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A CALIFORNIA HIGHWAY TREATED WITH LIGHT ASPHALTIC OIL

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LIGHT ASPHALTIC OIL ROAD SURFACES

Reported by C. L. McKESSON, Materials and Research Engineer, California Department of Public Works, Division of Highways, and W. N. FRICKSTAD, Highway Engineer, United States Bureau of Public Roads [1]

IN ALL States the problem of developing satisfactory types of surface for light-traffic roads is an important one because of the large mileage of such roads in the county and local systems, and even in the systems that are set apart for improvement by the States.

In the Western States the need for such types of construction is felt, perhaps more sharply than in other sections, not only because of the somewhat more extensive mileage on which traffic is now and will remain light, but also because similar forms of construction are needed for the initial improvement of a very considerable mileage upon which a rapid increase of traffic is expected. On roads of the latter class the inexpensive surface is regarded as merely a first stage of improvement, to be replaced as traffic demands and funds become available; but for the present the problem is one of improving the service of such roads at minimum expense in order that the benefit may be quickly and widely distributed over a large mileage.

To meet this need the States of the West have built in recent years many miles of traffic-bound metaled roads, the surfacing material of which is finely crushed rock or gravel. Differing from waterbound macadam in several aspects this type has practically supplanted true macadam because it is less expensive in first cost and more readily maintained under traffic. However, such surfaces wear rapidly under traffic, and highway authorities are becoming seriously concerned at the mounting cost of renewing the road metal. Also, the dust nuisance is very annoying, costly and even dangerous, and the cost of operating vehicles upon these surfaces is rather high.

Recognizing the objectionable features of present practices, and convinced of the necessity of developing satisfactory types of highway surfacing intermediate between ordinary gravel and sand-clay and the expensive pavement types, and having in mind, especially, the need of such types in the Western States, the United States Bureau of Public Roads and the California Highway Commission, in 1926, undertook the cooperative investigation of which the preliminary findings are presented in this report.

The particular purposes of the investigation were to determine the service value that may be expected of fine crushed rock and gravel surfaces; to ascertain what methods might be employed to conserve material and increase serviceability by the use of bituminous material; and to study their value as bases for higher types of less cost than the plant-mixed surfaces. Rather than undertake experimental construction, it was hoped the solution would be found in an examination and analysis of surfaces already existing.

The first effort upon inauguration of the study was the accumulation of data regarding successful and unsuccessful examples of the respective types, records of processes and materials, cost data, weather and soil information, service history, and maintenance methods and costs. These examples were found to fall within three natural groups:

1. Untreated surface, generally of the fine crushed rock or gravel type.
2. Roadway, either natural soil or metaled, treated with "light" or "fuel" asphaltic oil, material which can be applied at atmospheric temperature or by gentle warming.
3. Metaled roadways treated with "road" oil or with soft grades of asphalt.

The multiplicity of roadway types within the field of the study even when limited to the Western States, has made clear that much time will be required to complete the work undertaken. In the meantime, the disadvantages of untreated surfaces have become all too apparent and everywhere there is a desire to find the remedy at the earliest possible date. Many experiments are being undertaken, some of which repeat methods discarded elsewhere. Therefore a progress report has been prepared for publication by the California Division of Highways, and the essential portions of this report are reproduced in this article. This is done to make immediately available to highway authorities certain information that has been gathered as to the use of "light" asphaltic oil residuum in the two Pacific coast States of Oregon and California. Field, office, and laboratory data pertaining to the second group of examples above mentioned are presented and discussed; and sufficient data pertaining to the first group, "Untreated surfaces," are included to tie the main subject to the present construction and maintenance situation.

Although "road" oils and soft asphalts overlap the field of "fuel" oil, and some mention thereof will necessarily find its way into this progress report, the use of the former has not been examined sufficiently to warrant presentation at this time. The study of surface treatments with the heavier asphaltic products, and the possibility of utilizing existing crushed rock and gravel surfaces as bases for bituminous macadam construction, are the purposes of the extension of the investigation. Consequently, no general conclusions as to relative utility of types are yet formulated. Such conclusions as are here presented relate to the scope of this progress report only.

FINE CRUSHED ROCK AND GRAVEL SURFACES

As commonly constructed, the fine crushed rock and gravel surfaces are built in two courses to a total thickness of about 6 inches. The maximum size of the base stone is approximately 1½ inches and that of the top course, 1 inch or ¾ inch. Crusher-run material is used for both courses—often with an admixture of clay or other binder—and both courses are compacted under traffic, the construction trucking being utilized as much as possible for this purpose.

Such surfaces are maintained by frequent blading or dragging or by a combination of the two. Ideally, there should be maintained on the surface of the road a light mulch, consisting of about half an inch of loose fine material to protect the compacted metal beneath; and the constant working of this fine material across the surface has been found effective as a means of preventing the formation of pits and corrugations.

[1] B. A. Anderton, formerly of the Bureau of Public Roads, collaborated in the field investigations on which this report is based.

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Intended for light traffic, and serving best where the traffic does not exceed 300 vehicles per day, these roads can usually be kept smooth at a yearly cost of about $1 per mile for each unit of average daily traffic. For example, a road carrying an average traffic of 300 vehicles per day can be kept smooth at a cost of about $300 per mile per year.

This, however, does not include the cost of replacing the material worn from the surface by the traffic, a loss which is very considerable, and which, with the accompanying dust nuisance, is perhaps the most serious objection to the types. Estimating from the interval between resurfacing operations and the amount of metal added, reports received indicate that from 1 to 1½ inches of metal will be removed in a year by a traffic of 500 vehicles a day. It is possible that these are extreme cases, and that the heavy loss indicated is the result of imperfect compacting or the use of inferior material; but even if the estimates be heavily discounted, and the loss be assumed to average no more than three-fourths inch of compacted material a year, the annual cost of replacement, at $2.50 per cubic yard, loose measurement, will be $750 a mile of 18-foot surface. Adding to this the $500 per mile required for ordinary maintenance, the total annual cost of upkeep for an 18-foot roadway, carrying 500 vehicles a day, is found to be no less than $1,250 a mile; and this is a conservative figure, as indicated by the detailed cost data to be found elsewhere in this report.

The other objections that have been raised against the type are, (1) that the tractive resistance of the surface is high, and (2) that it causes heavy tire wear.

Recognizing these defects, the Oregon State Highway Commission, in 1923, conducted experiments with a view to developing methods of treating the fine crushed metal with bituminous materials to improve its service and reduce the heavy loss by attrition; and the successful use in these experiments of a light asphaltic residual oil, known locally as "fuel oil" led to the use of the material for the treatment of several hundred miles by the commission in 1924, 1925, and 1926.

Impressed by the Oregon experience, the California Division of Highways conducted similar experiments in 1925, which were followed by the oiling of 190 miles of State highway in 1926, and by the scheduling of about 700 miles for oiling in 1927; and the Washington and Idaho State Highway Departments also treated experimental sections in 1926, using methods adapted from Oregon practice.

OIL TREATMENT OF FINE CRUSHED ROCK AND GRAVEL ROADS

Two general methods of treatment have been developed, which may be described, respectively, as the method of surface treatment, and the method of surface mixing. These are briefly described as follows:

Surface treatment method.—This treatment as practiced in Oregon and California contemplates the impregnation of the upper portion of a compacted fine crushed rock or gravel road with light asphaltic oil. The process resembles the ordinary surface treatment of macadam when light oils or tars are used, but differs from surface treatments with heavy oils in that there is no formation of a distinct mat of stone, chips, and binder. For practical reasons, some cover material is commonly used, but the amount is usually limited, and the light oil so penetrates the road crust that there is finally little left on the surface to be absorbed by the application of chips.

The first step in this process is the thorough sweeping of the existing road surface with a power broom, supplemented by hand brooming if necessary, to remove all loose material and scales of fines and expose the compacted rock surface. The light oil is then applied under pressure at the rate of about three-tenths of a gallon per square yard and allowed to penetrate, the time required depending upon the texture of the surface and the viscosity of the oil. Usually two or three days is sufficient, during which time the road is closed to traffic if practicable. At this stage in Oregon small imperfections in the surface are repaired with a lean mixture of oil and aggregate.

When the first application of oil has thoroughly penetrated, a second is spread at the rate of about two-tenths of a gallon per square yard, and, as before, is allowed to stand for several days without traffic if possible, while the oil is being partially absorbed. The treatment is completed by spreading stone chips over the surface before the road is opened to traffic, and, if vehicles can not longer be kept off, the chips are spread immediately after the second application of oil. The quantity of cover material usually used ranges from 10 to 25 pounds per square yard depending upon the viscosity of the oil and whether or not the road is to be opened to traffic immediately. The larger amount is necessary if the road is to be opened immediately; and oils of high viscosity require more cover than the thinner oils.

There is a tendency in some places to modify the surface treatment method described by substituting heavy road oil. As before stated, no recommendations have yet been formulated on this subject. It should be pointed out, however, that heavy road oil is more costly than "fuel oil," demands more equipment and better technic in application, and requires from 100 to 200 cubic yards per mile of screenings for cover.

Surface mixing method.—In the method of surface mixing, the surface of the previously constructed fine crushed rock or gravel road is first scarified to a uniform depth of 1½ to 3 inches according to the thickness of bituminous surface desired. The light asphaltic residual oil is then applied in two or three applications, each consisting usually of about one-half gallon per square yard; and after each application the oil and loose stone are partially mixed with a disk cultivator or spring-tooth harrow, or both. The material is then bladed repeatedly into windrows and respread until a uniform color is attained. It is finally spread to the desired crown and the road is then opened and continually dragged or bladed while it is being compacted by the traffic.

Roads treated by these methods are of distinctive type and are not to be confused with roads treated for dust palliative purposes. In appearance they resemble other asphaltic surfaces. Skillfully prepared and treated, their smoothness shortly after completion, as indicated by "roughometer" readings, is equal to that of the best pavements. When well maintained, they appear to rate with good bituminous macadam; but, at their worst, when maintenance is neglected or when the surfacing material or its condition at the time of treatment is poor, they may become intolerably rough. There is no dust, and tractive resistance and tire wear are both low.

In the progress report which follows there are descriptions of what appear to be the best methods of constructing and maintaining fine crushed rock and gravel surfaces and of treating them with light asphaltic residual oils according to the two general processes that have been developed. Comparative initial and annual cost data are presented to show the relative economy of treated and untreated roads; and observations of the character and condition of a number of roads are reported to show the effects of traffic, moisture and climatic conditions, quality of materials and their availability, upon the cost and serviceability of the roads, as a guide to the selection of one type or another under various conditions.

CONCLUSIONS

Although the investigation so far has been limited territorially and in subject matter as already stated, progress has been sufficient to justify a number of conclusions, particularly with reference to the economy of the light oil treatments for fine crushed rock and gravel roads, and the essential features of the construction methods. These, which are set forth below, are based principally upon data gathered in Oregon and California, but the climate, topography, soil, traffic, and costs vary so widely in the two States that the observations have a rather wide application.

The principal conclusions are as follows:

1. Light asphaltic risidual treatments as practiced in Oregon and California have demonstrated their utility in the preservation of existing metaled road surfaces, and are justified in places where the cost of the oil is not prohibitive.

2. Oil treatment has substantially reduced maintenance and replacement charges on fine crushed rock and gravel roads in Oregon and California. The first cost is frequently less than the value of the metal lost yearly from the same road before treatment. Maintenance after oiling will probably not exceed the cost of adequate maintenance of the untreated surface, exclusive of the replacement of metal.

3. Oil treatment improves service and is, therefore, popular with the public. It eliminates dust, increases smoothness, decreases tire wear, and lowers fuel consumption.

4. Any road in Oregon or California which has justified improvement with a fine crushed rock or gravel surface warrants the additional expense of a light oil treatment, except possibly in rare instances of isolation, extraordinarily cheap material supply, or low service requirements. Direct financial justification will generally follow a comparison of the estimated maintenance after treatment plus a reasonable annual portion of the oiling cost with the known maintenance cost prior to oiling plus the value of untreated metal destroyed annually.

5. An efficient maintenance organization is essential to the success of light oil treatments. Maintenance must be immediate and continuous, otherwise oiling will be unsuccessful and should not be undertaken. While proper maintenance is stressed as a prime requisite, the total annual cost is less than that of untreated roads.

6. The recorded success with light oils should not stop continued development of present practices or experimentation with heavy asphalts. However, the most that can be expected of the latter is some further reduction of annual costs, particularly where traffic is heavy, and that possibility can not justify failure to accept and use present methods until or unless better are developed.

7. In the matter of new construction no conclusions can yet be formulated as to the relative merits of building fine crushed rock or gravel surfaces, to be immediately oil-treated, or of adopting some form of bituminous macadam.

8. Protection of vehicles from freshly applied oil is indispensable; otherwise, damage to traffic may more than offset the benefits resulting from treatment.

9. Examples of oil-treated natural soil roads furnish impressive figures of good service and low costs. This type has a larger field than has heretofore been realized where soil, climate and traffic are favorable. It deserves more scientific study and active consideration.

10. *Precautions.*—The immediate improvement that generally follows oil treatment has sometimes encouraged a feeling that almost any road may be successfully treated by almost any method. Subsequent complete or partial failure has discredited the process. The facts are that success will be proportionate to the suitability of physical conditions, intelligence of supervision, and skillfulness of workmanship. The following are important precautions to be observed.

(*a*) Unless there is a maintenance organization accustomed to giving daily attention to necessary repairs, oiling should not be undertaken. Delay and neglect cause rapid destruction and discredit the process with the public, which expects more of an oiled than of an untreated road. The success in Oregon which has led to renewed interest in the whole subject was due in large measure to the prior development of an efficient maintenance organization.

(*b*) There must be sufficient thickness of metal to carry the expected traffic.

(*c*) The width of the stone surfacing should be adequate—rarely less than 18 feet. Vehicles turning on and off the oiled surfaces tend to crumble the edges.

(*d*) The metal must be compacted completely from top to bottom if the method of surface treatment is to be used, and at least through the untreated base if the surface-mixing method is to be followed. A layer of loose material between base and mixed top may cause rutting, shoving, or breaking.

(*e*) For surface treatment, repairs should be completed and the road compacted well in advance of oiling. Spots escaping attention should be repaired between applications of oil.

(*f*) All loose material and scales of fines must be removed before the oil is applied to the surface. Sweeping must expose clean rock or gravel firmly embedded.

(*g*) The texture of the stone surface should be uniform. Results of surface treatment will be poor if portions of the road are porous while other portions are impervious. Minor irregularities will disappear in the mixing process, but large areas of irregular grading require skillful treatment.

(*h*) Asphaltic materials must be applied uniformly under pressure. Streaks and omissions will be a constant source of future trouble.

(*i*) California asphaltic residual oil does not evaporate under atmospheric conditions, and hardens by oxidation but slowly. Therefore, excessive applications should be avoided during construction and maintenance. This precaution is now better observed during construction than formerly, but is still neglected in maintenance. Excess oil in patching causes lumps which are hard to remove. Reoiling should be done sparingly and only where there is clearly a deficiency in oil.

(*j*) Cover material for surface treatment should be coarse rather than fine. Clean chips are the best cover material. Fine material tends to form an unstable mat and absorbs oil which should be allowed to penetrate. Success with the surface-mixing method requires sufficient insert fines to fill all voids. If not already present they must be added. Fuel oil will not bind clean, coarse material.

(*k*) Heavy clay binder mingled with the road metal greatly reduces the probability of success with oil treatment. A road that breaks up in the spring or that becomes muddy in wet weather should not be oiled.

FINE CRUSHED ROCK AND GRAVEL ROADS

The fine crushed rock and gravel roads which, since the war, have been built extensively in the Western States are different from true macadam in several particulars. The maximum mechanical bond, obtained in macadam by the interlocking of carefully sized broken rock, is not developed. The fine surfacing material is bonded under traffic, frequently with the addition of filler and binder, and sometimes with water. The usual requirement of maximum size is 1½ inches for the base course and 1 inch or three-fourths inch for the surface course.

Fig. 1.—Mixing Road Metal and Binder, one of the Processes in the Construction of Fine Crushed Rock and Gravel Roads

TYPICAL SPECIFICATIONS

The following extracts from specifications are typical:

Separation of fine from coarse material.—In the hauling of materials the contractor shall use means which will prevent, as far as possible, a separation of the fine and coarse materials. So far as possible material being transferred into stock piles, bins, or vehicles shall be dropped vertically.

Size of materials.—Materials for the base course shall all pass a 1½-inch circular opening and shall be well graded from that size to dust, containing not to exceed 35 per cent of material passing a ¼-inch screen. Materials for the top course shall all pass a 1-inch circular opening and shall be well graded from that size to dust, containing not to exceed 35 per cent of material passing a ¼-inch screen. (Some specifications limit the size to that passing a ¾-inch opening and permit 50 per cent or more passing a ¾-inch screen.)

Dumping on roadway.—The spreading of any course or layer of materials shall be done with suitable spreader wagons and dump trucks with gauge adjustments to give the proper spread or from piles dumped along the road. No segregation of large and fine particles will be allowed and the materials as spread shall be free from pockets of large or fine material.

Hauling, dragging, etc.—With the view of securing a maximum amount of uniformly compacted surface, the contractor will be required, as far as practicable, to do his hauling over the surfacing as it is placed; to construct the surfacing beginning at the point of loading and working away from that point; to construct the entire base course from any set-up before beginning construction of the top course from the same set-up; and to thoroughly drag the surfacing at frequent intervals during the course of the construction.

It is common practice to require manipulation of the surfacing material with a heavy blade grader by repeatedly casting into windrows and respreading. This is for the purpose of correcting segregation of materials and improving the distribution of fines and binder uniformly throughout the mass. The operation is illustrated by Figure 1. Even where water is expensive its use during manipulation of material is frequently required and is highly advantageous.

THE COST OF THE UNTREATED ROADS

The fine crushed material generally ranges in cost from $2 to $3 a cubic yard, measured in trucks at the point of delivery, but has been as low as $1.20 and more than $5, depending upon relative availability and length of haul. The quantity used ranges from 1,200 to 2,500 cubic yards per mile; and the normal cost is, perhaps, $4,000 to $6,000 per mile for 18-foot width. Compared with gravel roads of the older type these surfaces are little if any more expensive and their riding qualities are often much superior. As previously stated, they cost less than water-bound macadam and are more readily maintainable.

Ordinary maintenance of this type of road is accomplished with a road drag or with a blade grader or a combination of the two. Ideally, the road should have on its surface a light mulch of about half an inch of loose, fine material to protect the compacted metal. The constant working of the fine material across the road is a most effective precaution against the formation of pits and keeps corrugations to the minimum.

Frequently the available surfacing material is deficient in cementing properties or in fines. Because of such a deficiency, many crushed rock and gravel roads, constructed a few years ago, failed to compact under traffic, and it was later found necessary to add cementitious material. More recently California and Oregon have added filler or binder during construction. Oregon frequently uses about 6 cubic yards of clay binder per 100 feet of 18-foot surface, which is approximately 25 per cent of the top course. This tends to make a firm surface and reduces the loss under traffic. A mulch is not required under such circumstances, and maintenance consists of scarifying and reworking once or twice yearly instead of systematic and continuous dragging. A road so bound becomes more or less pitted and potholed prior to each reworking, and is susceptible to damage during the spring season, particularly if the binder is a heavy clay, highly retentive of moisture.

The road metal used varies widely in characteristics. Crushed, hard rock is much preferred, but soft crushed rock, crushed gravel, and even water-worn screened gravel are used where better materials are unavailable.

It has been commonly assumed that a fine crushed rock or gravel road, without clay binder, built of average material in arid territory is satisfactory for traffic not exceeding 200 or 300 vehicles per day. With exceptionally good material, or under favorable climatic conditions, its field may be extended to 400 or even 500 vehicles per day. R. H. Baldock, maintenance engineer for the Oregon highway department, estimates that a clay-bound road of this type will successfully carry 600 vehicles per day in arid territory, but opportunity to verify this estimate has been lacking.

The cost of maintenance varies widely according to traffic, climate, and character of material, but even more according to the service standards of the authorities in charge. If an average figure must be set, it may be estimated at $1 per year per average daily vehicle where the traffic ranges from 200 to 500 vehicles per day. This covers ordinary maintenance alone; that is, the preserving of a smooth surface under traffic. It does not include periodical renewals of material.

Advantages and disadvantages of fine crushed rock and gravel roads.—Fine crushed rock and gravel roads, by systematic maintenance, may be kept smooth under modern automobile traffic more readily than surfaces composed of coarse material. The wear under traffic and weather, however, is rapid. Steps are being taken to determine definitely the wear under varied conditions —information which has not been acquired heretofore. However, various State highway departments have estimated the approximate wear by the interval between resurfacing operations and the amount of material added over a series of years, and these estimates indicate that the loss of material is large. Wyoming and Colorado report an inch of material lost per year under traffic of 200 or 300 vehicles per day and even higher losses in districts where wind is unusually severe. Wisconsin reports a loss of 1 to 1½ inches per year for traffic of 500 vehicles per day, and Oregon and California confirm the Wisconsin figures.

A loss of 1 inch of compacted material on an 18-foot road represents approximately 400 cubic yards of loose material per mile which will cost from $800 to $1,200 to replace.

Assuming a daily traffic of only 200 vehicles, a loss of one-half inch per year at $2.50 per cubic yard, loose measurement, and disregarding interest, the annual cost of maintaining a mile of fine crushed rock or gravel surface may be estimated as follows: Ordinary maintenance, $200 per year; replacement, 200 cubic yards at $2.50, $500; total $700. This is $3.50 per daily vehicle, or nearly 1 cent per vehicle-mile. This illustration is not necessarily an average case, but it shows that the amounts spent year by year do not represent the ultimate maintenance costs.

With good road metal and a moist but not excessively rainy climate the replacement cost may be lower than above estimated. With poor material and an arid climate it will be much higher. It will be an extraordinary case where the item of replacing destroyed material is not as high as ordinary maintenance and frequently it may be expected to be two to four times as much. It is an item frequently overlooked in fixing annual budgets, accumulating as "deferred maintenance" until resurfacing is required.

Metal is removed from the road in two forms: (1) Particles thrown to shoulders; and (2) dust produced by grinding of stone on stone. A considerable portion of the loss consists of particles thrown from the road; and the dust is a menace to the traveling public. It is intensely disagreeable on a heavily traveled road; sometimes causes accidents by obscuring vision; and damages cylinders and bearings in motor vehicles, and causes serious financial loss, where the road is bordered by farms, villages, or resorts.

