	3,850,185.52	Colorado
Connecticut	245.9	3,117,621.20	1,302,014.40	19.8		19.8	456,213.95	84,060.00	5.6		5.6	1,282,645.45	Connecticut
Delaware	289.5	697,391.10	348,695.54	33.8		33.8	61,045.10	30,522.55	3.6		3.6	618,546.89	Delaware
Florida	533.8	4,680,361.00	2,229,234.31	76.0	5.5	81.5	536,794.06	254,135.15	21.9		21.9	2,640,709.47	Florida
Georgia	2,648.9	6,644,688.58	3,177,029.04	169.9	123.9	293.8	2,041,872.80	915,920.42	51.7	37.9	89.6	4,673,135.92	Georgia
Idaho	1,282.1	2,208,013.74	1,345,265.26	153.7	11.6	165.3	353,001.64	210,500.00	27.9	8.2	36.1	1,844,899.98	Idaho
Illinois	2,112.3	22,135,650.69	10,056,260.68	631.6	68.6	700.2	1,357,755.66	645,586.15	47.6		47.6	7,135,946.20	Illinois
Indiana	1,569.1	2,332,076.25	1,133,362.55	75.3		75.3	3,636,840.80	1,245,135.86	68.7		68.7	4,441,544.58	Indiana
Iowa	3,230.4	105,290.11	1,892.77		4.0	4.0	799,905.20	303,600.00		26.6	26.6	3,039,343.56	Iowa
Kansas	2,931.6	4,742,450.00	2,225,663.70	253.4	44.8	298.2	983,226.16	480,341.44	77.9	42.9	120.8	4,121,506.67	Kansas
Kentucky	1,417.3	6,787,619.35	2,915,375.56	136.3	176.9	313.2	3,380,207.33	777,579.69	63.2	35.6	98.8	1,559,730.32	Kentucky
Louisiana	1,397.3	4,675,971.76	2,264,239.69	172.0	20.9	192.9	542,276.46	235,764.18	15.0	7.1	22.1	2,521,358.23	Louisiana
Maine	580.4	2,482,503.55	832,271.08	54.0		54.0	578,520.39	285,808.09	.9		.9	1,918,144.20	Maine
Maryland	656.3	1,851,370.52	881,913.20	33.7	16.9	50.6	188,899.75	41,957.10		2.4	2.4	999,144.32	Maryland
Massachusetts	711.8	5,301,076.22	1,260,619.66	42.8		42.8	1,276,711.03	544,323.81	10.3		10.3	2,845,608.09	Massachusetts
Michigan	1,739.9	9,499,427.33	3,864,213.65	231.4	18.1	249.5	1,338,790.47	609,275.00	44.0	6.4	50.4	4,352,565.43	Michigan
Minnesota	4,210.1	5,128,605.07	1,790,415.52	80.9	137.1	218.0	1,418,167.96	545,745.64	6.2	40.4	46.6	2,747,399.50	Minnesota
Mississippi	1,840.2	594,023.67	296,715.35	35.7	7.7	43.4	422,595.83	208,805.55		20.3	20.3	5,510,835.47	Mississippi
Missouri	2,522.5	10,069,679.30	3,436,511.36	154.9	76.0	230.9	1,986,479.46	818,716.36	60.3	3.1	63.4	3,301,109.05	Missouri
Montana	1,873.9	7,675,598.38	4,332,550.68	589.3	44.1	633.4	895,210.00	486,922.85	98.0	11.5	109.5	4,708,614.16	Montana
Nebraska	3,817.6	5,119,229.71	2,439,275.31	269.5	97.2	366.7	533,065.12	187,203.55	23.2	14.1	37.3	4,143,529.85	Nebraska
Nevada	1,252.0	1,121,084.75	974,209.01	39.8	89.3	129.1	103,231.27	91,720.96	12.6	.8	13.4	1,887,644.63	Nevada
New Hampshire	378.9	1,217,769.47	429,124.66	21.1	1.6	22.7						572,280.18	New Hampshire
New Jersey	548.2	3,478,351.90	870,331.32	26.3		26.3						2,548,366.76	New Jersey