Another objection to the fine crushed rock or gravel type arises from excessive tire wear and rather high tractive resistance. Measurements made during the past three years by the State College of Washington [2] indicate that tire wear from four to five times as great as that caused by concrete or asphaltic concrete surfaces may be caused by untreated fine crushed rock surfaces upon which a loose mulch is maintained; and the same tests indicate that there is a great reduction in the amount of tire wear when the crushed rock surface is treated with asphaltic oil. The tests are not sufficiently extensive to justify acceptance of the exact ratios mentioned but, in a qualitative way, they confirm inferences that are obvious from the nature of the respective types.

Similarly, studies at the Iowa State College [3] indicate that the gasoline consumption may be one-fourth more on a gravel road than upon a hard pavement. A similar relation presumably prevails between the fine crushed type and oil-treated roads.

[2] Engr. Bulletins, Nos. 17 and 18. Engineering Experiment Station of the State College of Washington, Pullman, Wash.

[3] Bulletin No. 69. "Highway Transportation Costs," Engr. Exp. Station, Iowa State College, Ames, Iowa.

TABLE 1.—*Cost of ordinary maintenance and value of metal destroyed by traffic on fine crushed rock and gravel roads prior to oiling, in Oregon and California*

Project	Daily traffic	Length	Time from construction to resurfacing [1]	Ordinary maintenance		Loss of metal				
				Total expenditure	Cost per mile per year	Depth	Cost per unit	Unit	Value	
									Per mile	Per mile per year
Oregon:		*Miles*	*Months*			*Inches*				
Federal Aid No. 37	600	12.5	45	[2] $13,976	$372				$4,474	$1,192
Federal Aid No. 25	470	14.81	42	[2] 20,140	453				[3] 610	[3] 174
Federal Aid No. 24	500	14.95	39	[2] 15,138	338				[3] 1,260	[3] 386
Federal Aid No. 42	450	6.80 15.08	30 41	[2] 30,722	468				4,911	1,567
Morrow-Umatilla County line to Echo	420	19.8	51	[2] 21,210	357				5,378	1,265
California:										
Imperial-27-B	1,000	14.07	23	4,826	180	2.50	2.65	Cubic yard	1,934	1,010
Imperial-26-A	1,000	3.93	30	13,184	1,342	3.48	4.53	do	4,729	1,890
Imperial-26-F	2,500	.50	15	957	1,531	1.88	2.55	Ton	2,156	1,726
Imperial-26-G	2,500	8.81	10	24,264	3,310	2.25	2.55	do	2,581	3,097
South Boulevard-31-D	500	15.44	6	20,361	2,640	.78	2.79	do	979	1,958
South Boulevard-31-E	275	9.55	6	11,326	2,372	1.77	2.79	do	2,222	4,444

[1] For California projects the time is from construction to oiling.
[2] Three complete years, 1922, 1923, and 1924.
[3] Restoration incomplete.

Fine crushed rock and gravel roads are intended for light traffic, generally not exceeding 300 vehicles per day. However, lack of funds for heavier construction or the need of temporary surfacing on a new grade prior to paving have frequently led to the use of this type for heavy traffic. When the traffic exceeds the normal volume for which the type is suitable, maintenance increases in proportion. Sprinkling is a common device introduced at this stage. Constant addition of material becomes necessary and maintenance operations seriously interfere with traffic.

Table 1 shows losses of material on several projects in San Bernardino and Imperial Counties, Calif. The loss of material is indicated by the amount of new material it was found necessary to apply to restore the original thickness of the surface when it was being prepared for bituminous treatment. Estimated in this way, no account is taken of large quantities of material added between the date of original construction and bituminous treatment; yet it will be seen that even on this conservative basis the loss of material ranges in value from $1,000 to nearly $4,450 per mile per year, under traffic which in no case exceeded 2,500 vehicles per day.

To summarize: The fine crushed rock or gravel road is a type that can be built at relatively low cost; is adaptable, by the use of the requisite thickness of material, to most kinds of soil and weights of vehicle; and can be kept in smooth condition by a reasonable expenditure with simple tools and ordinary skill. There are three main objections to its use, which are, (1) that the loss of material under traffic makes it ultimately a very expensive type of surface, (2) that the dust is a serious nuisance and often costly, and (3) that the cost of operating vehicles over it is high.

SURFACE OILING OF CRUSHED ROCK AND GRAVEL ROADS IN OREGON

The extensive oil treatment program in Oregon is the outcome of an attempt in 1923 to use a grade of oil known locally as "fuel oil" as a dust palliative. A section of road was oiled at that time with one-half gallon per square yard. The section thus treated was so sticky and spattered automobiles so badly that the remainder of the road that season was given a somewhat lighter treatment. The section with the heavier application, however, turned out so well the following season that R. H. Baldock, then division engineer, now maintenance engineer for the Oregon Highway Commission, carried on extensive experiments with the idea of standardizing the treatment so that it could be economically and safely used on the hundreds of miles of crushed rock and gravel surfaces in eastern Oregon, and similar experiments were carried on in another division under the direction of C. W. Wanzer, division engineer. The experiments were regarded as successful, and the State, in response to the wishes of enthusiastic motorists, has carried on oiling as rapidly as possible on all roads in condition for treatment. Over 500 miles were reported by the commission as having been treated up to the close of 1926.

These treated Oregon highways are typical crushed stone, crushed gravel, or screened gravel roads constructed from one to four years before oiling. Usually the surface as originally constructed had been formed by the spreading of about 2,200 cubic yards of the surface metal per mile to a width of 16 to 20 feet. Normally, the base course, consisting of material passing a 1½-inch circular opening, constituted half the finished thickness, the wearing course, of equal depth, consisting of material passing a three-fourths-inch circular opening. Usually each course had been subjected during construction to the traffic of trucks, had been well watered, and was well bound at the completion of the project.

Most of the projects had been resurfaced before treatment to replace losses caused by traffic and weather, but the resurfacing had not in all cases restored the surfaces to their original condition. On inspection in the course of this cooperative investigation, sections were found of which the thickness was only 3½ inches and others of varying depths between this minimum and the original thickness of 6 inches. The subgrade of the thin sections inspected was generally rather sandy—in some cases pure sand—and this probably accounts in a measure for their ability to carry traffic.

In some of the earlier treatments the surface of the road was not broomed before applying the oil. Such surfaces observed in the course of the cooperative investigation were found to be slightly nonuniform. While quite comfortable to ride over they are not as satisfactory or as easy to maintain as the sections that have been broomed before treatment.

Brooming has been the standard practice for some time, and most of the treated roads observed had been thus prepared. The general practice in preparation for oiling now requires that the surface to be treated be bladed, sprinkled, and dragged until smooth and uniform. All holes and other irregularities are repaired; and, immediately prior to oiling, the surface is thoroughly swept with a power broom (fig. 2), supplemented occasionally by hand brooming, the sweeping being continued until all patches of loose fine material are removed and the larger pieces of rock are exposed. This was the method that had been followed in the treatment of most of the sections inspected.

CHARACTER AND AMOUNT OF OIL USED

Immediately after sweeping the majority of the sections were treated with the oil in two applications with an interval of two or three days between them to permit the first to penetrate. In general, the first application was at the rate of three-tenths, and the second at the rate of two-tenths gallon per square yard. This is the original treatment, to which it is the general practice in Oregon to add in the fall of each year a light application—at the rate of from 500 to 700 gallons per mile—to freshen the previously applied oil and seal the surface for the winter; and other light applications are made from time to time as required. This practice is referred to hereafter as reoiling. For applying the oil a pressure sprayer has been found to give more uniform distribution, although fair results have been obtained with a gravity sprinkler. (See fig. 3.)

The oil used in the early work in Oregon was purchased simply as "fuel oil," with the requirement that

[4] Throughout this investigation, the Oregon State Highway Commission, through Mr. Roy A. Klein, State highway engineer, Mr. R. H. Baldock, maintenance engineer, and Messrs. C. W. Wanzer and H. C. Smith, division engineers, has cooperated to the fullest extent by furnishing samples of materials and historical and financial data. The assistance rendered has been invaluable.

it contain at least 50 per cent of asphalt of 80 penetration, and it usually contained from 50 to 60 per cent. This oil came from various fields in California and other Western States. That most commonly used in the extensive program of 1925–26 came from California and contained from 60 to 65 per cent of asphaltic residue of 80 penetration. Its specific viscosity was usually low—ranging from 10 to 20 Engler at 122° F.—but even such light oils were found to be too viscous to be applied successfully without heating. At a temperature of from 150° to 200° F., however, they spread readily, and the requisite heating may be accomplished with steam.

During 1926 the treatment with two applications of light oil, as above described, was varied by the substitution of a heavier oil or tar for the second application in the treatment of over 130 miles of road. On these sections the first application consisted of about one-fourth gallon per square yard of the 60 to 65 per cent asphaltic oil, followed in most cases by an application of one-fourth gallon of oil containing 70 to 80 per cent of asphalt of 80 penetration. In other cases a tar was used for the second application, the material being prepared from crude tar obtained in the manufacture of gas from petroleum oil. Reports received in February, 1927, indicate that these heavy oil treatments have made a good showing during the winter in sections where snowfall was heavy. Table 2 shows tests of typical oil used during the 1926 season.

Table 2.—*Typical California oils used in surface treatment by the Oregon State Highway Commission in 1926*

Laboratory No.	Date sampled	Used near	Specific gravity	Specific viscosity, Engler, 122° F.	Loss 325° F., 5 hours	Per cent asphalt (80 penetration)	Distillation— 170° to 235° C.[1]	235° to 270° C.	270° to 300° C.	Above 300° C.
20235	June 26	Baker	0.940	10.0	10.8	65.4	3.7	9.5	19.3	67.5
20236	do	do	.940	9.5	10.8	65.4	3.6	12.5	11.7	72.2
20001	June 4	Payette, Idaho	.973	84.2	4.1	73.1	----	2.3	8.9	88.8
20002	do	do	.973	81.1	3.3	72.3	----	2.5	6.9	90.6
20168	June 22	Quartz	.942	9.4	10.2	61.6	----	9.4	14.2	76.4
20169	do	do	.942	9.3	10.6	62.2	----	8.0	15.5	76.5
20492	July 16	Durkee	.945	10.6	10.7	63.4	1.4	7.1	9.7	81.8
20128	June 17	do	.944	10.5	9.8	63.3	----	9.7	9.0	81.3
20263	June 28	Pleasant Valley	.940	10.9	10.4	63.8	2.6	8.8	11.1	77.5
20352	July 3	do	.945	10.3	10.5	63.2	----	8.6	12.2	79.2
20501	July 16	do	.952	13.2	9.7	66.4	0.8	6.1	9.5	83.6
20434	July 12	Huntington	.946	11.1	11.7	61.6	2.0	6.0	10.0	82.0
20491	July 15	do	.945	10.9	10.9	63.8	1.0	6.5	10.5	82.0
20431	July 10	do	.946	13.0	12.5	62.6	2.3	8.2	11.5	78.0
20432	do	do	.946	12.0	11.0	62.0	2.1	8.1	11.3	78.5
20433	do	do	.942	10.7	12.0	60.8	----	7.9	13.2	78.9
20386	July 7	do	.946	10.7	10.3	63.5	----	9.1	13.0	77.9
20387	do	do	.944	11.0	12.1	62.9	2.0	9.3	9.5	79.2
20353	July 3	do	.944	9.5	11.2	63.5	----	9.9	10.9	79.2
20354	do	do	.940	10.9	11.0	63.2	----	10.2	9.7	80.1
20355	do	do	.940	11.8	10.1	63.2	----	8.2	10.7	81.1
20384	July 6	do	.940	10.2	10.9	63.6	----	9.1	14.0	76.9
20385	do	do	.940	8.8	12.3	61.9	----	9.2	13.0	77.8
20288	July 2	Haines	.940	9.2	9.7	64.5	1.0	5.5	11.6	81.9
20526	July 13	do	.975	74.8	3.9	76.5	----	.5	4.8	94.7
20525	July 10	Baker	.975	75.2	3.4	77.2	----	.5	4.9	94.6
19632	April 21	Blalock	.975	92.3	3.4	75.0	----	1.0	3.3	95.7
19801	May 18	Parkdale	.952	12.7	10.4	65.3	----	7.0	8.0	85.0
19845	May 21	do	.945	10.8	14.3	64.5	----	8.5	9.9	81.6
19849	May 24	Redmond	.945	10.2	11.1	61.5	----	5.7	10.5	83.8
19850	do	do	.944	10.2	11.6	61.8	----	6.0	10.0	84.0
19789	May 18	do	.943	9.8	10.2	62.9	----	4.8	10.2	85.0
19790	do	do	.943	9.6	9.7	64.0	----	5.0	9.8	85.2
19843	May 22	do	.944	9.9	9.7	62.2	----	5.4	11.0	83.6
19844	do	do	.945	10.2	9.5	63.2	----	5.2	10.6	84.2
19887	May 26	do	.945	8.8	10.1	63.0	----	5.0	10.3	84.7
19869	do	do	.945	10.3	9.4	62.1	----	5.8	10.0	84.2
19870	do	do	.945	9.8	10.2	62.8	----	5.8	9.6	84.6
19868	May 25	Parkdale	.933	7.9	10.8	64.3	----	6.5	9.0	84.5
19891	May 26	do	.943	9.4	12.7	62.8	----	7.7	9.3	83.0
19908	May 29	do	.942	9.0	9.4	63.8	----	6.3	10.0	83.7
19909	do	do	.943	10.5	10.7	61.2	----	8.9	9.6	81.5
19959	June 3	do	.943	9.2	9.7	60.7	----	9.2	9.7	81.1
20041	June 9	Rufus	.947	10.2	10.3	61.8	----	9.1	10.0	80.9
19910	May 28	Redmond	.945	9.2	10.8	64.0	----	7.6	10.1	82.3
19920	June 1	do	.945	9.1	11.0	61.5	----	7.7	10.7	81.6
19998	June 4	do	.943	9.2	10.0	61.3	----	8.0	11.4	80.6
20043	May 29	do	.944	9.3	12.4	61.5	----	7.7	12.7	79.6
20427	July 9	do	.946	11.6	11.6	61.6	2.0	10.5	11.4	76.1
20146	June 19	Bend	.948	12.1	11.9	64.6	1.8	9.1	12.5	76.6
20670	July 26	Blalock	.950	14.3	9.1	65.3	6.5	24.3	25.5	43.7
20566	July 21	Parkdale	.945	12.7	7.4	64.0	9.3	8.8	15.0	66.9
20671	July 26	Bend	.950	12.8	9.5	66.2	4.6	15.6	19.0	60.8
20742	July 29	Rufus	.950	13.8	10.0	66.9	5.0	12.9	17.1	65.0
20775	August 4	Biggs	.950	13.8	10.0	65.8	1.8	7.3	14.7	76.2
20743	July 29	Blogett	.950	13.8	10.0	67.0	5.0	12.8	30.0	52.2

[1] No fraction below 170° C.

Fig. 2.—Power Broom for Cleaning Road Surface Prior to Treatment

Fig. 3.—Type of Distributor Used for Application of Oil

To absorb the excess oil, chips have been applied in quantities ranging from 15 to 50 cubic yards per mile. Practice in this particular has not been standardized. Larger quantities were required on the sections treated with heavy oils and tars; and in some instances sand or screenings have been used instead of chips. After re-oiling, the use of sand or fine stone chips has been found necessary where the surface had a "sheet-asphalt" texture to prevent vehicles from skidding.

The cover material has sometimes been spread from trucks by opening the end gate an inch or so and driving rapidly over the oiled surface. In other instances mechanical spreaders have been used, as shown in Figure 4.

Maintenance in Oregon begins immediately after the final oiling. At this state, brown areas appear where there is a deficiency of oil, the result generally of the picking up of the surface by steel tires or of sandy spots in the surface. These are spotted with oil, and any depressions that may require it are filled with additional chips and oil.

Thereafter the maintenance men patrol the road, carrying with them a supply of chips and oil or premixed oil and chips. Holes or depressions are filled as soon as they appear, care being taken to use no more filling material that is needed to bring the patch flush with the surrounding surface and avoid transforming the depression into a hump. The experience thus far indicates that a two-man patrol can cover 50 miles or more of road, performing the work described.

Fig. 4.—A Mechanical Spreader having Whirling Disks to Distribute Screenings over Road Surface

COSTS OF TREATMENT AND MAINTENANCE

The average cost of the treatment described on 343 miles of Oregon highway oiled during 1926 was $752 per mile, exclusive of the cost of cover material. The average total cost, including cover material, was placed at $854 per mile. These averages include the cost of 133 miles which received a first treatment—about 3,000 gallons per mile—of light "fuel oil" (about 60 per cent asphalt) followed by an equal amount of heavier oil containing about 75 per cent of asphaltic residue of 80 penetration.

An analysis of the cost of a 65.8-mile section treated with two applications of light oil is given in Table 3. This shows an average cost of $637 per mile, exclusive of the cost of cover material. The cost of the treatment in which heavy oil is used in the second application is estimated by the engineers of the Oregon department at $888 per mile, exclusive of cover for 1927, and in their estimates of cost they allow $53 per mile for screenings on light oil and $150 per mile on heavy oil.

That the cost of maintaining the oiled surfaces is not expensive is shown by Table 4, which summarizes expenditures on five sections of the Columbia River Highway from 1922 to 1926. The table was compiled from information furnished by the State highway commission, except that some of the reoiling cost has been rather arbitrarily included in the cost of original oil treatment. Table 5 is a summary of the data contained in Table 4.

These tables show that the cost of maintaining the untreated crushed rock surfaces on these projects, under an average traffic of 500 vehicles a day, averaged $402 per mile per year; and that the cost of replacing the surfacing material destroyed by traffic and weather was $1,351 per mile per year—a total of $1,753 per mile per year, or an average annual charge of $3.50 per mile per average daily vehicle.

The cost of maintaining these surfaces after oiling, during 1926, which was the only complete year covering all projects, averaged $333 per mile, a figure which includes some reoiling. If the treatment is assumed to have a life of only three years, of which half on the average has already passed, $198 (one-third of $594, the cost of oiling) should be added to the yearly maintenance charge to obtain the total annual cost, which

Table 3.[1]—*Cost per mile of oiling between Heppner Junction and Barnhart, Morrow and Umatilla Counties, Oreg., 65.8 miles*

Section	Length	Supervision	Preparation of road	Application of oil	Spreading cover material	Traffic protection and miscellaneous	Cost of oil	Freight on oil	Total
	Miles								
Heppner Junction-Umatilla County line	30.6	$29	$115	$53	$47	$38	$214	$90	$586
Umatilla County line-Echo	19.5	22	89	59	51	40	272	137	670
Echo-Barnhart	15.7	33	110	61	84	61	219	128	696
Average cost per mile		28	106	57	57	44	232	113	637
Cost per square yard		0.002	0.009	0.005	0.005	0.004	0.019	0.010	0.054
Cost per gallon in place		.005	.019	.010	.010	.008	.041	.020	.113
Per cent of total cost		4.4	16.6	9.0	9.0	5.8	36.4	17.8	100

[1] Prepared from information furnished by R. H. Baldock, maintenance engineer, Oregon Highway Commission.

A total of 373,682 gallons was used, an average of 5,700 gallons per mile and 0.495 gallon per square yard.

Table 4.—*Maintenance and treatment costs of Columbia River Highway in Oregon*

Project	Length	Year	Average daily traffic	Untreated road costs		Treated road costs	
				Ordinary maintenance	Resurfacing to restore thickness	Oiling and reoiling	Maintenance of oiled surface
	Miles						
Federal aid No. 37	12.5	1922	309	$4,002			
		1923	674	1,880	$21,359		
		1924	828	8,094	34,568	$2,059	
		1925	880			3,068	$5,836
		1926	1,000				6,080
Total				13,976	55,927	5,127	11,916
Average per mile per year				372	[1] 1,192		
Average per mile						410	[2] 486
Federal aid No. 25	14.81	1922	309	2,833			
		1923	455	2,729			
		1924	640	14,578	9,034	1,920	
		1925	1,035	785		7,402	7,160
		1926	904				4,699
Total				[3] 20,140	9,034	9,322	11,859
Average per mile per year				[3] 453	[4] 174		
Average per mile						628	[2] 317
Federal aid No. 24	14.95	1922	309	1,296			
		1923	484	2,272			
		1924	728	11,570	18,782	1,099	
		1925	1,000	868		6,838	1,832
		1926	900				3,532
Total				[3] 15,138	18,782	7,937	5,364
Average per mile per year				[3] 338	[5] 386		
Average per mile						531	[2] 236
Federal aid No. 42	21.88	1922	309	8,577			
		1923	466	8,737	71,514	749	
		1924	585	13,408	32,460		
		[6] 1925	877	2,500	3,485	11,693	11,662
		1926	1,085				7,204
Total				[3] 30,722	107,459	12,442	18,866
Average per mile per year				[3] 468	[7] 1,587		
Average per mile						568	[2] 329
Non-Federal aid west of Echo	19.8	1922	300	6,500			
		1923	400	6,980			
		1924	550	7,730	106,480		
		1925	800	2,785		13,128	5,487
		1926	1,000			2,342	6,676
Total				[3] 21,210	106,480	15,470	12,163
Average per mile per year				[3] 357	[8] 1,265		
Average per mile						781	[2] 337

[1] Untreated road under traffic 3.7 years before oiling.
[2] Average for 1926 only.
[3] For three years only, 1922–1924.
[4] Untreated road under traffic 3.5 years before oiling.
[5] Untreated road under traffic 3.2 years before oiling.
[6] 0.8 mile non-Federal aid road added.
[7] Untreated road under traffic 3.1 years before oiling.
[8] Untreated road under traffic 4.2 years before oiling.

TABLE 5.—*Analysis of surface maintenance expenditures on a portion of the Columbia River Highway in Oregon, 1922–1926, inclusive*

Project	Length	Untreated road costs: Ordinary maintenance 1922–1924, inclusive	Untreated road costs: Resurfacing to restore thickness	Treated road costs: Oiling and reoiling	Treated road costs: Maintenance of oiled surface, 1926
	Miles				
Federal aid No. 37	12.50	$13,976	$55,927	$5,127	$6,080
Federal aid No. 25	14.81	20,140	9,034	9,322	4,699
Federal aid No. 24	14.95	15,138	18,782	7,937	3,532
Federal aid No. 42	21.88	30,722	107,459	12,442	7,204
Non-Federal aid west of Echo	19.80	21,210	106,480	15,470	6,676
Total	83.94	101,186	297,682	50,298	28,191
Average per mile per year		[1] 402	[2] 1,351		
Average per mile				[3] 594	[3] 333

[1] Average daily traffic on untreated roads, 500 vehicles per day.
[2] Federal-aid projects Nos. 24 and 25 excluded because they were not fully restored to original thickness.
[3] Average for 84.7 miles, because of addition of 0.8 mile to Federal-aid project No. 42 in 1925.

is thus computed as $531 per mile. As the traffic since oiling has averaged 980 vehicles per day, the above estimated annual cost would be equivalent to only 54 cents per daily vehicle per mile.

The costs presented in Tables 4 and 5 do not necessarily represent average conditions in the West. The use of more and better binders in the untreated surfaces, and larger expenditures for ordinary maintenance of these surfaces during the first two years would have cut the cost of replacement of untreated rock materially, although wind and dry atmosphere are particularly trying on these projects. However, there is ample evidence that the resurfacing operations did not restore the surface to its original thickness in many places, which means that the actual loss of material was greater than indicated by the cost reports. On the other hand, the operations of oil application and maintenance of the oiled surface were new to the organization, which suggests the possibility of lower costs for the same class of work in subsequent years. The tables do represent the actual history of the first extensive section of Oregon State highway to be treated with asphaltic "fuel oil." And they do indicate also the economy of the surface oiling as a means of salvaging these surfaces, for this fact stands out: That the cost of oiling this section was less than the annual cost of replacing lost surfacing material on the untreated roads, and the cost of maintaining the oiled surfaces is no greater than the cost of ordinary maintenance of the untreated surfaces before oiling and under lighter traffic.

INSPECTION OF OREGON OIL-TREATED HIGHWAYS

In May, 1926, during the course of the cooperative investigation here reported, an inspection was made of about 235 miles of the oil-treated crushed rock and gravel roads in Oregon, the treatment of which has been generally described in the foregoing pages. As the inspection progressed, samples were taken as representative of the surfacing materials used in the original construction, of the oil used, and of the oiled surface and base of the treated roads; and at the same time the surfaces examined were classified according to the texture and degree of displacement of the surface.

Differences in texture and surface condition were quite noticeable. A considerable mileage has a nonskid surface. Other portions have a fine, smooth texture closely resembling that of sheet asphalt, and a small percentage has a similar fine texture but is unstable and shows a noticeable tendency to creep, push, and "cabbage leaf."

The three types of surfacing were classified according to appearances as:

A.—Nonskid.
B.—Fine, granular, sheet-asphalt texture.
C.—Surface showing a tendency toward displacement.

In some places sections of A and B types or of B and C types were found quite close together.

In taking samples of the surfacing material they were selected as representative of these three conditions of surface in an effort to determine by tests the reasons for the differences noted.

TABLE 6.—*Tests of binder material used in Oregon*

Test No.	Source	Point of use	Mechanical analysis—material passing various screens: ½-inch screen	No. 3	No. 10	No. 20	No. 30	No. 50	No. 100	No. 200	Removed by elutriation[1]	Cementing value	Lineal shrinkage	Field moisture equivalent
		Columbia River Highway:	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Pounds per square inch*	*Per cent*	*Per cent*
2407	Bluff above Seufert	Mile 94–106.44	95	95	92	90	87	83	77	67	63	226	5.7	25.2
536	Pit above Rufus	Mile 110–121.31			99	98	97	95	91	87	75.6	212	10.8	45.1
2411	Pit, mile 125.7	Mile 121±–127±			100	99	99	97	93	75	68	101	2.1	23.5
2401	Arlington pit, milepost 147.4	Mile 136.27–156.62	[2] 100	90	60	42	35	31	27	20	18	68	1.7	17.6
2412	Castle pit, mile 162.3	Mile 156.62–191+	97	96	94	91	88	88	82	72	70	114	8.8	33.1
564	Pit 2 miles south of mile 181.7	Mile 175–190		100	99	97	94	91	86	80	75	125	7.4	48.6
2408	Pit, mile 194.4	Mile 191–198+	98	98	97	95	93	91	79	69	66	94	8.8	30.8
561	Pit, mile 199	Mile 197–201			100	99	97	96	94	91	86	88	10.2	57.8
562	Pit, mile 203	Mile 201–208	100	92	65	35	26	23	20	18	15.7	54	0.0	11.8
563	Pit, mile 211.5	Mile 208–214				100		98	96	94	81.2	198	5.3	29.5
2415	Stannel pit, mile 220	208 to 224+		100	99	98	97	96	95	93	92	103	3.3	22.9
2413	Campbell pit, mile 241.49	Old Oregon Trail	100	99.2	96.4	94.8	93.6	92	89.6	85.4	83.0	193	8.4	32.0
2410	Bad Roads pit, mile 245.56	do		100	99	94.8	94.4	82	76.8	71.8	70.6	165	4.7	23.9
2420	Pit 3 miles east of Kamela, about mile 271.	do	100	98.4	75.2	57.6	53.6	49.4	47.4	36.4	36.0	135	2.2	22.5
2419	Pit 5 miles east of Redmond	The Dalles-California Highway, mile 115–140.			100	99.8	99.3	97.9	96.3	95.1	94.6	260	9.6	31.7

[1] See Department Bulletin 1216, U. S. Department of Agriculture, p. 10, Clay and Silt Test.
[2] Binder in pit mixed with gravel.

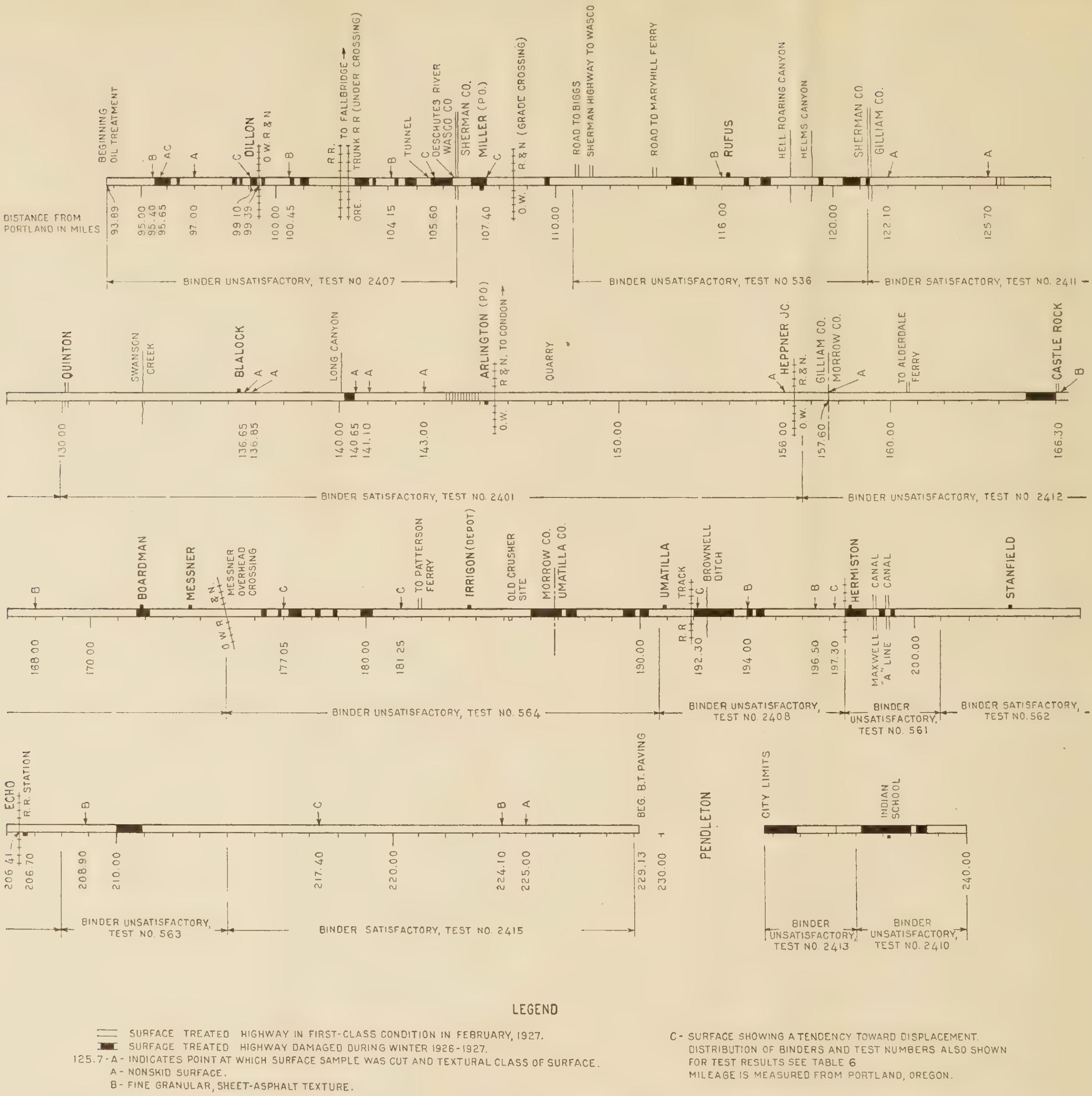


Fig. 5.—Condition of Oiled Surfaces on Columbia River Highway from a Report on an Inspection Made in February, 1927

The condition of the various sections of the Columbia River Highway between The Dalles and Pendleton, the classification of the surface according to texture at a number of points, and references to tests of samples taken from these points are shown in Figure 5. Figures 6 to 19 show the appearance of the surface at various points (identified with the chart by distance in miles from Portland) and indicate the generally satisfactory condition of the oiled surfaces.

The results of physical tests of the mineral binder contained in samples of the crushed rock taken at various points along this highway are given in Table 6; and tests of samples of the oil-treated surface, showing the mechanical analysis of the crushed rock and the character and amount of the oil, are reported in Table 7.

Several outstanding facts appear to be established by these tests.

The A samples were found to contain the least average amount of bituminous material. However, the variation in the amount in the three types of surface is apparently slight, and can not be the sole cause of the physical differences visible on the road. (See Table 7.)

It is significant that the A, or nonskid, type of surface contained the least proportion of mineral binder, and that the binder present had relatively low water carrying capacity and a low shrinkage value. (See Table 6.)

The proportion and character of the clay and silt binder appear to be the principal difference between the A and B samples as revealed by analysis. It is interesting to note (Table 6) that, although the texture of

Table 7.—*Analyses of surface samples from surface-treated sections of the Columbia River Highway*

Distance of sampled section from Portland	Texture of surface	Test No.	Analysis of total sample: Passing ½-inch screen	Analysis of total sample: Passing 10-mesh sieve	Analysis of material passing 10-mesh sieve: 10-mesh sieve	20-mesh sieve	50-mesh sieve	100-mesh sieve	200-mesh sieve	Clay	Number of washings to remove clay	Oil as a percentage of 10-mesh material	Bituminous content: Evaporation 325° F.	By extraction	Per cent of total sample	Sample: Depth	Thickness	Oil in surface
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*		*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Ins.*	*Ins.*	*Gals. per sq. yd.*
95.65	A	18	83.2	32.4	100	78.6	61.5	48.4	36.5	12.3	24	2.8	0.3	0.6	0.9	0–1.5	1.5	0.106
		20	58.1	37.2	100	92.0	76.9	55.3	40.6	17.9	16					Base.	2.0	
97.0	A	26	92.1	35.1	100	79.5	60.6	47.6	36.3	13.0	39	2.6	.4	.5	.9	0–.625	.625	.067
		30	93.4	54.5	100	79.3	63.8	51.9	42.1	18.2	16					.625–3	2.375	
122.1	A	1	73.4	40.9	100	81.0	63.6	55.7	33.1	6.6	12	5.4	.9	1.3	2.2	0–1	1.0	.262
		22	73.4	52.9	100	92.4	80.8	72.6	36.6	6.8	10	.4	.1	.1	.2	1–4.5	3.5	
125.7	A	19	65.0	42.7	100	80.2	63.1	53.0	34.9	6.3	16	5.4	.5	1.8	2.3	0–1	1.0	.274
		10	44.3	29.2	100	78.5	69.5	61.5	42.3	14.2	12	.6	.04	.15	.19	1–3.5	2.5	.056
136.65	A	4	97.7	44.2	100	77.2	57.1	45.0	27.9	6.2	13	9.5			4.2	0–.75	.75	.375
		25	88.9	60.8	100	82.6	65.8	51.6	32.1	8.8	17	1.8	.5	.6	1.1	.75–3.5	2.75	
136.85	A	27	89.3	41.9	100	81.3	58.1	42.8	25.8	9.3	28	6.7	1.4	1.4	2.8	0–.75	.75	.250
		2	96.3	61.0	100	82.7	60.0	45.4	27.1	7.6	11	3.7	1.2	1.1	2.3	.75–1.5	.75	.204
		29	64.8	33.4	100	78.5	62.1	48.6	29.0	9.4	13	3.0	.4	.6	1.0	1.5–3.5	2.0	.238
140.65	A	9	79.8	29.8	100	85.5	66.7	54.0	35.6	8.1	24	4.6	.5	.87	1.37	0–.375	.375	.0612
		8	94.4	55.2	100	88.3	68.2	53.5	34.6	9.7	20	3.8	.8	1.3	2.1	.375–1	.625	.156
		7	71.5	28.9	100	81.7	64.2	55.6	42.3	14.2	12	7.0	.7	1.3	2.0	1–3	2.0	.476
141.1	A	5	73.9	25.9	100	83.3	64.4	50.8	30.1	8.2	14	23.5	2.1	4.0	6.1	0–.125	.125	.091
		13	91.4	48.3	100	84.9	64.6	52.3	32.5	9.6	42	3.9	1.0	.9	1.9	.125–.75	.625	.141
		11	90.4	61.7	100	80.5	59.5	48.7	33.0	11.3	24	3.2	.8	1.2	2.0	.75–1.5	.75	.179
		15	70.3	43.8	100	84.3	68.4	54.9	28.6	6.3	14	4.7	.8	1.2	2.0	1.5–4	2.5	.593
143.0	A	3	97.2	36.5	100	87.0	65.5	44.8	31.2	8.2	12	6.6			2.4	0–1	1.0	.285
		36	71.2	35.2	100	75.1	55.0	42.2	30.0	11.3	26					1–4.5	3.5	
156.0	A	14	87.7	43.9	100	83.6	68.0	56.1	34.3	10.2	18	3.2	.3	1.1	1.4	0–.75	.75	.125
		37	94.1	57.4	100	75.1	55.0	42.2	30.0	11.3	16					.75–5	4.25	
157.6	A	17	82.0	45.5	100	84.3	74.2	61.6	37.9	11.5	44	3.9	.9	.9	1.8	0–1	1.0	.214
		6	78.3	51.8	100	87.9	66.0	57.6	35.6	15.0	15	2.0			1.1	1–4	3.0	.392
225.0	A	32	82.4	38.2	100	69.6	47.2	38.0	30.3	9.6	28	6.5	1.3	1.2	2.5	0–1	1.0	.297
		24	72.2	49.3	100	88.3	73.9	64.5	41.7	10.6	13	3.7	.8	1.0	1.8	1–5	4.0	.853
95.4	B	8	87.1	35.0	100	83.0	66.0	51.4	39.2	13.6	36	8.6			3.0	0–1	1.0	.356
		19	73.5	33.2	100	86.4	71.0	56.4	44.5	20.4	23							
100.45	B	1	98.3	54.6	100	74.8	52.3	42.9	34.2	13.4	29	2.4	.8	.5	1.3	0–1.5	1.5	.232
		18	61.5	31.3	100	81.6	64.8	54.7	44.0	20.0	16					1.5–4	2.5	
104.15	B	2	97.4	60.9	100	75.8	54.0	42.0	27.8	7.9	20	6.0	2.5	1.2	3.7	0–1	1.0	.441
		25	71.4	36.1	100	74.0	56.0	43.7	32.3	12.7	9					1–4	3.0	
116.0	B	30	91.1	42.3	100	72.8	50.7	41.8	33.1	9.1	28	7.7	1.0	2.3	3.3	0–0.5	.5	.197
		27	81.2	53.3	100	79.8	54.2	45.1	37.7	16.7	20					.5–3	2.5	
166.3	B	6	91.2	45.5	100	81.6	65.1	50.6	37.8	13.6	43	3.0	.7	.7	1.4	0–0.5	.5	.084
		9	64.2	37.0	100	90.2	75.3	56.7	45.5	22.4	47	4.6			1.7	.5–2	1.5	.304
		31	39.0	30.5	100	93.4	72.5	43.3	30.9	13.2	24					2–4	2.0	
168.0	B	22	71.9	28.5	100	76.3	57.5	45.2	35.2	15.2	38	17.2			4.9	0–0.75	.75	.437
		17	67.4	47.8	100	90.6	78.9	60.0	48.8	25.0	18					.75–4	3.25	
194.0	B	5	86.6	41.3	100	82.5	61.0	45.5	34.4	12.0	42	11.6			4.8	0–1.25	1.25	.714
		26	86.5	72.9	100	91.1	74.1	36.0	19.3	9.9	9					1.25–4	2.75	
196.5	B	3	80.4	39.3	100	78.8	60.0	49.9	41.4	17.1	39	13.7	1.2	4.1	5.3	0–0.75	.75	.473
		23	82.3	47.5	100	87.8	75.9	67.1	56.0	26.5	24	2.5	.4	.8	1.2	.75–2	1.25	.179
		20	83.2	64.2	100	95.0	61.8	40.1	31.1	11.4	8					2–4	2.0	
208.9	B	4	85.9	44.0	100	80.1	63.2	56.2	50.4	19.0	42	13.4			5.9	0–.75	.75	.527
		24	84.1	48.4	100	89.2	81.8	77.8	72.2	31.0	15					.75–5.75	4.25	
224.1	B	7	75.9	42.0	100	84.9	60.0	51.8	42.2	13.2	40	7.1			3.0	0–1	1.0	.356
		16	67.7	36.8	100	85.2	68.3	58.2	49.5	19.5	11					1–4	3.0	
95.65	C	25	77.4	38.3	100	76.4	56.3	42.2	32.2	11.2	33	11.5	.6	3.8	4.4	0–1	1.0	.524
		24	87.1	24.1	100	81.6	68.9	59.5	49.9	20.4	47	2.0	.1	.4	.5	1–2	1.0	.059
		4	71.8	20.9	100	84.6	75.9	68.9	59.8	27.8	30	12.0	.8	1.7	2.5	2–3	1.0	.298
99.1	C	14	95.0	34.4	100	71.4	55.7	42.3	30.0	9.4	35	6.3	.5	1.6	2.1	0–1	1.0	.250
		6	89.4	26.0	100	85.4	73.8	59.2	45.7	19.7	30	7.7	.1	1.9	2.0	1–2	1.0	.238
		5	67.8	50.4	100	93.2	80.4	59.0	42.5	18.7	26					2–4	2.0	
105.6	C	3	95.5	46.8	100	73.0	48.4	37.5	29.0	11.6	25	7.9	.8	2.9	3.7	0–1.25	1.25	.546
		23	95.1	39.4	100	77.3	54.6	43.2	33.5	11.7	57–63–33	1.0	.2	.2	.4	1.25–2.5	1.25	.059
		27	74.6	41.3	100	87.4	72.8	60.6	49.6	21.6	27					2.5–4.5	2.00	
107.4	C	2	92.6	48.2	100	75.4	51.1	40.2	31.4	11.4	18	10.8	.4	4.8	5.2	0–1.5	1.5	.923
		26	92.7	47.4	100	68.5	45.3	35.4	27.9	11.5	9					1.5–4.5	3.0	
177.05	C	11	91.4	43.5	100	83.4	61.3	44.0	30.4	10.2	41	3.9	.9	.8	1.7	0–1.125	1.125	.225
		12	82.6	38.5	100	78.4	54.0	40.4	30.7	12.2	46	1.5	.4	.1	.5	1.125–5	3.875	.275
181.25	C	R1	84.9	36.4	100	84.6	60.9	35.6	20.3	7.8	26	3.3	.5	.7	1.2	0–.25	.25	.036
		R5	84.9	37.4	100	90.4	69.0	40.8	24.0	8.6	40	3.5	.7	.6	1.3	.25–1	.75	.116
		R4	61.1	28.7	100	88.7	69.6	50.2	35.1	15.4	40	1.4	.3	.06	.4	1–4.75	3.75	.187
192.3	C	R3	75.6	25.2	100	76.4	50.3	36.9	26.6	9.8	51	7.5	.6	1.3	1.9	0–.25	.25	.566
		R2	72.7	33.7	100	79.3	60.7	51.4	43.0	17.4	51	1.2	.3	.09	.4	0.25–2	1.75	.084
		R6	73.7	36.1	100	76.0	41.9	30.7	23.9	13.2	17	1.1	.04	.3	.4	2–4	2.0	.095
197.3	C	22	91.8	55.2	100	74.6	52.5	39.1	28.0	8.5	35	4.2	.9	1.4	2.3	0–1	1.0	.274
		1	64.5	34.0	100	88.8	66.8	47.0	33.8	13.3	29	3.5	.5	.7	1.2	1–2	1.0	.143
		7	62.0	36.1	100	86.2	57.6	39.8	30.1	15.1	23					2–5	3.0	
217.4	C	28	88.2	48.5	100	72.6	48.6	40.6	34.9	14.4	28	2.4	.4	.8	1.2	0–.75	.75	.107
		13	93.1	46.3	100	79.2	60.9	54.7	49.9	23.7	34	4.3	.7	1.3	2.0	.75–1.25	.5	.120
		27	84.4	66.1	100	87.0	73.4	66.3	59.5	26.8	14					1.25–5	3.75	

the A surface was classed as nonskid, it actually contains more sand passing a 10-mesh sieve than the B or C types. Removal of fine sand and binder by thorough sweeping prior to oiling probably contributed to some extent to produce the nonskid surface.