New Mexico	1,949.0	4,051,089.18	2,690,988.30	189.4	58.0	247.4	385,796.30	323,061.87	14.3	.2	14.5	2,351,742.57	New Mexico
New York	2,594.3	23,481,321.76	4,582,355.00	308.6		308.6	5,307,365.10	1,272,196.50	85.4		85.4	11,774,405.54	New York
North Carolina	1,881.6	3,618,874.15	1,732,800.08	128.4	35.1	163.5	536,307.37	264,659.06	49.7	4.2	53.9	4,442,681.70	North Carolina
North Dakota	4,502.8	2,129,399.54	1,068,766.80	265.8	167.4	433.2	1,174,218.95	586,815.85	181.9	120.1	302.0	2,478,336.14	North Dakota
Ohio	2,415.1	17,235,055.81	5,676,877.94	271.9	25.2	297.1	816,363.50	227,861.15	3.1	1.9	5.0	4,525,110.64	Ohio
Oklahoma	1,892.9	5,972,041.75	2,856,679.90	189.7	87.8	277.5	580,607.86	294,519.50	40.8	7.3	48.1	2,626,318.47	Oklahoma
Oregon	1,201.0	5,993,561.23	3,524,937.44	243.0	81.9	324.9	618,982.65	339,544.74	15.6		15.6	1,787,010.80	Oregon
Pennsylvania	2,610.3	10,333,868.77	3,158,573.30	88.3		88.3	738,014.19	324,026.66	6.0		6.0	5,367,086.51	Pennsylvania
Rhode Island	203.2	2,075,922.82	870,964.74	32.7		32.7						626,545.33	Rhode Island
South Carolina	1,848.4	6,190,351.17	2,410,005.89	112.0	122.8	234.8	647,266.54	320,751.87	.2	19.9	20.1	1,300,684.58	South Carolina
South Dakota	3,699.8	3,694,629.41	2,069,190.26	347.2	68.5	415.7	760,477.38	418,262.45	114.2	19.8	134.0	2,282,747.95	South Dakota
Tennessee	1,313.0	4,629,445.80	2,097,233.60	179.0	41.5	220.5	806,731.68	403,365.83	19.7		19.7	3,286,924.38	Tennessee
Texas	6,909.6	14,479,488.59	6,032.738.68	554.9	185.0	739.9	2,111,675.75	819,064.59	65.3	48.2	113.5	10,236,080.52	Texas
Utah	986.9	1,221,740.61	903,647.91	92.4	43.9	136.3	637,205.22	456,203.41	15.9	55.9	71.8	1,518,504.97	Utah
Vermont	290.1	885,601.67	214,396.44	14.7	1.4	16.1	20,775.32	10,387.66				613,889.05	Vermont
Virginia	1,568.1	4,501,089.95	2,153,980.85	190.0	1.9	191.9	869,875.21	380,383.98	20.6	14.2	34.8	2,255,550.02	Virginia
Washington	978.4	3,144,127.11	1,365,300.00	60.1	36.3	96.4	944,944.38	416,400.00	35.3		35.3	2,545,064.15	Washington
West Virginia	709.3	5,126,542.51	1,872,504.98	121.9	41.2	163.1	739,659.65	323,076.27	7.0		7.0	1,107,727.72	West Virginia
Wisconsin	2,394.9	6,417,090.04	2,691,250.00	154.5	38.4	192.9	212,787.83	100,000.00	8.8		8.8	2,591,034.41	Wisconsin
Wyoming	1,735.8	2,473,263.97	1,649,663.85	183.2	107.2	290.4	118,396.47	77,726.61	3.6	16.3	19.9	1,679,190.43	Wyoming
Hawaii	41.2	882,655.31	374,008.63	21.7		21.7	197,730.75	98,865.37	9.0		9.0	1,862,769.59	Hawaii
TOTALS	87,540.5	264,934,768.13	110,960,487.07	7,784.9	2,385.4	10,170.3	47,963,952.16	20,153,046.78	1,547.6	637.8	2,185.4	155,383,876.90	TOTALS

[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.

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