In explanation of the apparent importance of the character of the binder as an element in the success or failure of the oil treatment, it may be observed that the treatment produces an air and water tight surface which, although it prevents entrance of water from above, also serves to prevent the escape of moisture brought up from the subgrade by capillarity. The concentration of moisture beneath a waterproof surface has often been observed; and it may be anticipated that an increase in the moisture content of the surfacing will follow oil treatment. Under these conditions it is logical to suppose that a binder possessed of high water-carrying capacity and a tendency to expand greatly and become unstable with increase of moisture would affect the stability of the surface.

TESTS OF BINDER USED ON COLUMBIA RIVER HIGHWAY

To determine the character of the binder used in the various sections of highway, samples taken were subjected to three tests used in recent years by the testing and research laboratory of the California Highway Commission. These include two of the simplest soil tests which were found to be generally indicative of the suitability of binder material. These are the lineal shrinkage test and the field moisture equivalent test,[5] as described in detail by A. C. Rose of the United States Bureau of Public Roads in the issue of PUBLIC ROADS for August, 1924, except that the soil is dried at 212° F. in preparation for the moisture equivalent test.

FIG. 6.—MILE 96 ON COLUMBIA RIVER HIGHWAY. SURFACED IN 1921, RESURFACED AND OILED IN 1924

FIG. 7.—MILE 106 ON THE COLUMBIA RIVER HIGHWAY. SURFACED IN 1921, RESURFACED AND OILED IN 1924, AND REOILED IN 1925

It has been demonstrated in the soil studies that low moisture-carrying capacity and low lineal shrinkage are desirable characteristics. Such soils usually make good natural roads, except those too sandy to compact. Soils which have high moisture capacity absorb excessive quantities of water and when wet lose most of their cementing or binding property. A high lineal shrinkage indicates excessive fineness or colloidal properties, and such a soil has little road value when in a saturated condition. Such material, when mixed with road metal, can not add stability or wearing qualities except when dried or when liberally adulterated with fine sand or inert rock dust.

In addition to the soil tests the binder samples were also tested by a test used during the past three years in the testing and research laboratory of the California Highway Commission to measure the cementing property of the material. For the purpose of this test the samples of surfacing material were screened to segregate the material passing a one-half-inch circular opening. This portion of the sample was mixed with water to the consistency of stiff concrete and tamped into 4½-inch cubical molds. After drying to constant weight at atmospheric temperature the resulting specimens were capped with plaster of Paris and broken in a standard compression machine, the average compressive strength per square inch as determined from three specimens being taken as the measure of the cementing value of the material. In its use of this test the California laboratory has found that there is wide variation between the results obtained with different materials, but fairly uniform results are had from retests of the same material. The strength ranges from 0 to 225 pounds per square inch; and a unit strength of 100 pounds has been established as the criterion of satisfactory binder.

In general, it has been found that at least 15 per cent of the material passing a one-half-inch circular opening should pass the 100-mesh sieve, and 8 to 10 per cent

FIG. 8.—MILE 116 ON COLUMBIA RIVER HIGHWAY. SURFACED WITH CRUSHED GRAVEL BOUND WITH CLAY IN 1924. LOOSE UNSWEPT SURFACE TREATED WITH 0.24 GALLON PER SQUARE YARD IN 1924. REOILED IN 1925 AT A RATE OF 0.42 GALLON PER SQUARE YARD

FIG. 9.—MILE 126 ON COLUMBIA RIVER HIGHWAY. RESURFACED WITH CRUSHED ROCK BOUND WITH CLAY IN 1924. OIL APPLIED AT A RATE OF 0.5 GALLON PER SQUARE YARD TO UNSWEPT SURFACE IN 1925. SURFACE IS NOT ROUGH BUT LACKS UNIFORMITY

should be removed in the washing test to establish satisfactory cementing property. A smaller proportion of fines, except in very soft rock, will usually result in a loose, uncompacted surface.

In addition to testing in this way the samples of crushed rock and gravel taken from the surface of the

[5] The relation of this test to the standard moisture equivalent test is discussed by Dr. Charles Terzaghi in PUBLIC ROADS, vol. 7, No. 8, October, 1926.

FIG. 10.—MILE 136 ON COLUMBIA RIVER HIGHWAY. RESURFACED IN 1924, USING CEMENTITIOUS GRAVEL FOR SURFACE COURSE. OIL APPLIED IN 1925 AT A RATE OF 0.5 GALLON PER SQUARE YARD. THE SURFACE IS UNIFORMLY SMOOTH

FIG. 12.—MILE 176 ON COLUMBIA RIVER HIGHWAY. RESURFACED IN 1923 AND OILED IN 1925

FIG. 11.—MILE 146 ON COLUMBIA RIVER HIGHWAY. RESURFACED WITH CRUSHED CEMENTITIOUS GRAVEL IN 1925. OILED IN THE SPRING OF 1926

FIG. 13.—MILE 185 OF COLUMBIA RIVER HIGHWAY. RESURFACED IN 1923 AND OILED IN 1925. THE SURFACE BECAME BADLY RUTTED AND IN APRIL, 1926, A TAR TREATMENT WAS APPLIED WITHOUT APPARENT BENEFIT. A SURFACE SAMPLE SHOWED AN EXCESS OF CLAY SATURATED WITH MOISTURE

roads inspected, the cementing test was also applied to samples of binder which had been mixed with these roads during construction, obtaining the samples directly from the pits from which the construction supplies were taken. The method of testing in this case was similar to that previously described except that clean concrete sand was mixed with the sample of binder in lieu of the fine rock or gravel with which it would be mixed in the road. In preparing the test specimens, binder material was added to the clean concrete sand in amount sufficient to bring the fines passing a 100-mesh sieve up to 15 per cent and the amount removed by washing to about 10 per cent of the mixture. As clean concrete sand has no cementing value, the strength of the specimens measures the cementing properties of the binder material; and separate binder tests when compared with tests of the same binder mixed with surfacing material indicate that the method gives a fair measure of the additional strength contributed by the binder.

The results of these three tests—lineal shrinkage, field moisture equivalent, and cementation—together with mechanical analyses of the material are given for samples of the binder used in the Columbia River Highway between The Dalles and Pendleton in Table 6.

In practically every instance an excess of clay was found in samples taken from surfaces which were pushing or corrugating. No such defects were found in any of the sections which had been bound with volcanic ash soil or with fines obtained in quarries or gravel pits.

If the limits suggested for the field moisture equivalent and lineal shrinkage tests (i. e., a field moisture equivalent percentage of 20 and a lineal shrinkage value of 5) and a cementing value of 100 pounds per square inch be used as criteria of satisfactory qualities in the binder, it will be noted that the samples represented by tests 536, 561, 563, 564, 2407, 2408, 2412, 2413, and 2419 would be classed as unsatisfactory. The material represented by test 2410 would be regarded with suspicion and would probably be rejected because of the high moisture capacity, the lineal shrinkage being so near the limit; and only the material represented by tests 562, 2401, 2411, 2415, and 2420 would be considered suitable for use. Figure 20 shows typical shrinkage test specimens from these tests after drying.

Figure 5 shows the points where the samples of surfacing material were taken from the highway, and the limits between which the binder materials represented by the tests reported in Table 6 were used. It also shows the location and extent of failures in the oiled surface resulting from frost and precipitation during the last winter, as reported by A. F. Morris, associate highway engineer of the Bureau of Public Roads, under

FIG. 14.—MILE 156 OF COLUMBIA RIVER HIGHWAY. RESURFACED WITH CRUSHED CEMENTITIOUS GRAVEL IN 1925 AND TREATED WITH 0.5 GALLON PER SQUARE YARD OF OIL IN THE SPRING OF 1926

FIG. 16.—MILE 196 ON COLUMBIA RIVER HIGHWAY. RESURFACED IN 1924. OIL APPLIED AT A RATE OF 0.495 GALLON PER SQUARE YARD IN 1925. SURFACE RECENTLY REOILED LIGHTLY AND SANDED

FIG. 15.—MILE 166 ON THE COLUMBIA RIVER HIGHWAY. RESURFACED IN 1923. TREATED WITH OIL AT A RATE OF 0.495 GALLON PER SQUARE YARD AND STONE SCREENINGS AT A RATE OF 15 TO 20 CUBIC YARDS PER MILE IN 1925

FIG. 17.—MILE 206 ON COLUMBIA RIVER HIGHWAY. RESURFACED IN 1924 AND TREATED WITH OIL AT A RATE OF 0.495 GALLON PER SQUARE YARD IN 1925. NOTE THE TRAFFIC GUIDE LINE AS USED UPON HIGH-TYPE SURFACES

date of February 11, 1927. It will be noted that the sections bound with suitable binder, 57.5 miles, show only one mile of broken surface; whereas sections surfaced with material rated as "unsatisfactory," 85.8 miles, show 16.8 miles broken.

The failures reported do not imply that the road is unserviceable, but merely that the bituminous surface has broken or potholed to the extent of requiring partial retreatment during the coming season.

The subsoil conditions on these eastern Oregon highways are generally favorable, the subgrade being sand or sandy soil. If the subgrade had consisted of material having high moisture carrying characteristics, it is quite likely that the failures would have been much more extensive and complete on the sections bound with heavy clay binder.

Clay binder represented by test 2419 (Table 6) was used on about 25 miles of The Dalles-California Highway between the Crooked River and Bend. This section was surfaced in 1921 with fine gravel containing little or no cementitious material. The surfacing did not compact under traffic, and in 1923 and 1924 binder was mixed with the gravel at the rate of from 5 to 8 cubic yards per hundred feet of road. The surfacing then compacted readily. In 1926 the road was treated with light "fuel oil" at the rate of 0.408 gallon per square yard. The surface remained in good condition during the summer and fall, but T. M. Davis, associate highway engineer of the Bureau of Public Roads, reported in February, 1927, that there had been a general breaking up following alternate freezing and thawing during the rather severe winter. Mr. Davis reported that the destruction of the surface had been practically complete where drainage conditions were unfavorable.

A study of test 2419 shows the binder to be a heavy, unstable clay, as evidenced by the high field moisture equivalent value and excessive lineal shrinkage. The oil surface prevented the escape of moisture by evaporation, and the freezing of this accumulated moisture was followed by a general breaking up of about half of the section. Figures 21 and 22 are typical views of this section before and after the winter. Comparison of the condition of surfaces bound with suitable and unsuitable binder gives strong emphasis to the importance of the binder as an element in the success of oil treatment.

TESTS OF OIL-TREATED SURFACING FROM COLUMBIA RIVER HIGHWAY

Table 7 shows the results of tests of the samples taken from the oil-treated surfacing of the Columbia River Highway at various points indicated by reference to the mileage from Portland corresponding to the

Fig. 18.—Mile 216 on Columbia River Highway. Resurfaced in 1923 and Oiled in 1925

Fig. 19.—Mile 226 on Columbia River Highway. Resurfaced and Treated with Oil at a Rate of 0.24 Gallon per Square Yard in 1923 and an Additional Treatment of 0.26 Gallon per Square Yard in 1924

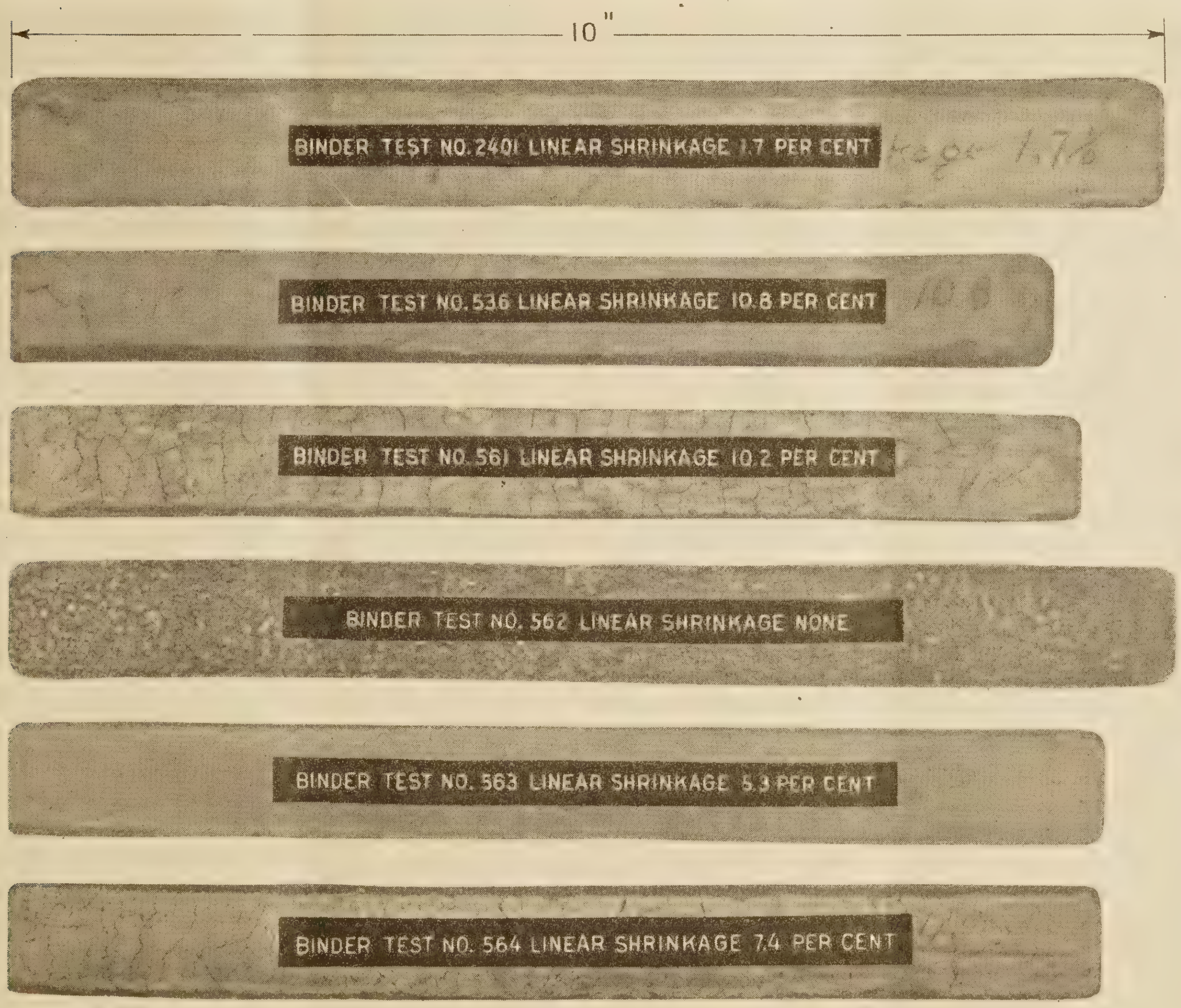


Fig. 20.—Typical Specimens from Tests to Determine the Linear Shrinkage of Binder Material

Fig. 21.—Condition of Oiled Surface on Mile 130 of The Dalles-California Highway in August, 1926

Fig. 22.—Mile 115.8 on The Dalles-California Highway Showing Surface Broken Up. A Section Can Be Seen in the Distance Where Only the Edges Are Broken

mileage designation in Figure 5. The character of the surface represented by the samples is indicated in each case by the letters A, B, or C, referring to the surface types previously described.

In these tests the samples were first dried and then subjected to a constant temperature of 325° F. until loss had practically ceased. The purpose of this was to determine the amount of bitumen volatile at 325° F. The remainder of the bitumen was then extracted, using benzol as a solvent. The oils used in these treatments were all residues produced as by-products of distillation at high temperatures, and the tests as tabulated seem to indicate that the oil does not lose any considerable portion of volatile fractions by evaporation after exposure for a considerable period on the road. The apparent drying on the roadway is probably due to absorption and not evaporation.

After the bituminous material had been removed from the sample, the clay content was determined and a mechanical analysis was made of material passing a 10-mesh sieve. The clay determination was made in accordance with A. S. T. M. tentative specification D137–22 T, except that suspension clay was not separated. Clay as reported in the tests includes suspension clay.

The number of washings required to remove the clay is significant. Where suitable binder materials had been used, relatively few washings were required. Where heavy, sticky clay binder had been used, the number of washings was greatly increased.

The samples were taken in strata to determine the depth of penetration and the character of material in the roadway, and at the time of sampling notes were made as to condition of the road and any unusual features. Following are descriptions of a few typical samples:

Sample 99.1: This sample represents a class C surface, i. e., one showing a tendency toward displacement. The field notes read: "Layer 0 to 1 inch rich and loose. Layer 1 to 2 inches apparently clayey with some free oil and water. Layer 2 to 4 inches, excessive binder. Road has pushed and rutted but is fairly comfortable to travel." The analysis shows about equal oil content in the upper two strata, each 1 inch thick. The amount of bitumen averages 7 per cent of the 10-mesh sand or 2 per cent of the total wearing surface. Clay and silt in the upper inch are about normal for an A-type surface, but the two lower strata apparently contain about 19 per cent of clay and 25 per cent of silt. The total amount of oil found in the upper 2-inch stratum equals approximately one-half gallon per square yard, and the lack of stability in the wearing surface is not believed to be due to an excess of oil. The high clay content was probably responsible for the displacement noted. Clay for binder on this section was obtained from the Seufert pit, represented by test 2407, Table 6.

Sample 122.1: This represents a class A surface. The field notes read: "Rocky surface is typical of the John Day-Quinton section. Coarse rock in the surface stands up and gives nonskid effect. Oiled surface 1 inch thick." The analysis shows a bituminous content of 5.4 per cent of the 10-mesh material, which is about normal for A-type surfacing. The clay content is unusually low; otherwise the grading is normal. From the standpoint of nonskid qualities as well as smoothness, the section is probably ideal. The binder came from the pit at mile 125.7, test 2411 (see fig. 5 and Table 6). Only 12 washings were required to remove the clay from this sample.

Sample 192.3: Another C surface. The field notes read: "Irrigation ditch parallels road about 40 feet from the center line. Surface is rutting and pushing badly. Has been treated with tar recently on old oil applied in 1925, and the tar cake is one-fourth inch thick. From one-fourth to 2 inch depth, surfacing filled with soft, wet clay. Under this, to a depth of 4 inches, gravel bound with sandy material. Failure evidently due to excess of clay binder in upper 2 inches of road." The analysis shows a high percentage of undesirable clay binder in the wearing surface. Fifty-one washings were necessary to remove this clay. Thirteen per cent of clay was found in the base course, but the difference in the character of the clay in the base is revealed by its removal in 17 washings. In this instance, water evidently reached the surfacing by seepage from the irrigation canal and the oil mat on the surface of the road prevented the moisture from escaping by normal evaporation. Subsoil conditions were not unfavorable. The base course, as noted, was sandy. This sample and the condition of the road emphasizes the importance of the character of the binder in a roadway which is to be oiled.

Sample 224.1: This sample represents a class B surface i. e., one having a fine, granular, sheet asphalt texture. The field notes read: "This sample is from a section which was oiled in September, 1923, using one-half gallon per square yard of roadway. Texture of surface smooth and uniform. Oil surface 1 inch thick and very hard. Base from 1 to 4 inch depth bound tight." The analysis shows a very low bituminous content and a fairly high percentage of binder in the top inch. The base course, from 1 to 4 inch depth, appears to have been bound with a volcanic ash similar to that represented by test 2415. (Table 6.) This is one of the earliest oil sections constructed in the State of Oregon.

The study of the tests of surface-treated material seems to show quite conclusively that stability is best obtained where the road is well bound under traffic without the use of sticky, heavy clays. The amount of bituminous material required is small. It is quite apparent that stability in the surfacing is more dependent upon the stable character of the road material than upon the amount or kind of oil used.

SURFACE OILING OF CALIFORNIA STATE HIGHWAYS

The use of "fuel oil"—an oil with an asphalt content of 40 to 50 per cent—for dust pallative purposes was begun on California State highways in 1924. The treatment at that time consisted of an application of one-tenth to one-seventh of a gallon per square yard repeated two or three times during a season. On many sections this repeated oiling, even with light oil, tended to produce a hard, oil-bound surface. The surface thus formed was not uniform and it was necessary to keep a thin covering or mulching of oil and sand or fine gravel over the surface of the road.

Fig. 23.—Power Broom Attached to Front End of a Tractor Used for Cleaning Surface Before Application of Oil

Somewhat heavier oiling was undertaken on the Redwood Highway in Division I under T. A. Bedford, division engineer, in 1925. This division is composed of the coast counties in the northern part of the State, including Humboldt and Mendocino, and the 1925 work was done in these two counties. These counties are mountainous, heavily timbered, and have a rainfall of 40 to 80 inches per season; but there is comparatively little frost and the summers are hot and dry. The dust nuisance on the Redwood Highway, which had previously been surfaced with crushed stone, was particularly objectionable where the highway passed through the orchards, vineyards, and the redwood forests. Short sections of the highway were given applications of oil in varying amounts with little or no preparatory treatment of the road. In some cases as much as one-third of a gallon per square yard was applied, and the results, from a dust-pallative standpoint, fully justified the expenditure.

In the spring of 1926 it was found that the oiled surface had withstood the winter and was in good condition in many places. The results of the applications made during the preceding season were so encouraging that the work was undertaken on a much larger scale, with the idea of attempting to produce a more lasting dustless surface. The sections selected were in typical condition; some were in a good state of preservation and others were worn to the danger point. The traffic averaged about 1,000 vehicles per day during the summer and somewhat less in winter.

From his previous experience the division engineer had concluded that sweeping prior to treatment would be very desirable, but, because of delays in obtaining the necessary equipment, this practice was not instituted until June 15, 1926. In general, the sections which were swept prior to oiling are now in the best condition.

On the sections completed prior to June 15, 1926, the preparation consisted of the blading of the mulch into rows along the shoulders of the highway. Oil was then applied at the rate of 0.44 gallon per square yard and the loose material bladed back over the freshly oiled surface. The mulching averaged about 1 inch in thickness and served as a blanket which absorbed the oil. While this method had the merit of giving traffic entire protection against the spattering of fresh oil, the treatment was open to the very serious objection of producing a rather thin mat of oil-treated material which was not properly traffic bound. Beneath this mat there was found in practically every case examined a layer of loose, dry, unsaturated screenings and dust.

On the work carried on after June 15 the blading of the mulching into windrows was followed by thorough sweeping with a power broom attached to the front end of a tractor as shown in Figure 23, and the brooming was continued until the loose material was removed and the surface of the rock exposed, as shown in Figure 24.

After the loose material had been swept from the surface of the road, oil was applied in two applications of approximately one-quarter of a gallon each, as shown in Figure 25, the second following within a few minutes of the first. The mulching was then bladed back over the fresh oil, usually within 10 to 30 minutes after the spreading. Figure 26 shows the same section of road after the loose material had been bladed half-way across the freshly oiled strip. The next passage of the blade completed the covering.

Fig. 24.—Exposed Rock Surface upon Completion of Brooming

Later in the season the dust was screened by hand from the mulching before spreading upon the oil.

On certain sections the traffic had bound the surfacing material so thoroughly that a negligible amount was removed by the sweeping. Even when supplemented by additional screenings, the cover upon the oil was very thin and was composed of relatively clean material.

About March 1, 1927, the sections treated during 1926 were examined for differences due to cover material. Although comparisons were somewhat obscured by other variables, it was evident that the well-bound sections covered with a minimum of material were in best condition, that removing dust from the mulching was an advantage, and that sections improperly swept before oiling were distinctly inferior to those thoroughly cleaned.

OIL TREATMENT AS AN EMERGENCY MEASURE

On a number of sections in Division I the metal was known to be too thin for satisfactory treatment and was lacking in the uniformity which is required for best results. The treatment in these cases was given to prevent anticipated destruction during the subsequent rainy season. The road was bladed to remove the rough spots, and was treated with a heavy grade of "fuel oil" at the rate of a half-gallon per square yard. When the oiling was completed, the rough spots and holes were patched with premixed oil and screenings. Results have entirely justified the expenditure. In general, the sections are much smoother than they were prior to treatment, and the application of the oil has had the effect of waterproofing the road, of stopping the loss of metal, and, in many cases, of preventing a break-up during the winter.

Fig. 25.—Application of Oil to Cleaned Surface

Fig. 26.—Mulching Partly Bladed Back over Oiled Surface

While oil treatment without proper preparation of the surface is not generally recommended, many cases will be found where such use of oil will be economical. Failures in such instances should not discredit oil treatment. Maintenance costs on surfaces which are treated without proper preliminary preparation will be considerably higher and the same degree of smoothness will perhaps never be attained. The engineers estimate that a two-man patrol, with a suitable truck and the necessary premixed material, can patch all breaks in 40 to 60 miles of highway. They say tht it is extremely important that such patching be kept up continuously and that small breaks be repaired immediately. Otherwise moisture collects in the depressions, saturates the surface under the adjacent oil top, and the break spreads with great rapidity. Experience up to this time indicates that the cost of patching and other maintenance will be less than the cost of the dragging and blading of the untreated sections.

The character of the oil used in the work done in Division I varied widely. That used in Humboldt County had a specific viscosity (Engler) of about 10 at 122° F. The asphalt content (80 penetration) ranged from 60 to 65 per cent. This oil is identical with most of the oil used in the Oregon work, and an inspection of the treated sections about March 1, 1917, indicated that it is too light for use in localities in which the rainfall is as heavy as in the California county. The specific gravity of such oil is about 0.94. If, therefore, rainfall is heavy and the road metal is moved or disturbed, the oil floats off on the surface of the water. This condition was particularly noticeable on the sections above described which had been covered with a rather thick layer of mulching. The rainfall for the season at the time of the inspection had been about 50 inches, and it is estimated that in places one-half of the oil had been removed in the manner described. Where the road metal had been thoroughly compacted prior to oiling the oil had withstood the winter rains quite satisfactorily.

On other parts of the same highway in Mendocino County the oil used had a specific viscosity of 45 to 80 at 122° F. This oil has a considerably higher specific gravity, and the surfaces treated with it were generally tight and uniform and showed no evidence of appreciable loss.

Experience of maintenance engineers verified by measurements justifies the estimate that the average loss of metal on the Redwood Highway was about 300 tons per mile per year, and the cost of replacing this metal would average not less than $750 per mile. The average cost of oil treatment in Division I last year was about $500 per mile, including such screenings as were necessary to produce a covering. Table 8 shows the cost of treating sections in the same division where little or no screenings were added.

Table 8.—*Cost of surface treatment in Division I, California, 1926 (practically no cover material used)*

Project	Length	Width	Quantity of oil	Cost per mile: Labor	Rental	Oil [1]	Miscellaneous	Total
	Miles	*Feet*	*Gals. per sq. yd.*					
Men.-1-A	0.73	18	0.45	$98	$78	$233	$27	$436
	1.23	18	.47	192	115	215	29	551
Men.-1-B [1]	4.12	18	.50	109	81	291	24	505
	4.11	18	.44	71	58	236	18	383
	1.4	18	.45	167	71	235	29	502
Men.-1-D [1]	1.11	18	.30	91	54	158	18	321
	3.96	18	.38	90	33	198	14	335
Men.-15-A	13.1	18	.30	50	33	154	7	244
Men.-70-A	1.4	18	.46	84	70	239	14	407
	2.2	18	.33	114	43	156	11	324
Men.-1-E [2]	2.61	18	.28	98	68	199	30	395
Lak.-16-A	1.15	21	.49	176	185	301	82	744
Son.-1-A	4.3	18	.54	163	92	242	35	532
Total and average	41.42							379

[1] Cost of oil at refinery, $1.04 per barrel. Freight averaged substantially the same amount. Average cost of oil, including freight, 4.9 cents per gallon.

The oil treatment as here applied was effective in stopping loss of metal and would be economical if the operation had to be repeated annually. That it will not have to be charged off annually but that it may be expected to give at least two or three years of average service is evidenced by the present condition of work done last year, at least 80 per cent of which is in first-class condition.

The cost of oil treatments in other counties and divisions of California is shown in Table 9. Tests of the oils used in these treatments are reported in Table 10.

TEMPORARY OIL TREATMENT UNDER HEAVY TRAFFIC IN SHASTA COUNTY

Similar oil treatments have been carried on in several other divisions of California but not so extensively. Two other sections of surface treatment show the possibilities of the use of such treatment for temporary purposes under heavy traffic. One of these is a section north of Redding designated as II–Sha.–3–B. This section, 6.12 miles in length, has an average traffic of about 1,500 vehicles per day, and an occasional maximum of 3,000 or more during midsummer. Crushed rock surfacing 21 feet in width had been completed in 1925 and maintained by dragging and blading. Considerable binder material had been added and the road was thoroughly compacted, and calcium chloride had been used as a dust palliative during the 1925 season.

This section was surface treated in June, 1926, the general method being similar to that followed in Oregon and Division I in California except that sweeping was continued much longer than is the usual practice. The road was swept and reswept until the rock particles were exposed to a depth of one-fourth to one-half

TABLE 9.—*Cost of surface treatment in California, 1926 (with cover material)*

Project	Length	Width	Quantity of oil	Operation	Cost per mile [1]				
					Labor	Equipment	Material	Miscellaneous	Total
	Miles	*Feet*	*Gals per sq. yd.*						
I Hum.-1-AB	4.3	16	0.5	Preparing base		$9	$5	$4	$18
				Oiling	$89	184	132	27	432
				Cover	105	25	130	8	268
				Total	194	218	267	39	718
I Hum.-1-C	13.9	16	.56	Preparing base	3	13		1	17
				Oiling	97	121	170	49	437
				Cover			214		214
				Total	100	134	384	50	668
Hum.-1-D	11.2	16	.64	Preparing base	6	28		2	36
				Oiling	79	112	196	41	428
				Cover			275		275
				Total	85	140	471	43	739
II Sha.-3-B	6.12	21	.5	Preparing base	128	152		38	318
				Oiling	61	51	257	11	380
				Cover	138	36	153	10	337
				Traffic protection				37	37
				Total	327	239	410	96	1,072
II Sis.-3-BC	18.9	24		Preparing base	120	85	46	58	309
				Oiling	81	63	317	33	494
				Cover	145	77	38	25	285
				Traffic protection				81	81
				Miscellaneous				[2] 215	[2] 215
				Total	346	225	401	412	1,384
III Gle.-45-A	2.0	18		Preparing base	13	8			21
				Oiling	44	20	188		252
				Cover	21	5	62		88
				Miscellaneous				10	10
				Total	78	33	250	10	371
III Col.-15-E	2.0	18		Preparing base	6	25			31
				Oiling	64	43	181		288
				Cover	52	30	218		300
				Miscellaneous				27	27
				Total	122	98	399	27	646
III Ama	6.5	19	.52	Preparing base	65	25	18		108
				Oiling	43	48	181	40	312
				Cover	117	83	26		226
				Miscellaneous				57	57
				Total	225	156	225	97	703
IV S. F.-55-A; S. M.-55-A_1	5.5	33	.5	Preparing base	63	35		9	107
				Oiling	96	45	328	14	483
				Cover	188	161	276	13	638
				Miscellaneous				92	92
				Total	347	241	604	128	1,320
IV Mrn.-52-A	4.89	18	.4	Preparing base	64	53		3	120
				Oiling	31	21	154	18	224
				Cover	50	57	116	14	237
				Total	145	131	270	35	581

[1] Average cost per mile reduced to 18-foot width, $830.
[2] Mostly patching.

Table 10.—*Typical California fuel oils used in bituminous treatments by the California Highway Commission in 1926*

Type of treatment and project	Lab. No.	Date sampled	Specific gravity	Baumé gravity	Specific viscosity, Engler, 122° F.	Viscosity, Saybolt-Furol, 122° F.	Per cent of asphalt, 80-penetration
Surface treatment:							
I-Hum.-1-C	1540	June 23	0.9409	18.8	9.1		51.0
I-Hum.-1-D	1541	July 10	.9409	18.8	9.1		52.9
I-Hum.-1-G_1	1741	Oct. 8	.9453	18.1	10.9		55.0
I-Hum.-1-G_1	1742	do	.9446	18.2	10.5		55.5
I-Hum.-1-I_2	1683	Sept. 11	.9557	16.5	10.8		54.4
I-Men	1690	Sept. 4	.9743	13.7	126.7		73.8
I-Men.-1	1446	May 25	.9742	13.7	68.1		74.5
I-Men.-1	1458	May 26	.9642	15.2	73.8		81.2
I-Men.-1	1479	June 9	.9655	15.0	76.4		52.5
I-Men.-1	1480	do	.9695	14.4	83.7		77.8
I-Men.-1	1526	June 25	.9668	14.8	64.4		71.0
I-Men.-1	1528	do	.9722	14.0	71.1		69.1
II-Sha.-3B_3	1469	May 25	.9675	14.7	44.8		62.0
II-Sha.-3B_3	1470	May 29	.9668	14.8	52.3		66.4
II-Sha.-3B_2	1471	June 2			43.7		63.2
II-Sha.-3C	1487	June 12	.9668		59.0		57.0
II-Sis.-3B_2	1713	Sept. 16	.9749	13.6	68.0		60.0
II-Sis.-3B_2	1714	Sept. 18	.9749	13.6	68.0		63.0
II-Sis.-3C	1672	Sept. 2	.9695	14.4	54.6		63.0
II-Sis.-3C	1709	Sept. 6	.9688	14.5	48.5		65.8
II-Sis.-3C	1711	do	.9722	14.0	50.4		64.8
II-Sis.-3C	1712	do	.9681	14.6	50.0		66.5
Surface mixing method:							
VIII-Imp.-26G	1654	Aug. 25	.9550	16.6	23.9	117	67.4
VIII-Imp.-26G	1655	Aug. 26	.9537	16.8	25.9	115	64.5
VIII-Imp.-26G	1656	do	.9531	16.9	24.4	116	64.1
VIII-Imp.-26G	1657	Aug. 27	.9557	16.5	35.8	115	60.9
VIII-Imp.-26G	1658	do	.9544	16.7	30.1	115	64.5
VIII-Imp.-26G	1659	Aug. 28	.9492	17.5	29.8	115	63.6
VIII-Imp.-26G	1663	Aug. 20	.9655	15.0	30.9		64.6
VIII-Imp.-26G	1664	Aug. 30	.9655	15.0	28.2		63.8
VIII-Imp.-26G	1665	Aug. 31	.9531	16.9	24.8	116	65.6
VIII-Imp.-27B_5	1433	May 1	.9428	18.5	16.9		63.0
VIII-Imp.-27B_5	1431	Apr. 30	.9459	18.1	18.4		67.8
VIII-S. Bd.-31D	1772	Aug. 24	.9628	15.4	30.9		62.7
VIII-S. Bd.-31D	1773	Aug. 25	.9681	14.6	49.4	215	62.3
VIII-S. Bd.-31D	1775	Aug. 26	.9688	14.5	50.0	215	67.4
VIII-S. Bd.-31D	1776	Aug. 27	.9628	15.4	26.7		63.4
VIII-S. Bd.-31D	1777	Aug. 30	.9662	14.9	26.4		63.3
VIII-S. Bd.-31-58_F	1778	do	.9675	14.7	52.0	184	69.7

inch. This was to insure a nonskid texture on account of steep grades and sharp curves. Fuel oil having an asphalt content of about 65 per cent was then applied in two applications of one-fourth gallon each. The oil had a specific viscosity (Engler at 122° F.) of 45 to 50. Because of its high viscosity, the oil penetrated slowly and chips were added after each application. The chips ranged in size from three-fourths inch to 10-mesh, and the amount used averaged about 50 cubic yards per mile. The heavy, sticky oil effectively held the chips in place, and these, together with thorough sweeping prior to treatment, gave the resulting surface the desired nonskid texture closely resembling that of bituminous macadam, as shown in Figure 27. This texture remained unaltered under traffic throughout the season.

Roughometer readings [6] taken on this section during the latter part of August, 1926, showed a roughness of 25 to 30 inches per mile, which corresponds with that usually found on first-class bituminous macadam.

The cost of treating this section was $1,072 per mile, or 8.7 cents per square yard, compared with $726 per mile of 16-foot width, or 7.7 cents per square yard for similar work in Division I. The difference lies in the thorough preparatory sweeping and in the amount of chips applied. Table 9 shows detailed costs of surface treatment on this and other sections upon which cover material was used in considerable quantities.

H. S. Comly, division engineer in charge of this construction, states that the average cost of maintenance on a 60-mile section of untreated road between Redding and Dunsmuir, including the section above described has been averaging about $1,900 per mile per year under traffic of about 1,500 vehicles. This cost of maintenance included the cost of such metal as was replaced, calcium chloride dust palliative, and sprinkling. The experience already indicates considerable reduction as a result of the oil treatment. In addition, a smoother, nonskid, dustless surface has an increased service value difficult to estimate.

[6] Readings were made with a Bureau of Public Roads roughometer operated at 20 miles per hour and calibrated to give results comparable with those obtained on the same road with a vialog. The calibration consisted of running the car over five 1 by 10 inch boards placed at 50-foot intervals on a smooth surface. The result is taken to represent "10 inches" of roughness and a conversion factor is established.

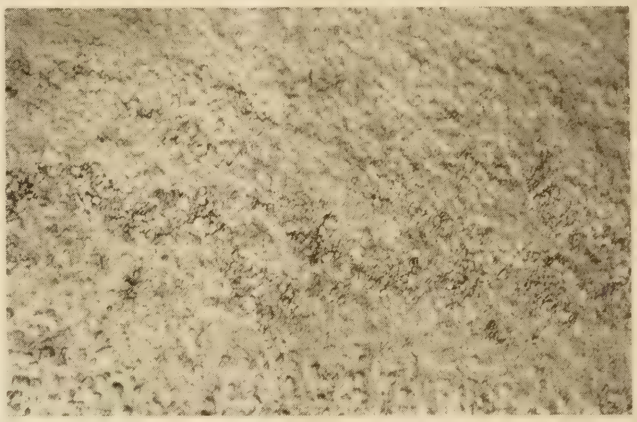


Fig. 27.—Picture Taken on the Pacific Highway near Redding One Month after Completion of Surface, Showing Surface Texture which was Retained under Heavy Traffic

THE SKYLINE BOULEVARD

Another section, 5½ miles long, was treated during the season of 1926 in Division IV near San Francisco under traffic even more severe than those above described. The section is a pleasure drive extending southerly from the city of San Francsico and carries little truck traffic.

Traffic, according to the 1926 census, averages about 2,000 vehicles per day with an occasional Sunday maximum of several times this number. The road had been surfaced with crushed rock, the northerly 3½ miles to a width of 35 feet and the remainder 29 feet. Light oil had been used as dust palliative but was relatively ineffective under this extremely heavy traffic. Patches of oil-bound surface had formed which tended to add to the roughness of the road, but it is probable that the use of the light oil had somewhat reduced the loss of the metal. It was not otherwise successful. The section was given a surface treatment in August, 1926, under the supervision of John H. Skeggs, division engineer. Preparation for the new treatment consisted of smoothing, blading, and thorough sweeping. The mulching on the road was hand screened to remove the dust and the coarser material was used to cover the fresh oil which was spread in two applications of approximately one-fourth gallon each. Additional screenings were applied as needed, and on the completion of oiling a program of intensive patching and mending was undertaken. Depressions were carefully filled with pre-mixed material and compacted under traffic. The construction and maintenance produced a very satisfactory surface which has withstood traffic for about a year. Roughometer readings on February 17, 1927, gave an average roughness of 25 to 30 inches per mile, which, as has been stated, is about normal for first-class bituminous macadam. A section of asphaltic concrete adjoining this highway within the city limits of San Francisco gave a roughness of 40 inches per mile.

The average cost of the treatment on the Skyline Boulevard was $1,320 per mile and the width of the surface treated averaged about 33 feet. The cost, width being considered, was about average.

With the cooperation of the automobile clubs, traffic was kept off the oil during the treatment and work was carried on without complaint from the traveling public.

GENERAL COMMENTS ON THE METHOD OF SURFACE TREATMENT

On the basis of the cooperative study to date and the inspection of the methods and results of surface oiling in Oregon and California, several general comments are pertinent.

It is apparent that the cost of this bituminous treatment in many cases is less than the value of the metal which would otherwise be lost in a single year.

The treatment, where properly conducted results in a dustless surface which is much smoother than the untreated crushed rock and gravel surface; and experiments by the Washington State College indicate that the tire wear caused by roads of this type is no greater than that caused by more expensive pavements.

Two physical features of the road to be treated are most important. There should be an adequate thickness of surfacing, and the binder in the road metal should not be a heavy, unstable clay. Such binder has given satisfactory results in some cases in untreated roads, but the application of oil forms a waterproof cover which holds moisture in the road, and clays of this character remain saturated, unstable, and without cementing value.

It has been demonstrated by experience that the treatment can be employed successfully under climatic conditions as widely varying as those of eastern Oregon and Humboldt and Mendocino Counties in California. In eastern Oregon the roads have been subjected to a relatively low annual precipitation, to long hot summers, and winters in which the temperature goes well below zero. It has been demonstrated in this section that satisfactory results can be obtained where extremes of temperature prevail except where the surface metal is mixed with unsatisfactory clay binders. The sections in Humboldt and Mendocino Counties show that a successful result can be obtained under conditions of long-continued rainfall; but in such wet climates it has been found that variations in the characteristics of the oil have far more influence than is apparent in the drier, colder sections.

In the drier climates, where considerable penetration is desired, the light grade of "fuel oil" has given excellent results. In sections where rainfall is heavy, it has been found that the heavier "fuel oil" should be used, at least in the surface coat. Heavy oil, however, requires more screenings than light oil and is, therefore, more costly. In certain localities a first application of light oil followed by an application of heavy oil will accomplish the desired results and keep the cost of screenings at a minimum. It is apparent, therefore, that the selection of the bituminous material requires careful consideration.

A nonskid texture can be secured on a road which is bound with stone dust or inert binder by sweeping before treatment until the stone particles are exposed. A covering of screenings on the last coat of oil improves the texture.

Intelligent and efficient maintenance beginning immediately after construction is essential to the success of surface treatment, and if a highway organization is not in a position to carry on such maintenance work the treatments herein described are not recommended.

Accurate cost data as to maintenance of crushed rock and gravel roads thus treated with light "fuel oil" are not yet available, but indications point to a cost of $300 per mile per year with traffic of about 500 vehicles.

Freshly oiled surface is readily damaged by iron tires which pick up the oil and leave bare tracks that do not entirely heal. Rubber tires do not appreciably damage such a road; but a reckless driver on a freshly oiled surface not only endangers himself and his own property but is a menace to others. Skidding upon the recently oiled roadway has caused several accidents. Also it is very difficult to drive a car over such a surface without spattering it from end to end with oil. The cleaning of a car in this condition costs from $5 to $10, and a considerable loss in the aggregate may result to motorists on a road carrying heavy traffic. One thousand cars per day would mean a cleaning charge of $5,000 per day or more. If this damage has resulted from travel over 5 miles of freshly oiled surface, the charge is $1,000 per mile per day against the oil treatment. This damage might accumulate for several days and would largely nullify the benefits of this very economical type of surface treatment. Traffic protection should receive most careful attention, otherwise the treatment is likely to fall into disfavor. Especially would this be the case if oiling proceeds slowly, new sections being opened as others are finished.

The application of chips in the amount of about 40 or 50 cubic yards per mile (10 or 12 pounds per square yard) immediately after oiling reduces the damage to rolling stock. This is not sufficient, however, unless cars are operated at very slow speed. Where detours are available, the road should be closed to traffic until the oil has penetrated. Chips may be applied, but rather to add nonskid quality to the road surface than as a protective measure.

If traffic can not be detoured and the road closed during treatment, oiling should proceed in successive strips, leaving enough untreated or completely covered roadway to care for traffic. In any event, traffic should be cautioned that a speed in excess of 8 miles per hour on a freshly oiled surface, even for a few hundred feet, will result in an expensive cleaning job.

Where traffic is carried on a road under treatment, traffic control is ordinarily installed. The usual control is not sufficiently rigid to provide protection. Such a control system, it is suggested, should consist of special officers stationed at each end of the freshly oiled road. The officers should stop each car and present the driver with a ticket showing the time at which the car will reach the other end of the control if operated at a speed of not more than 8 miles per hour. The driver should be told that he will not be permitted to pass the control at the other end until the time indicated Merely cautioning the drivers is not sufficient, as has been demonstrated in many cases.

Too much stress can not be placed on the importance of such protective measures. The motorists will benefit after oil treatment by the complete elimination of dust, but this subsequent benefit is forgotten when an owner discovers that his car is rather thoroughly covered with black, sticky oil.

BITUMINOUS TREATMENT OF CRUSHED ROCK AND GRAVEL ROADS BY THE SURFACE MIXING PROCESS

Wisconsin [7] began using a surface-mixing process in 1923, Wyoming experimentally in 1925, and California in 1926. The immediate occasion in each case was a section of road with too much loose material on the surface to permit use of the ordinary surface-treatment process; but promise of durability, extraordinary riding qualities, and special adaptability to fine crushed surfaces indicate a wide field for the process.

Wisconsin reports a cost of about $1,250 and California an average of about $1,268 a mile for an 18-foot width of this type of treatment. (See Table 11.) The lower cost of oil in California as compared with tar in Wisconsin permits a greater thickness of treated material for about the same cost. No figures are available as to the cost of maintenance, but both States are convinced that it will be less than the maintenance of surface-treated roads.

TABLE 11.—*Cost of surface-mixing treatment on southern California projects, 1926*

Project	Length	Width	Annual cost of untreated surface per mile: Ordinary maintenance	Annual cost of untreated surface per mile: Loss of metal	Annual cost of untreated surface per mile: Total	Quantity of oil applied	Cost of surface-mixing treatment per mile: Oil	Cost of surface-mixing treatment per mile: Labor	Cost of surface-mixing treatment per mile: Equipment	Cost of surface-mixing treatment per mile: Supplies and miscellaneous	Cost of surface-mixing treatment per mile: Total
	Miles	*Feet*				*Gals. per sq. yd.*					
Imp. 26-G	8.81	20	$3,310	$3,097	$6,407	1.5	$893	$168	$260	$83	$1,404
Imp. 26-A	3.93	20	1,342	1,890	3,232	1.5	1,017	118	193	35	1,363
Imp. 27-B	14.07	20	180	1,010	1,190	1.5	783	282	268	97	1,430
S. Bd. 31-D	13.60	18	2,640	1,958	4,598	1.25	535	272	290	61	1,158
S. Bd. 31-E	4.60	18	2,372	4,444	6,816	1.25	697	298	339	246	1,580
Average per mile					3,980						1,315

Reduced to 18-foot road, the average cost of the mixed surface treatment is $1,268 per mile.

Experience with the surface-mixing method is too short to permit an accurate estimate of probable life. However, examination of a number of treated earth roads constructed 10 or more years ago shows no deterioration of the oil binder with age, and, apparently, the oil treatment should have the life of the underlying structure, which depends upon such factors as weight and volume of traffic, adequate thickness, subsoil, and climate. The residual asphaltic oil does not evaporate and hardens but slowly. Roughness and breaks in the surface are to be remedied by reworking or patching as a part of routine maintenance.

Although construction costs are relatively low, discussion of the economics of the type requires that a term be assumed within which the cost of treatment should be written off. Depending as it does upon many factors, the term must be rather arbitrarily selected. It is suggested that the period be assumed to lie between 5 and 10 years, dependent upon subsoil, climate, and probable increase of traffic. The type is believed to be adequate for a maximum of 1,000 vehicles per day. If the treatment is an emergency measure to protect a road of insufficient thickness, the outcome is too uncertain to justify assuming life beyond the current maintenance year.

[7] Tar Surface Treatment of Gravel Roads, by N. M. Isabella, PUBLIC ROADS, vol. 6, No. 2, April, 1925, p. 40.

This process presumes prior construction of a roadway of strength ample to carry the loads, which implies a sufficient thickness of surface material and also compactness beneath the oil mixture. A layer of fine, loose material between the compacted base and the treated surface should be avoided. Mechanical operations will be difficult where the road metal contains any considerable quantity of large stone, but are simple on fine crushed rock or gravel. The presence of heavy clay binder is objectionable, but the proper amount of fine inert filler is an advantage.

Ths viscosity of the oil used is an important factor in this process. It must not be too heavy to mix with the road metal readily at prevailing temperature. Quantity is even more critical; an excess results in rutting and other displacement; a deficiency causes raveling. Heretofore the only gauge has been the appearance of the mixture, but the similarity to other asphaltic types and the expense and unreliability of cut-and-try methods suggest the possibility of utilizing a modified form of the stain test, once common in sheet asphalt practice. As stated elsewhere in this report, experiments along this line have been very promising. Uniformity is difficult to attain because inevitably the thickness will vary from place to place, and with uniform application of oil the result will be an irregular richness. If the irregularity is sufficient to be observed during the construction process, additional fine material beneath the richer portions should be loosened and incorporated into the oiled material.

THE SURFACE-MIXING METHOD AS USED IN CALIFORNIA

So far as known no metaled roads on the Pacific coast were treated according to the Wisconsin method or in a similar manner until the summer of 1926. During the latter part of that year approximately 50 miles of this type was constructed on the California highway system in San Bernardino and Imperial Counties with, however, a number of differences in the details of the process. Eighteen miles of this work is in San Bernardino County between Victorville and Barstow, and the remainder in Imperial County between Westmoreland and Yuma, Ariz. This is a desert region where the rainfall is very light, the summers long and extremely hot, and consolidation for surface treatment is impractical. The application of the surface-mixing method to graveled roads in this area was developed by E. Q. Sullivan, division engineer, California Division of Highways, and his assistant, J. E. Stanton.

Experimental section.—An experimental surface-mixed section 700 feet in length was constructed near Westmoreland, Imperial County, in June, 1926. The road had been surfaced with crushed gravel to a width of 18 feet in May, 1924 (contract No. 430, Imp.–26–A), but had never compacted under traffic. This first experimental treatment consisted of the application of 1.75 gallons per square yard of "fuel oil" containing approximately 65 per cent of 80-penetration asphalt. The oil was spread to a width of 15 feet and mixed with the loose gravel by blading and working until the mixture was more or less uniform in color. When inspected on July 7, 1926, the oil mixture appeared richer on the northerly side of the road, in some places contained more sand than in others, and in general lacked uniformity. However, it was reasonably smooth and did not displace readily. The thickness of the mixture was found to be 2 to 2½ inches. The results of this experiment were encouraging and similar treatment of the 18 miles of the San Bernardino-Needles route was undertaken.

San Bernardino-Needles route.—The sections treated on this highway consisted of 13.6 miles from Victorville northerly and 4.6 miles between Hicks and Barstow. These sections of highway were surfaced in the early part of 1926 with 4 to 6 inches of gravel crushed to pass a 1-inch circular opening. (Contracts 476 and 489, S. Bd.–31–D–E–F.) The subgrade consisted of disintegrated granite and gravelly desert soil. Because of heat and lack of rainfall, the surfacing material did not bind under traffic, and addition of disintegrated granite and other binders failed to remedy conditions, so that, in July, 1926, there was a blanket of 1 to 2 inches of fine, loose gravel covering the entire roadway. The road was dusty and much metal was being lost. The effort to bind the road metal is reflected in the high maintenance costs shown in Tables 1 and 11.

The treatment adopted was based upon the experimental section just completed near Westmoreland and was as follows:

1. The road metal was scarified to a uniform depth of about 2 inches.

2. Oil was spread upon one-half of the road in three approximately equal applications to a total quantity of 1.25 gallons per square yard. After each application the material was partially mixed with disk cultivators and spring-tooth harrows sufficiently to remove the excessive stickiness of clear oil. The other half of the roadway was then treated in like manner. When thus partially mixed the roadway was passable for traffic without damage to vehicles or to the road, which was a material convenience where detours were not available. The oil had an asphaltic content of 60 to 70 per cent and specific viscosity (Engler) ranging from 25 to 101 at 122° F.

3. The partially mixed material was gathered into windrows by blade graders, and these windrows were moved from side to side of the road until the material was thoroughly mixed as indicated by uniform color.

4. The mixed material was spread by blade graders to the final cross section and compacted by traffic. A blade grader was continued in operation for several days during the compacting process to fill ruts and remove irregularities.

On the Victorville section the treated material averaged 2.4 inches in thickness at the center and 1.74 inches at the sides after being compacted. On the Hicks-Barstow section the thicknesses averaged 3.04 and 1.43 inches, respectively.

The cost of the treatment ranged from $1,158 to $1,580 per mile for the width of 18 feet. The details are shown in Table 11.

A significant and even startling loss of road metal occurred during the six months interval between the completion of gravel surfacing and the treatment with oil. (See Table 1.) On the Victorville section measurements showed a reduction of the average thickness from 5 to 4.22 inches. At $2.79 per ton the value of the lost metal was $979 per mile in the period of six months. The Hicks-Barstow section suffered a reduction of average thickness from 5 to 3.23 inches, which at the same unit price amounts to $2,222 per mile for the six-month period. General failure of the treated road due to lack of metal would have been probable in the near future if the subgrade had not been mainly disintegrated granite or stable sand-clay.

The surface of the treated road is clean, dustless, reasonably nonskid, and smooth. Roughometer readings taken in October, 1926, immediately after completion showed a total roughness of only 10 inches per mile. In July, 1927, readings were again taken and the roughness was approximately the same. For comparison, it should be stated that the usual degree of roughness on first-class asphaltic pavement ranges from 15 to 25 inches per mile and on best concrete from 6 to 10 inches. In so far as smoothness is concerned, the mixing method as practiced on this section gave better results nine months after completion than hot-mixed asphaltic concrete. The reason for the smoothness is the method of manipulation, by which the bituminous mixture is compacted gradually under traffic from the base upward rather than downward from the top as occurs under a roller in ordinary bituminous construction. The use of long-wheel-base blades removes corrugations or other irregularities which might otherwise form during construction and the low bituminous content probably contributes to stability.

For comparison with the treated sections, roughness readings were taken on an untreated section 7 miles in length between the two treated sections. These averaged 119 inches per mile, showing that the untreated surface was twelve times as rough as the treated sections. The untreated gravel was maintained in the usual manner by blading and keeping a loose mulch over the surface and, in addition to being much rougher than the treated surface, was very dusty and was probably being worn away at such a rate that the loss would equal the cost of oiling in a few months.

SURFACE MIXING IN IMPERIAL COUNTY

Mixed bituminous treatment was applied also to 27.4 miles in the Imperial Valley in September and October, 1926. These sections had been surfaced with crushed gravel (contracts 430, 438, and 465) in 1924 and 1925, but, excepting the Sand Hills-Yuma portion, had never properly compacted because of extreme heat and lack of humidity. During subsequent maintenance disintegrated granite binder was added between El Centro and Imperial and water was freely used but without accomplishing much toward compacting the material or reducing the dust nuisance. In 1925 several applications of 40 to 50 per cent asphaltic oil was spread at the rate of one-seventh to one-tenth gallon per square yard in a further effort to overcome the dust, but the looseness of the surfacing material rendered this ineffective except on the Sand Hills-Yuma section, where some improvement resulted. It afterwards appeared that the oil used on this portion of the road actually contained as much as 68 per cent of asphalt, but the amount applied was not sufficient to produce a permanent wearing surface.

The mixing method finally adopted on these Imperial Valley sections was quite similar to that used in San Bernardino County, excepting that the quantity of oil was at first reduced to 1 gallon per square yard. After completing the treatment with this amount of oil evidence of insufficiency developed. The treated material was again scarified and an additional one-half gallon of oil per square yard was applied, the mixing process resumed, and finally the mixed material was distributed with a blade grader and compacted

Fig. 28.—Method of Applying Oil Treatment

A.—Disk and spring-tooth harrows following oil distributor
B.—Oil applied to one side of road at a rate of 1.5 gallons per square yard and harrowing completed
C.—One side of road stripped of oiled material, which is piled in a windrow just beyond the center
D.—Grader mixing material by taking it from windrow and casting into another on far side of road
E.—Condition of road surface on the day following final spreading with a 12-foot blade grader
F.—Traffic compacted surface about one month after final spreading

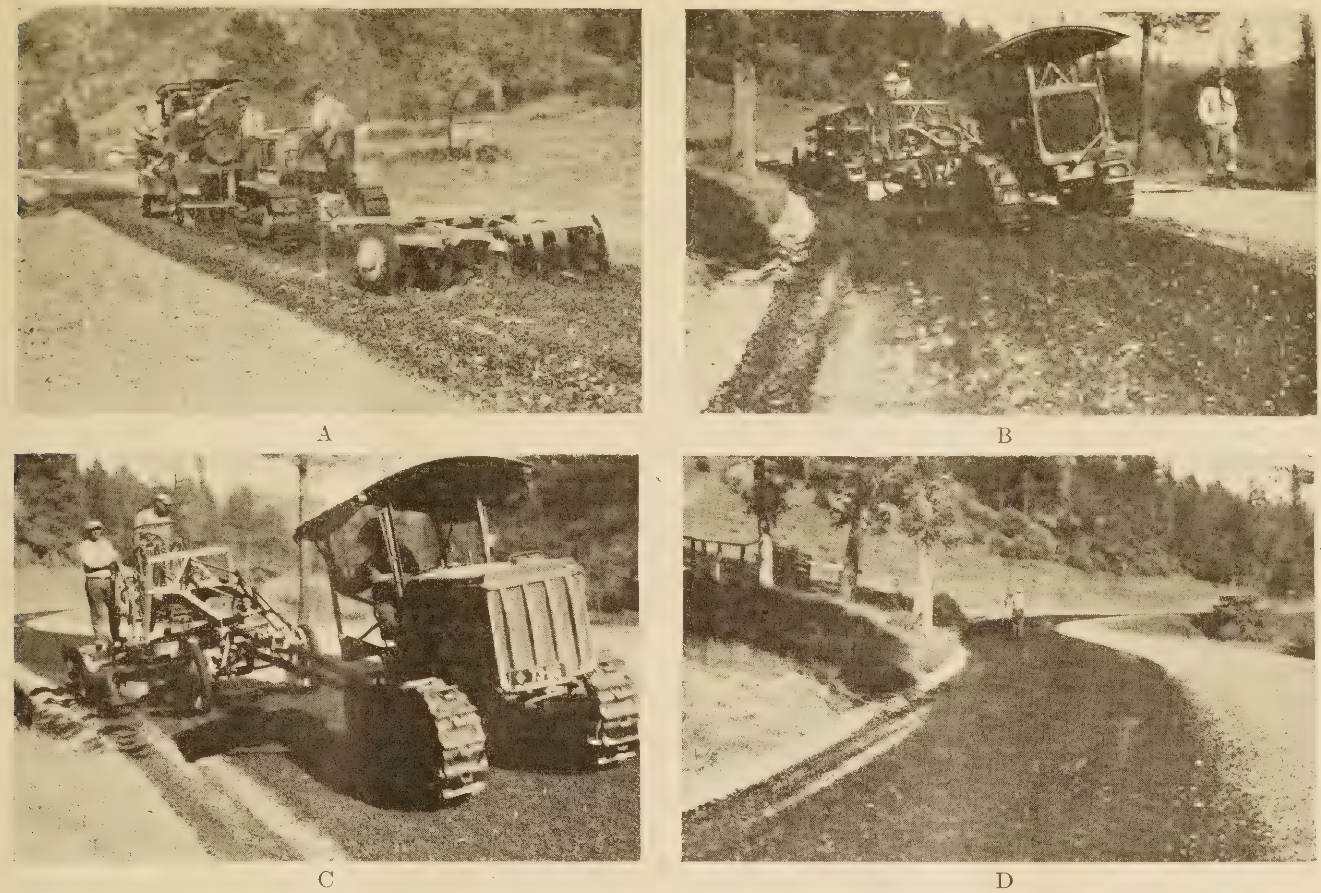


Fig. 29.—Modification of the Mixing Process on the Mariposa-Briceburg Road, Treating Half the Roadway at a Time

A.—Third oil application followed by disking. The material is somewhat coarser than on other projects
B.—Manipulating material with tractor-drawn grader
C.—Final distribution of mixed material
D.—Half of roadway completed and ready for traffic

as in San Bernardino County. According to measurements made in February, 1927, the average thickness is about 2½ inches.

The cost of the work in Imperial County was approximately $1,400 per mile for 20 feet of width. The details are shown in Table 11.

The Imperial Valley sections, when measured for roughness in February, 1927, were found to be even smoother than the Victorville-Barstow Road in San Bernardino County.

The loss of metal on these Imperial Valley sections prior to oiling was very high. (Table 1.) On the Sand Hills-Yuma section, the loss amounted to $1,010 per mile per year. On the others it ranged from $1,726 to $3,097 per mile per year. Consequently the material remaining was inadequate for oiling. In many places there was no metal between the oiled wearing surface and the clay and silt subgrade. Fortunately, however, the subgrade did not become saturated during the winter, and the road was in remarkably good condition in the spring.

On the section between Brawley and Imperial there are a number of places where the clay subgrade has become saturated and the surface rutted. A sample of clay from the subgrade beneath a rut had a lineal shrinkage of 7.7 per cent and a field moisture equivalent of 28.4 per cent, showing it to be unstable and unsuitable for subgrade purposes. The sections showing distress probably represent less than 1½ miles out of the total 9-mile length, and the defects do not interfere with the confortable use of the road. If this section of highway had not been oiled, it could not have carried traffic through the winter of 1926–27. As a result of the expenditure of approximately $1,400 per mile for oil treatment, 80 to 90 per cent of the surface has been saved from destruction, and after five months' use is, from the motorists' standpoint, equal to the highest type of pavement. The cost of oiling was less than the combined cost of maintenance and loss of metal would have been during the same five months under normal conditions. In view of the inadequacy of the metal on the road at time of treatment, it is not to be expected that this section can meet the heavy traffic requirements for an indefinite period without some reconstruction, but from the appearance at the present time it is believed that reconditioning of one-quarter of the mileage will care for the weak places and the remainder will give service for a considerable period.

The series of photographs in Figure 28 illustrate the various steps in the surface-mixing process as usually practiced; those in Figure 29 illustrate a modification of the process employed on the Mariposa-Briceburg Road, where half of the roadway was treated separately.

TESTS OF SURFACE MIXTURES

Analyses of samples taken from surface-mixed roadways show that apparently the amount of "fuel oil" required in a surface mixture is about three-fourths the quantity of asphalt that would be used for the same grading. So long as the correct amount of oil is used, it appears that wide variations in grading may be tolerated. Samples were taken from successful bituminous surfaces produced by the mixing method where the material varied from silt to crushed gravel.

An empirical formula has been developed which is tentatively submitted with the thought that it may be of value in estimating the amount of oil required. It is not applicable to porous or absorbent materials such as cinders or lava but otherwise it appears to give results which are consistent with service obtained from various mixes. The formula is:

$$P = .015a + .03b + .17c$$

in which P is the percentage of oil required, a is the percentage of metal retained on a 10-mesh sieve, b is the percentage of metal passing the 10-mesh and retained on the 200-mesh sieve, and c is the percentage passing the 200-mesh sieve.

The stain test hereafter described, apparently furnishes the only reliable means for determining the amount of oil required for absorbent materials.

Used with nonabsorbent materials, the proportion of oil calculated from the formula has furnished satisfactory stains from many mixtures prepared in the laboratory; but even with such materials the indications of the stain test seem to be a more reliable guide than the formula in case of conflict between the two methods.

Stain test.—Inasmuch as the success of the surface-mixing method depends upon correct gauging of oil requirements and upon uniform mixing, an attempt was made to find a field test which would be of value to those carrying on such work. Resort was had to a modified form of the pat stain test used for many years in the control of sheet asphalt mixtures. This stain test can not be made on samples containing coarse sand or gravel. It is, therefore, necessary to prepare samples for test by removing coarse particles, and it is also necessary that the samples be heated. The stain test as finally developed is described as follows:

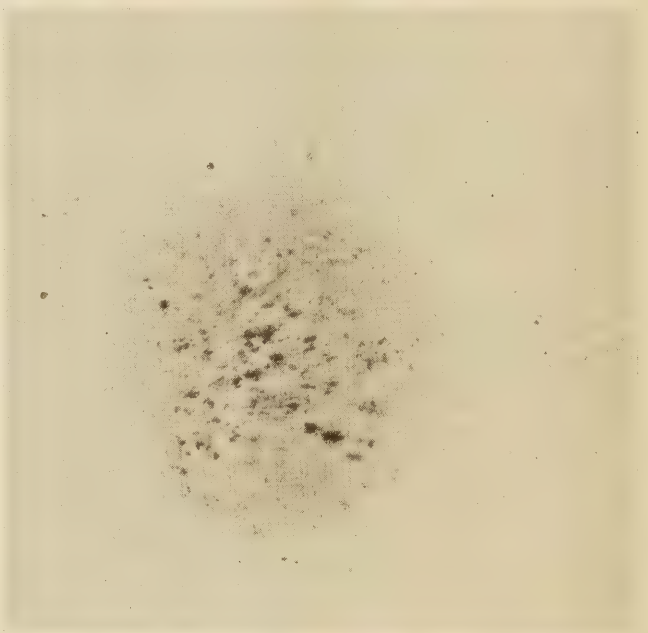
The sample from the roadway is first warmed. The fine material is then separated from the coarse by passing through a 10-mesh sieve. This can be readily accomplished by rubbing gently with the fingers and by loosening the fine particles that adhere to the coarse. The particles which do not pass the 10-mesh sieve may be discarded. The original sample should be of sufficient size to provide about 1 pound of material passing the 10-mesh sieve. This 10-mesh material is heated to approximately the boiling point of water, which may be conveniently accomplished by placing the sample in a fruit jar or can and allowing it to remain partially submerged in the boiling water for a period of about one hour. The heated mixture is then dumped in a pile on the center of a sheet of white typewriter paper and leveled to a thickness of about 1 inch, when another sheet of paper is placed on top. A wooden block 2 inches thick is placed on top of the paper and to this are delivered five blows from a 2-pound hammer, falling freely for a distance of about 1 foot. The two papers are then removed from the asphaltic mixtures and the stain produced indicates the relative amount of oil in the sample.

Satisfactory surface mixtures will 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. A heavy stain indicates the presence of excess oil, which is not only uneconomical but also causes displacement under traffic.

Samples of the completed surface mixture were taken from the sections of treated crushed gravel roads in San Bernardino and Imperial Counties, and also for comparative purposes from oiled earth and sand roads and shoulders in Imperial and Riverside Counties. These samples were subjected to mechanical analysis and to the above-described stain test with interesting and illuminating results. The results of typical tests are shown in Figures 30, 31, and 32.

The asphalt content of the samples taken from the crushed gravel roads in Imperial and San Bernardino Counties ranged from 4.3 to 5 per cent of the total mixture, or from 7.8 to 10 per cent of the sand present (material passing the 10-mesh sieve). The proportion of asphalt to fines in the treated earth and sand roads is also very similar. Examined in the light of the stain tests and the observed behavior, it is apparent that the amount of bitumen required in both the crushed gravel and earth mixtures varies with the grading of the material.

Tests 106, 110, 111, and 113, the results of which are shown in Figure 31, are particularly illuminating. Sample 106 was taken from an oiled earth road in Riverside County. The natural road material in this case was a fine silty soil and the treatment consisted of

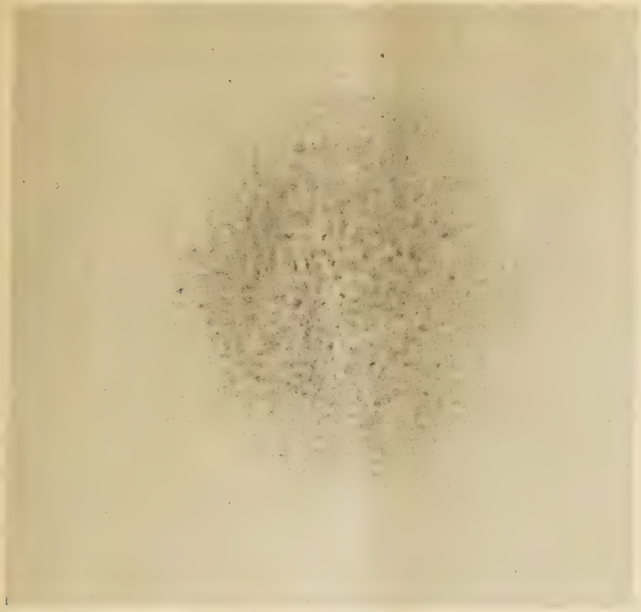


Test No. 107–VIII–Imp.–26–A. Reoiled surface 2 inches thick

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	11.9	200-mesh	25.0
10-mesh	47.5	100-mesh	53.3
3-mesh	62.8	50-mesh	69.9
½-inch	76.7	40-mesh	74.7
¾-inch	88.0	30-mesh	78.6
1-inch	94.6	20-mesh	89.0
1¼-inch	100.0	10-mesh	100.0

Bitumen: 7.8 per cent of total sample; 3.5 per cent theoretical requirement.

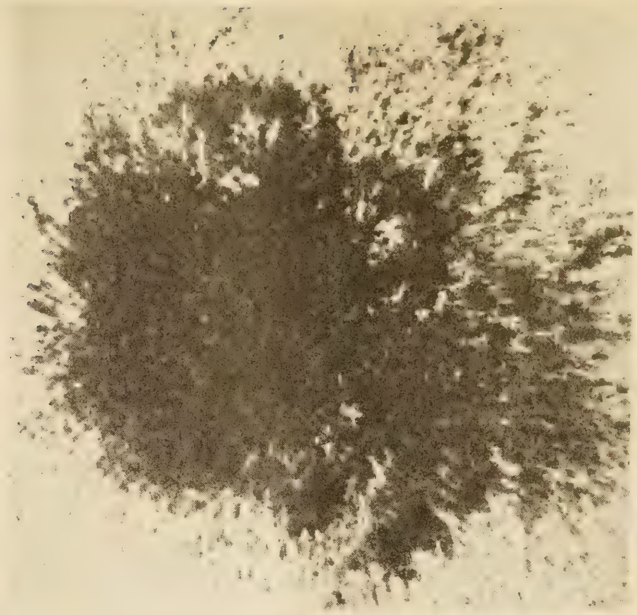
Fig. 30.—Typical Oil Stain



Test No. 110-VIII—Imp.-26-C. Crushed gravel treated by mixing method; bituminous surface, 2½ inches thick

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	11.0	200-mesh	24.0
10-mesh	45.8	100-mesh	38.2
3-mesh	82.4	50-mesh	50.7
½-inch	95.8	40-mesh	56.6
¾-inch	97.5	30-mesh	62.9
1-inch	100.0	20-mesh	74.5
		10-mesh	100.0

Bitumen: 4.6 per cent of total sample; 3.7 per cent theoretical requirement.



Test No. 111-VIII—Imp.-27-B. Oiled blow sand; shoulders adjacent to pavement soft and loose

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	4.6	200-mesh	4.6
10-mesh	97.1	100-mesh	24.0
3-mesh	98.0	50-mesh	50.2
½-inch	100.0	40-mesh	73.3
		30-mesh	88.2
		20-mesh	97.1
		10-mesh	100.0

Bitumen: 12.4 per cent of total sample; 4.1 per cent theoretical requirement.

Test No. 113-VIII—Imp.-12-A. Sand-oil detour road; bituminous treatment, 7½ inches thick

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	4.1	200-mesh	4.9
10-mesh	79.7	100-mesh	8.6
3-mesh	97.9	50-mesh	18.2
½-inch	99.4	40-mesh	26.6
¾-inch	100.0	30-mesh	36.5
		20-mesh	61.0
		10-mesh	100.0

Bitumen: 3.4 per cent of total sample; 3.3 per cent theoretical requirement.

Test No. 106, Coachella Valley-Riverside County. Oiled dirt road (mixing method) treatment about 5 inches thick

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	43.8	200-mesh	43.8
10-mesh	99.8	100-mesh	55.6
3-mesh	100.0	50-mesh	82.2
		40-mesh	89.2
		30-mesh	93.3
		20-mesh	98.1
		10-mesh	100.0

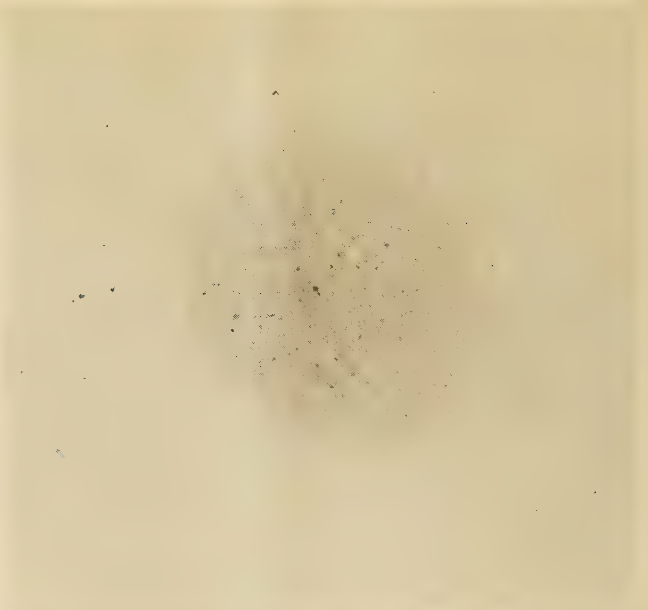
Bitumen: 9.4 per cent of total sample; 9.2 per cent theoretical requirement.

Fig. 31.—Typical Oil Stains

Test No. 112-VIII-Imp.-27-B2. Crushed gravel treated by mixing method; bituminous surface, 3-inch thick, is very hard and smooth

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	11.0	200-mesh	19.7
10-mesh	55.3	100-mesh	44.7
3-mesh	79.5	50-mesh	56.0
½-inch	89.9	40-mesh	63.9
¾-inch	97.9	30-mesh	68.1
1-inch	100.0	20-mesh	78.2
		10-mesh	100.0

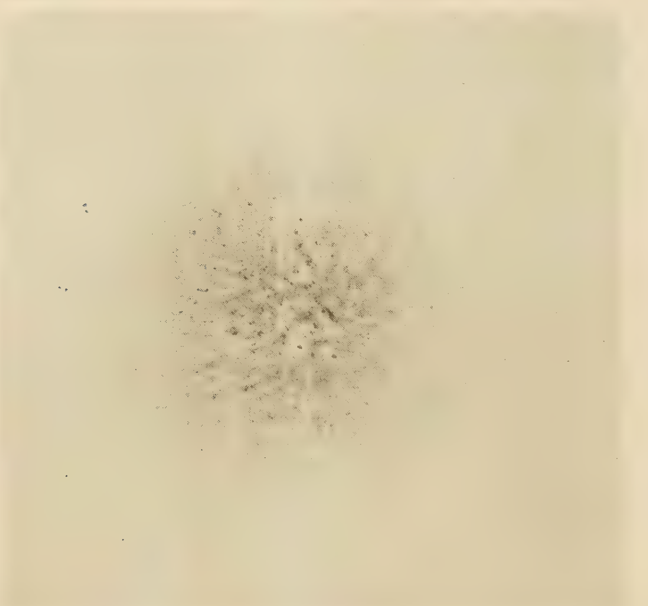
Bitumen: 4.3 per cent of total sample; 3.9 per cent theoretical requirement.



Test No. 108-VIII-Imp.-26-A. Crushed gravel treated by mixing method; bituminous surface, 2½ inches thick

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	12.9	200-mesh	22.6
10-mesh	58.5	100-mesh	41.4
3-mesh	75.9	50-mesh	57.7
½-inch	85.5	40 mesh	64.0
¾-inch	96.5	30-mesh	70.0
1-inch	100.0	20-mesh	81.9
		10-mesh	100.0

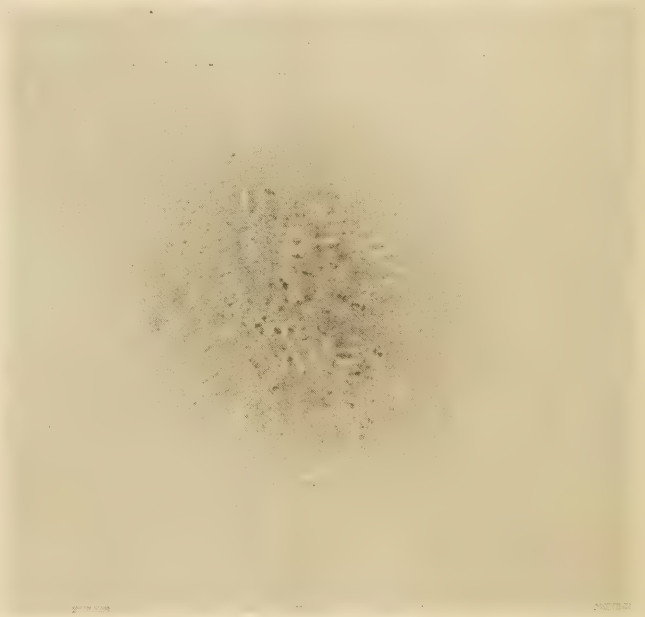
Bitumen: 4.8 per cent of total sample; 4.2 per cent theoretical requirement.



Test No. 101-VIII-S. Bd.-31-D. Crushed gravel treated by mixing method; bituminous surface, 1¾ inches thick

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	13.5	200-mesh	23.6
10-mesh	55.9	100-mesh	40.1
3-mesh	73.5	50-mesh	57.1
½-inch	83.4	40-mesh	64.5
¾-inch	96.4	30-mesh	70.6
1-inch	100.0	20-mesh	82.5
		10-mesh	100.0

Bitumen: 4 per cent of total sample; 4.3 per cent of theoretical requirement.



Test No. 105-VIII-S. Bd.-31-E. Crushed gravel treated by mixing method; bituminous surface, 2¾ inches thick, is hard, tight, and smooth

Grading of total sample		Grading of material finer than 10-mesh	
Size	Per cent passing	Size	Per cent passing
200-mesh	9.1	200-mesh	20.5
10-mesh	49.5	100-mesh	37.5
3-mesh	66.0	50-mesh	55.9
¼-inch	76.7	40-mesh	63.8
¾-inch	93.4	30-mesh	70.0
1-inch	100.0	20-mesh	82.4
		10-mesh	100.0

Bitumen: 3.5 per cent of total sample; 3.5 per cent theoretical requirement.

FIG. 32.—TYPICAL OIL STAINS

mixing 4 gallons of oil per square yard with the earth. The analysis shows a very high percentage of fines and the proportion of oil to sand is 9.4 per cent, which agrees very closely with the 9.2 per cent determined as the theoretical requirement by means of the formula mentioned above. The stain is typical of that produced where the amount of bitumen is just sufficient to coat the particles and to secure the necessary binding.

Test 110 represents material from the oil-treated crushed gravel surface between Brawley and Imperial. The sand in this sample is somewhat coarser than in test 106 and the amount of bitumen required is, therefore, less. A satisfactory stain produced in this case, by oil in the amount of 8.4 per cent of the material passing the 10-mesh sieve, indicates that percentage to be the correct amount of oil.

Test 111 was taken from the oiled sand shoulders adjacent to the pavement on the Sand Hills section between Holtville and Yuma. The analysis shows a very small percentage of dust passing the 200-mesh sieve and a moderate percentage passing the 100-mesh. The amount of oil is about 3 per cent higher than in test 106 and the very heavy stain clearly shows an excess. The suggested remedy would be to add fine material, either dust or sand, in sufficient amount to dry the mix until a normal stain is produced.

Test 113 is from a sample of the oiled sand roadway constructed east of Meyers Creek Bridge in Imperial County. The analysis shows the sand to be much coarser than the other samples; in fact, closely approaching a concrete sand. Fines are almost entirely lacking. A normal stain in this case was produced by 4½ per cent of oil. The road constructed with this material is satisfactory, and an inspection of the road shows that the amount of oil used was entirely sufficient.

In these samples three normal stains were produced with varying amounts of oil and the one extremely heavy stain was due to excess of oil and lack of dust in sand.

Figures 30 and 32 show other typical stains and analyses of samples. All of these samples with the exception of 107 are from surfacing which is giving satisfactory service and which apparently contains about the correct amount of oil. Test 107 was made on a sample of crushed gravel surface which had been reoiled and which appeared to contain more oil than is desirable. The stain corroborates the observations made at the time of the inspection.

SELECTION OF THE METHOD AND OIL FOR TREATMENT

From the foregoing description and analysis of the methods of surface treatment and surface mixing—the two methods of treating crushed rock and gravel roads thus far developed—it is apparent that the selection of one or the other for the treatment of a particular road is a matter requiring the exercise of seasoned judgment.

Method of surface treatment.—The method of surface treatment is adapted to compacted material only. Usually a road is in best condition for treatment after being subjected to traffic for a time. However, new surfacing material, if thoroughly compacted with water and traffic during construction, is very satisfactory. Being somewhat porous, such new material absorbs oil readily.

An old road containing considerable coarse material, if it can be repaired well in advance, is well adapted to surface treatment because the large stones are well anchored.

Method of surface mixing.—This treatment is adapted to any crushed rock or gravel road which is in need of the addition of considerable new material to restore its thickness, or which, because of lack of binder or climatic condition, is not tightly bound.

The surface-mixing method is the only one that is adapted to the treatment of a loose surface; but in the use of this method, as in surface treatment, the base course should be thoroughly compacted. The presence of material larger than 1 inch presents mechanical difficulties.

Where traffic can not be kept off the road during the time required for absorption of oil applied by the surface treatment method, the surface-mixing method is especially attractive. If the oil be partially mixed with the metal immediately after application, traffic can pass through without difficulty. The loose surface encourages slow driving, whereas the firm surface always present in the other type of treatment tempts rapid driving and the consequent spattering of oil on vehicles.

Many existing projects have lost so much material that renewal is required before treatment. If enough remains for a base, it may be repaired and shaped, covered with approximately 2 inches of material passing a three-fourths or 1-inch circular opening, and treated by the mixing process immediately.

Either type.—A well compacted, fine crushed rock or gravel surface of adequate thickness may be treated successfully by either method. Choice depends upon relative service and life, about which there is no definite information. The mixing treatment will cost more than the surface treatment, and, therefore, must show a correspondingly longer life or lower maintenance to justify its use. The surface treatment, if not thoroughly successful, can later be converted into a mixed treatment, with a final cost not greatly exceeding that of an original mixed treatment.

Emergency treatment.—A problem frequently arises with the discovery that untreated material is being dissipated so rapidly that a few months' delay will bring complete failure. Usually a large proportion of the original material has already been lost. If restoration to full original thickness or substitution of a heavier type of surfacing can not be done immediately, it may be expedient to oil the metal remaining to prevent its complete destruction. Some failures may be expected but can not reasonably be charged to the treatment.

OIL FOR SURFACE TREATMENTS AND SURFACE MIXING

In the treatments of crushed rock and gravel roads described in this report the bituminous binder has usually consisted of the material known locally on the Pacific coast as "fuel oil," or the lightest grades of "road oil." Both are asphaltic base products.

The material sold as "fuel oil" has an asphaltic content up to about 70 per cent and a viscosity, Saybolt-Furol, up to 300 at 122° F. The term "road oil" has been applied to oil residuum having an asphaltic content of 70 to 98 per cent, being thus distinguished from the heavier residuums which are usually termed "asphalts" of E or D grade.

Asphalt content in this connection and as used in this report is the percentage of residue having a penetration of 80 at 77° F. as "fuel oils" have usually been specified by specific gravity in degrees Baumé, or by viscosity rather than by asphalt content.

"Fuel oils" are considerably cheaper than "road oils" or "asphalt," and they are especially appropriate for most of the work that has been described because they penetrate readily and have the advantage of being much more easily reworked than the heavier materials.

"E" grade asphalt and the 90 to 95 per cent road oils have been very extensively used in the Western States in bituminous macadam work and to a more limited extent in surface-treatment work. Some of the cities and counties of California have secured very satisfactory results by building a well-bound coarse rock macadam the surface of which has been thoroughly broomed, then covered with road oil and screenings. Somewhat similar treatments have been widely used by various highway departments. Los Angeles, Orange, Monterey, San Joaquin, San Benito, Santa Cruz, San Bernardino, and other California counties have used large quantities of road oils in surface and penetration treatments with marked success. This report, however, is devoted to the use of "fuel oil" or the lightest grades of "road oil." "Fuel oils" are considerably cheaper than the "road oils" or asphalt, penetrate readily, and are more easily reworked.

Viscosity may vary widely independently of asphaltic content, which permits selection of various grades for special uses while specifying a single range of asphalt content, as 60 to 70 per cent. Maximum penetration can be secured by using oil of low viscosity. For mixed treatments medium viscosity appears desirable, because the oils with high viscosity are harder to handle and more difficult to mix with road metal. In surface-treatment work where chips are to be used in quantity high viscosity is desirable.

Probable rainfall is another consideration affecting the selection of oil. The lightest oil shows a tendency to wash out of the road during long-continued wet weather. In many instances good results have been secured by applying light oil as a first treatment, followed, after this treatment has penetrated, by an application of heavy oil and screenings. In all of these matters viscosity is an important characteristic.

All of the grades of "fuel oil" used in bituminous treatment are more uniformly distributed if heated to 150° F. or 200° F. The oil is usually heated with steam at the time it is unloaded from the car.

Following is a suggested specification which has been used by the California Highway Commission for the purchase of oil for 1927 operations. It provides "fuel oil" of three grades adaptable for use as outlined above. These specifications have been discussed with representatives of the large producers of California oil and are believed to exclude any unnecessary requirements which would be reflected in higher costs.

SPECIFICATIONS FOR FUEL OIL FOR USE IN BITUMINOUS TREATMENTS

Oil furnished under these specifications shall be made from an asphaltic-base oil. It shall be either a naturally homogenous oil or a homogenous residue from oil. It shall not have been distilled at a temperature high enough to injure by burning or to produce flecks of carbonaceous matter. It shall meet the following requirements:

Flash point.—The flash point by the Pensky-Martens closed-tester method shall not be lower than 175° F.

Viscosity.—Oil shall be classified as to viscosity in three grades as follows:

Light fuel oil shall have specific viscosity (Engler) at 122° F. of not less than 10 nor more than 25.

Medium fuel oil shall have a specific viscosity (Engler) at 122° F. of not less than 25 nor more than 45.

Heavy fuel oil shall have a specific viscosity (Engler) at 122° F. of not less than 45 nor more than 80.

Water and sediment.—Water and sediment combined shall not exceed 2 per cent.

Asphalt content.—Fuel oil shall contain not less than 60 per cent nor more than 70 per cent of asphaltic residue having a penetration of 80 at 77° F.

Test methods.—Except as hereinafter specified, all tests of fuel oils shall be made in accordance with standards of the American Society for Testing Materials applicable thereto, with amendments and revisions thereof adopted by said society. The following special test requirements are noted for viscosity and asphalt determinations:

VISCOSITY

Specific viscosity (Engler) shall be determined on a 50-cubic centimeter sample in the manner described in United States Department of Agriculture Bulletin No. 1216, page 59. The determination of viscosity may also be made, at the option of the producer, in accordance with the A. S. T. M. viscosity test D 88–26, using the Saybolt-Furol viscosimeter at a temperature of 122° F., in which case the Saybolt-Furol time shall be not less than 35 nor more than 90 seconds for the light fuel oil; not less than 90 nor more than 160 seconds for medium fuel oil; and not less than 160 nor more than 280 seconds for heavy fuel oil.

ASPHALT CONTENT

Asphalt content shall be determined by open evaporation using the A. S. T. M. tentative method D 243–26 T, the open-cup vapor-bath method as used in the laboratory of the California Highway Commission, or the Brown evaporator.

TREATMENT OF EARTH ROADS WITH OIL

The earliest oil treatment in California consisted of the application of crude asphaltic oil, approximately a gallon per square yard, to the surface of a dirt road. The oil was allowed to penetrate at will or dirt was thrown on top. This was virtually a surface treatment and generally proved inadequate except for very light traffic or where the subgrade was unusually firm. The next development was the reworking of the thin mat, adding more oil and stirring to a greater depth. This was the crude beginning of the mixing treatment. The process was repeated in later years until some of the roads first treated had a surface 6 inches or more in thickness.

Paralleling the stage development, some of the counties have in the first operation deliberately built an oiled earth surface from 4 to 8 inches in thickness.

The success or failure of these oiled earth roads depends largely upon the character of the material. Sandy, gravelly, or even silty soils have produced serviceable roads in most instances where properly treated and maintained. Heavy clays or alkali soils have been similarly treated but the results have been almost universally unsatisfactory. These clays are inherently unstable, have high moisture-carrying capacity, and are constantly changing in volume. Uniformity of soil from point to point on the project is highly desirable, but experienced workmen will overcome considerable irregularity of soil by varying the quantity of oil and the details of treatment.

Under California conditions the cost of treating an earth road 18 feet wide to a depth of 6 inches will approximate $3,000 or $3,500 per mile. The cost of a treatment 1 to 2 inches in depth, where conditions make such a light treatment satisfatory, is $200 to $500 per mile. Where the full depth of 6 inches or more is attained by progressive steps, the $3,000 cost will perhaps be reached in 8 or 10 years or more, this including the cost of maintenance during that period.

Heretofore the amount of oil for a given depth of treatment has been judged by the appearance of the product. The amount required depends, of course, upon the grading of material and probably follows the rules applicable to satisfactory sheet asphalt or asphaltic concrete, excepting that the lighter oil used in soil treatment covers the particles with a thinner film than the ordinary paving grades of asphalt. The amount of oil required is about one-fourth less than the amount of asphalt needed for the same grading. Samples show an oil content ranging from 4.5 to 10 per cent based upon the material passing a 10-mesh sieve. Reference is made to the discussion of the tests of surface-mixed material for more detailed information and suggestion as to the proportion of oil, and particularly to Figure 31.

This type of treatment is adapted to roads carrying less than 500 vehicles per day where soil conditions are suitable and particularly in arid or semiarid climates. The economy of omitting expensive road metal is obvious, and that possibility should always be considered. The oiled sand road in the Amargosa Desert in Nevada is typical. Here graveling was attempted and abandoned because of construction difficulties. The natural sand road was then oil treated and the surface obtained is as satisfactory as if the road had first been metaled.

Maintenance is a simple operation with blade and drag. Riding qualities are unexcelled and there is, of course, no dust. When reworking is required, a tractor, scarifier, and heavy blade grader must be available.

The examples and methods described hereafter are regarded as typical of oiled earth construction under somewhat varying conditions.

OILED SAND ROADS IN STANISLAUS COUNTY

Oiled earth roads have been successfully constructed in Stanislaus County, Calif., for about 18 years. The soil in this area is fine sand and sandy silt. Without treatment the roads are extremely dusty and loose during the summer season.

The Turlock-Snelling road, extending east from Turlock for a distance of about 3 miles, is a typical example of this construction. The surfacing has a width of about 20 feet and a depth of 6 to 7 inches. The material is plastic under a hammer and more or less rubbery. The contour is smooth, and some gravel is visible which has probably been placed during maintenance. In a number of places fine surface cracks were noted during an inspection in July, 1926, but examination showed these to be only one-eighth to one-quarter inch in depth through a thin hard crust which covered the softer plastic material beneath. The asphaltic oil in a sample cut from the road was alive and tacky. An analysis of this sample gave the following results:

	Per cent
Passing ½-inch screen	98. 7
Passing 10-mesh sieve	98. 5

The material passing the 10-mesh sieve was considerably finer than an ordinary sheet asphaltic mixture and the amount of silt slightly more than the dust filler in such a sheet asphaltic mix. It had the following grading:

	Per cent
Passing 10-mesh sieve	100. 0
Passing 20-mesh sieve	99. 9
Passing 30-mesh sieve	97. 4
Passing 40-mesh sieve	93. 1
Passing 50-mesh sieve	84. 1
Passing 100-mesh sieve	47. 1
Passing 200-mesh sieve	23. 8
Bituminous material	7. 9

The following statement regarding the construction of this highway is abstracted from a report by A. J. Leedom, county superintendent, who has been in charge of construction. The natural soil was graded to a flat section about 26 feet in width with very little crown, was loosened on top, and from 5 to 6 gallons of oil per square yard were spread in two equal applications. The first application covered a width of about 20 feet, and immediately the entire surface was plowed, starting at the edges and throwing furrows out, finally leaving a dead furrow in the center. This gave a roadway width of about 22 feet. The plowing was generally to a depth of about 6 inches. The road was then harrowed, winding back and forth in order to break up the furrows and thoroughly mix the oil and earth. The second application of oil was spread, with more at the edges than in the center to prevent excessive concentration of oil at the center after the next operation. The entire surface was then replowed, throwing furrows to the center and bringing the road to a uniform section, harrowed as before, and finished with a steel drag, 7 or 8 feet long and weighing about 600 pounds.

The bituminous material was California asphaltic oil residuum containing about 65 per cent of 80-penetration asphalt, and was applied from a gravity spreader at a temperature somewhat less than 200° F.

The Turlock-Snelling road is about 3 miles in length and has been in service for 17 years. The traffic was undoubtedly light during the early years, but has now grown to approximately 500 vehicles per day, and the maintenance cost is reported to be less than $100 per mile per year. The original cost of the work by county labor was about $3,500 per mile.

Fig. 33.—Typical Section of the Turlock-Snelling Road. The Sandy Soil Is Probably Responsible for the Success of the Road in Spite of Lack of Drainage

Roughometer readings on the surface thus produced show a smoothness about equal to average asphaltic macadam. It is entirely dustless and to the casual observer might easily pass for a higher type of bituminous construction. The low construction cost and extremely low maintenance combine to give an annual service charge among the lowest for improved roadway investigated in this study. Several other sections of roadway in this locality constructed by the same methods and varying in age from 1 to 12 years, where sufficiently wide to keep traffic from breaking the edges, were found to be uniformly satisfactory. Some of the older roads, oiled to a width of 12 feet, had ragged edges and somewhat irregular surfaces. A photograph of such a road is shown in Figure 33.

OILED EARTH ROADS IN RIVERSIDE COUNTY

Riverside County, Calif., constructed several experimental sections of oiled earth roads during the years 1924, 1925, and 1926, similar to the earlier work in Stanislaus County. Twelve and one-half miles was in the irrigated section of the Coachella Valley, where the soil is fine sandy silt, the climate extremely dry, and the roads almost impassable during the crop-hauling season.

The earlier projects were treated with 4 gallons of oil having a 60 per cent asphaltic content (80 penetration). The viscosity is not known, but the oil was fluid at temperatures of 100° to 150° F. The oil was spread in applications of 1 gallon per square yard, in widths of 6 and 8 feet, the finished width of roadway being 14 feet. Distribution was accomplished by a truck equipped with pressure sprays, towed through the loose soil by a 5-ton track-type tractor. Two sets of four-gang disks followed the spreader and mixed the oil with the earth. This operation was repeated through four applications of 1 gallon each and the oil was mixed with the earth to a depth of about 5 inches. In the later projects the oil was increased to 5 gallons and cultivated to a depth of 6 inches. After cultivation, the surface was smoothed with a grader and rolled with a 10-ton power roller. In some instances the roads were opened to traffic before rolling. William S. Conner, the engineer in charge of this work, expresses the opinion that extensive rolling is unnecessary and that consolidation can best be obtained by permitting traffic to use the road, provided it is kept smooth by drags.

The surface resulting from this treatment was practically identical with that in Stanislaus County where soil conditions were similar. On the Ripley-Blythe Road, where the soil contained a considerable percentage of clay, 4 gallons of oil did not produce uniformly satisfactory results, and the surface remained more or less unstable.

The Riverside County work is too recent to be interesting from a service standpoint, but is valuable because of the excellent cost data furnished by Mr. Conner. Table 12 shows the average cost to be practically $3,000 per mile exclusive of clearing and grading.

During an inspection in February, 1927, it was found that several sections had been resurfaced with about 1 inch of crushed stone, treated with 90 to 95 per cent road oil, and covered with chips. Sections not metaled are carrying traffic satisfactorily although they do not have the appearance of being maintained.

OILED SAND ROADS IN SAN BERNARDINO COUNTY

J. S. Bright, construction engineer, Bureau of Public Roads, gives data regarding the oiling of desert roads under his direction as county highway engineer of San Bernardino County in 1916. The natural road material in this case was sand. Intermittent sections of the Barstow-Needles road, aggregating about 40 miles, were treated to a width of 8 feet with 2½ gallons per square yard of oil having an asphalt content of 60 per cent. The road received very little attention until taken over by the State highway commission in 1924. Traffic, which at first amounted to 100 or more vehicles daily, has since increased to about 400 and the surface has been practically destroyed in many places.

One section, extending from Amboy easterly for about 15 miles, received 4 to 4½ gallons of oil per square yard on a width of 10 feet. The resulting surface was 5 to 6 inches in depth and is still in fair condition, although it received practically no maintenance for the first eight years. The natural material is a gravelly sand considerably coarser than that treated in Riverside and Stanislaus Counties. Samples were removed for test in February, 1927, and the oil was found to be alive and sticky. It was found that 30.9 per cent of the total was retained on the 10-mesh sieve and consisted of coarse sand, mostly less than one-fourth inch in diameter. The portion passing the 10-mesh sieve was graded as follows:

	Per cent
Passing 10-mesh sieve	100. 0
Passing 20-mesh sieve	71. 6
Passing 30-mesh sieve	42. 5
Passing 40-mesh sieve	37. 0
Passing 50-mesh sieve	31. 6
Passing 100-mesh sieve	22. 4
Passing 200-mesh sieve	11. 0
Bituminous material	8. 1

TABLE 12.—*Costs per mile of 14-foot oiled earth road in Riverside County, Calif.*

Item	1924–1925 treatments			1925–1926 treatments					
	Ripley-Blythe Road	Avenue 62	Average	Morgan-Ickes Road	Avenue 58 and Monroe Street	Avenue 57 and Pierce Street	Jackson Street	Avenue 66	Average
Length ... miles	8.13	2.00	...	1.51	2.00	1.00	2.00	4.00	...
Oil ... gallons per square yard	3.83	3.95	3.85	5.19	4.92	4.92	4.92	4.92	4.96
Average haul of oil ... miles	2.4	7.0	3.3	8.0	7.0	2.25	4.5	10.0	7.36
Labor:									
Clearing and grading	$234.10	$285.05	$244.16	$671.44	$351.85	$415.59	$353.53	$421.43	$430.64
Watering subgrade	141.88	226.08	158.51	72.85	131.12	...	100.27	100.22	92.64
Hauling and spreading oil	359.17	501.30	387.22	602.81	573.38	368.60	434.55	421.50	473.85
Cultivating	122.69	132.06	124.54	82.99	82.13	92.50	142.41	73.15	91.29
Rolling	47.00	64.25	50.41	88.49	61.65	80.88	43.40	25.46	50.89
Dragging	36.82	...	29.55	2.65	44.15	7.86	2.58	14.28	25.35
Maintaining detour and miscellaneous	21.05	32.29	23.27	244.51	56.11	35.47	19.38	72.02	70.38
Supervision	55.72	94.45	63.31	242.82	79.86	69.55	48.19	45.50	83.19
Total (excluding grading and clearing)	784.33	1,050.43	836.87	1,337.12	1,028.40	654.76	790.78	752.03	886.80
Materials:									
Oil	1,190.18	1,255.31	1,203.04	1,526.99	1,443.93	1,443.93	1,443.93	1,443.95	1,455.87
Freight	996.24	523.43	902.89	714.02	675.18	675.18	675.18	706.44	692.66
Miscellaneous	15.78	13.44	15.32	49.67	27.23	65.00	27.50	...	23.74
Total	2,202.20	1,792.18	2,121.25	2,290.68	2,146.34	2,184.11	2,146.61	2,150.39	2,172.26
Grand total cost	3,220.63	3,127.66	3,202.28	4,299.24	3,526.59	3,254.46	3,290.92	3,323.85	3,489.70

The condition of the Amboy section after 11 years of rather heavy service almost without attention indicates that similar construction of adequate width, properly maintained, would carry traffic very satisfactorily over the desert sections. The cost of such treatment would probably be about the same as reported in Riverside County.

OILED-SAND SURFACE ON NEVADA STATE HIGHWAY

A 10-mile section of the Las Vegas-Beatty road in the Amargosa Desert in Nevada is a recent example of oiled-sand construction. This section of highway, designated as Nevada Federal Aid Project 46, belongs to the same general type as the Amboy section in San Bernardino County, Calif. The difficulties encountered were extreme and unusual. The shifting sand was almost impassable for motor traffic prior to the improvement, and during construction the trucks could not travel through the sand without the assistance of tractors.

Late in 1922 bids were requested for the construction of gravel surfacing. Only one was received and that, being 84 per cent higher than the engineers' estimate, was rejected. In January, 1923, the State highway department undertook the work by day labor and opened a gravel pit near the middle of the 10-mile project. Because of the isolation of the job, the extremely hot weather, and transportation difficulties the work was discontinued after five months with but 2 miles partially constructed. The cost of gravel being prohibitive, early in 1924 the department undertook to mix asphaltic oil with the natural soil to a depth of approximately 6 inches. The oil used for mixing purposes had an asphalt content of 61 to 64.5 per cent of 80-penetration. The roadway was to be trenched to a depth of approximately 6 inches, and the material removed from the trench was piled along the shoulders to be used for covering the oil. Shortly after beginning work the depth of trenching was modified to approximately 3 inches, as the casting of sand upon the oil was found unnecessary and uneconomical except in small quantities.

After the first application of oil upon the prepared subgrade the roadway was cultivated with a double-action disk harrow. A second application of oil followed and was partially covered with sand from the shoulders to prevent the oil from collecting in large pools. Disking was resumed, followed by a large road grader which moved the oiled material into a windrow first on one side of the road and then on the other, and finally leveled it for the third application. The grader was the most effective implement used for mixing. This procedure was repeated until the required amount of oil had been applied and mixed. On most of the project four applications were spread. Table 13 shows data regarding amounts of oil used and number of treatments.

When the surface became uniform in appearance, it was shaped with the grader to a crown approximating 2 inches and compacted with a sheeps-foot roller. For the final smoothing, a drag 10 feet wide by 20 feet long was used in conjunction with an ordinary roller 3 feet in diameter having a weight of approximately 175 pounds per inch of width.

After the mixing was completed and the surface compacted, part of the project was covered with road oil containing 85 per cent of asphalt (80 penetration). This treatment, as shown in Table 13, was varied according to the condition of the surface, one section receiving the maximum of 1.30 gallons per square yard.

The plans called for a roadway 10 feet in width with 18 turnouts. Actually the width averages 12 feet because of a general squeezing outward during construction and under traffic before the mixture hardened.

The cost, shown in Table 14, averaged practically $5,000 per mile, or $0.82 per square yard. This is above normal because of the remoteness of the work. Oil was shipped from Los Angeles in tank cars, and was hauled an average of 19 miles from the railroad in distributor trucks having a capacity of 600 to 800 gallons. The work was carried on during extremely hot weather, so hot, in fact, that the light oil required no artificial heating.

The 2-mile section which had previously been graveled received the same treatment as the desert sand, except that the amount of oil was cut approximately in half and the thickness of the oil mixture proportionately reduced.

Two years after completion the surface was examined for width and thickness, and six samples were analyzed. The results are shown in Table 15. The oil content ranged from 6.40 to 8.47 per cent, averaging 7.40 per cent. The sand grading resembles that of sheet asphalt.

TABLE 13.—*Distribution of oil on Nevada Federal-aid project No. 46—an oiled-sand road*

Station to station	Length	Area of surface [1]	Quantity of oil applied: Total	Quantity of oil applied: Per square yard	Number of applications: 61–64.5 per cent asphalt	Number of applications: 85 per cent asphalt	Total quantity applied: 61–64.5 per cent asphalt	Total quantity applied: 85 per cent asphalt	Kind of material in roadbed
	Feet	*Sq. yds.*	*Gals.*	*Gals.*			*Gals. per sq. yd.*	*Gals. per sq. yd.*	
765+00- 794+50	2, 950	3, 278	15, 805	4. 82	4	1	4. 15	0. 67	Sand.
794+50- 812+00	1, 750	1, 944	11, 098	5. 71	4	2	4. 41	1. 30	Do.
860+00- 878+00	1, 800	2, 000	9, 603	4. 80	4	1	4. 12	. 68	Do.
878+00- 916+00	3, 800	4, 222	18, 291	4. 33	4	----	4. 33	------	Do.
916+00- 930+00	1, 400	1, 556	7, 223	4. 64	4	1	4. 11	. 53	Do.
930+00- 935+35	535	594	3, 411	5. 74	5	----	5. 74	------	Do.
935+35- 941+45	610	678	3, 000	4. 42	4	----	4. 42	------	Do.
941+45- 973+00	3, 155	3, 506	11, 800	3. 37	3	----	3. 37	------	Do.
973+00-1022+10	4, 910	5, 455	22, 412	4. 11	3	1	3. 50	. 61	Do.
1022+10-1040+00	1, 790	1, 989	9, 830	4. 94	4	1	4. 25	. 69	Do.
1040+00-1050+00	1, 000	1, 111	4, 396	3. 96	3	1	3. 27	. 69	Do.
1050+00-1081+90	3, 190	3, 544	15, 540	4. 38	3	1	3. 65	. 73	Gravel.
1081+90-1085+88	398	442	1, 536	3. 47	2	1	2. 59	. 88	Do.
1085+88-1087+80	192	213	479	2. 25	1	1	1. 47	. 78	Do.
1087+80-1122+00	3, 420	3, 800	15, 589	4. 10	3	1	3. 31	. 79	Do.
1122+00-1123+00	100	111	85	. 77	----	1	------	. 77	Do.
1123+00-1127+00	400	444	1, 741	3. 92	3	1	3. 15	. 77	Do.
1127+00-1210+00	8, 300	9, 222	13, 701	1. 48	1	1	. 64	. 84	Do.
1210+00-1227+00	1, 700	1, 889	2, 807	1. 49	1	1	. 48	1. 01	Sand.
1227+00-1235+35	835	928	1, 863	2. 01	2	1	1. 18	. 83	Do.
1235+35-1240+00	465	516	865	1. 68	1	1	. 87	. 81	Do.
1240+00-1284+20	4, 420	4, 911	29, 593	6. 02	5	1	5. 41	. 61	Do.
1284+20-1297+46	1, 326	1, 473	6, 589	4. 47	4	1	4. 01	. 46	Do.
1297+46-1312+00	1, 454	1, 616	9, 454	5. 85	5	1	5. 39	. 46	Do.
1312+00-1343+24	3, 124	3, 417	16, 914	4. 96	5	----	4. 96	------	Do.
Total	53, 024	58, 913	233, 625	------	----	----	------	------	
Average	------	------	-------	3. 97	----	----	3. 39	. 58	

[1] Surface assumed to be 10 feet wide. Actual width greater, due to turnouts and spreading of soft material under traffic.

TABLE 14.—*Summary of cost of Nevada Federal-aid project No. 46—an oiled sand road.*

Item	Cost per mile: Labor	Cost per mile: Equipment and supplies	Cost per mile: Total
Preparing subgrade	$25. 19	$65. 00	$90. 19
Trenching for surface	93. 85	162. 00	255. 85
Applying oil	829. 92	1, 406. 00	2, 235. 92
Oil	---------	1, 788. 39	1, 788. 39
Applying sand and cultivating	257. 16	180. 70	437. 86
Dragging and final shaping	90. 21	86. 70	176. 91
Signs	---------	10. 46	10. 46
Total	1, 296. 33	3, 699. 25	4, 995. 58
Cost per square yard (6,100 square yards per mile)	---------	---------	. 82

TABLE 15.—*Analysis of samples from Nevada Federal-aid project No. 46—an oiled-sand road*

[Samples taken in June, 1926, two years after construction]

Station	Dimensions of section: Width	Dimensions of section: Depth	Quantity of oil applied (gallons per square yard)	Fraction of aggregate passing various sieves (per cent): 10-mesh	14-mesh	20-mesh	30-mesh	40-mesh	50-mesh	80-mesh	100-mesh	200-mesh	Oil content (per cent)
	Ft.	*Ins.*											
770	12. 0	5. 75	4. 82	95. 8	95. 3	94. 8	90. 9	82. 5	69. 7	45. 7	27. 3	8. 9	8. 47
800	13. 0	5. 05	5. 71	98. 3	97. 9	97. 5	94. 4	84. 3	67. 9	43. 7	25. 4	7. 8	7. 27
900	11. 5	7. 05	4. 33	90. 9	89. 7	88. 8	85. 1	75. 8	63. 9	43. 6	26. 9	8. 5	6. 40
950	11. 0	3. 65	3. 39	92. 5	90. 7	88. 8	84. 5	75. 2	62. 2	44. 6	29. 8	11. 2	8. 20
1045	12. 5	4. 60	3. 40	93. 0	91. 5	89. 9	84. 8	76. 3	66. 7	49. 6	34. 9	15. 5	7. 32
1250	12. 0	6. 45	6. 02	87. 3	86. 2	85. 1	83. 4	75. 4	63. 8	42. 2	25. 0	6. 7	6. 73
Mean	12. 0	5. 42	4. 61	91. 3	----	----	----	78. 2	----	44. 9	28. 2	9. 8	[1]7.40

[1] Equals 8.1 per cent of aggregate passing 10-mesh sieve.

The roadway produced meets traffic requirements. It is smooth, and with moderate maintenance, will probably be durable. It is not as dustless as anticipated, because a film of sand has been kept on the surface to absorb surplus oil. Evidently the heavy oil last applied has furnished unnecessary richness at the surface. Evidence is lacking that it added to the quality of the work.

EMERGENCY OILED SAND ROAD IN IMPERIAL COUNTY

In December, 1926, a heavy flood destroyed nearly 2 miles of concrete pavement on the San Diego-El Centro road about 30 miles west of El Centro, Calif. The damaged road was paralleled by a broad expanse of sand in the Myers Canyon Wash, a strip of which was promptly oiled to serve as a detour pending reconstruction. Nominally 5 gallons per square yard of 60 to 70 per cent "fuel oil" was spread, but tests indicate that the actual rate of application was somewhat less than 4 gallons per square yard; the excess having been used to attain extra width. The oil was mixed with the sand by cultivation and grading to a depth of about 7½ inches. By the end of January, 1927, the surface had attained a fair degree of consolidation. On February 22 the center was supporting heavily loaded trucks and ordinary automobiles were running over the detour at 40 miles an hour. The edges, subjected to comparatively little traffic, were still soft.

A sample was taken on February 13 for test. All material passed the three-quarter-inch screen, 97.9 per cent passed the No. 3 screen, and 79.7 per cent passed the No. 10 sieve. The 10-mesh material had the following grading:

	Per cent
Passing 10-mesh sieve	100. 0
Passing 20-mesh sieve	61. 0
Passing 30-mesh sieve	36. 5
Passing 40-mesh sieve	26. 6
Passing 50-mesh sieve	18. 2
Passing 100-mesh sieve	8. 6
Passing 200-mesh sieve	4. 9

The oil content was 3.6 per cent of the total, or 4.5 per cent of the 10-mesh material.

The sand in this temporary road is coarser than any other treated soil described. The amount of silt and clay is negligible. The oil content is low, but the appearance of the road shows that ample was used.

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