Seal Coats: Laboratory Contributions Toward Better Performance

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Success or failure of a seal coat can often be traced to lack of control of material and condition of the equipment. Field tests are needed to enable the engineer to have more positive means for evaluating the actual quality of the work as it is performed. This paper discusses in detail a method for checking the uniformity of the transverse and longitudinal spread rates of the asphalt distributor.

Additional studies and experiments relating to seal coats are described, such as variation in temperatures of the bituminous binder from the time it comes in contact with the pavement to the time of rolling the screenings, degradation of screenings due to rolling and traffic, seasonal effect on performance of seal coats and permeability of pavements. The use of atmometers for determining drying conditions and setting time of the bituminous binder, particularly asphaltic emulsions, was investigated. The possible use of a simple centrifugal test which can be performed in the field to predict the adherence of screenings is discussed. This test should provide the engineer with some evidence as to a proper waiting time before opening the newly placed seal coat to traffic.

●SEAL COATS or light surface treatments in one form or another and for various purposes have been placed for many years in the conventional ways without any particular effort having been exerted to obtain better performance through more scientific control or test methods. Specifications are in many cases rather loose, leaving construction details to the judgment of the engineer, and the success or failure of the job frequently can be directly related to the experience of the field engineer.

The expanded program of highway construction makes it mandatory that the more experienced engineers be assigned to the multimillion dollar freeway projects. This leaves the relatively small and often considered unimportant seal coat jobs to the less experienced engineers. The young engineer may be very conscientious and eager to learn but even a job as lowly as a seal coat requires considerable "know how" to be successful.

As pointed out in the "Symposium on Surface Treatments" (1), "What seems to be needed is to bring the work of the testing laboratory closer to the field . . . and removing the need for guesswork on the part of those less experienced." It is hoped that this group especially will benefit from development of new tests and procedures.

Many of the staff of the California Division of Highways have long been aware of the need for improvement and more scientific methods in seal coat construction. Laboratory studies and field investigations have been conducted over a period of about ten years and a report outlining some of the factors involved in the design of seal coats was published in 1949 (2). The solving of many of these problems has not proved to be easy and a comprehensive study of all the variables involved could easily embrace a considerable number of separate investigations. The more pertinent points which affect the performance of seal coats and which warrant study and investigation in the laboratory as well as in the field are outlined in Appendix A.

It might be well to mention that the term "seal coat" as used in this paper denotes a single application of bituminous binder covered with a single application of screenings. Its purpose may be to "seal" the road surface but more often than not the "seal coat" is placed for other reasons. The screenings or stone chips used in seal coats in

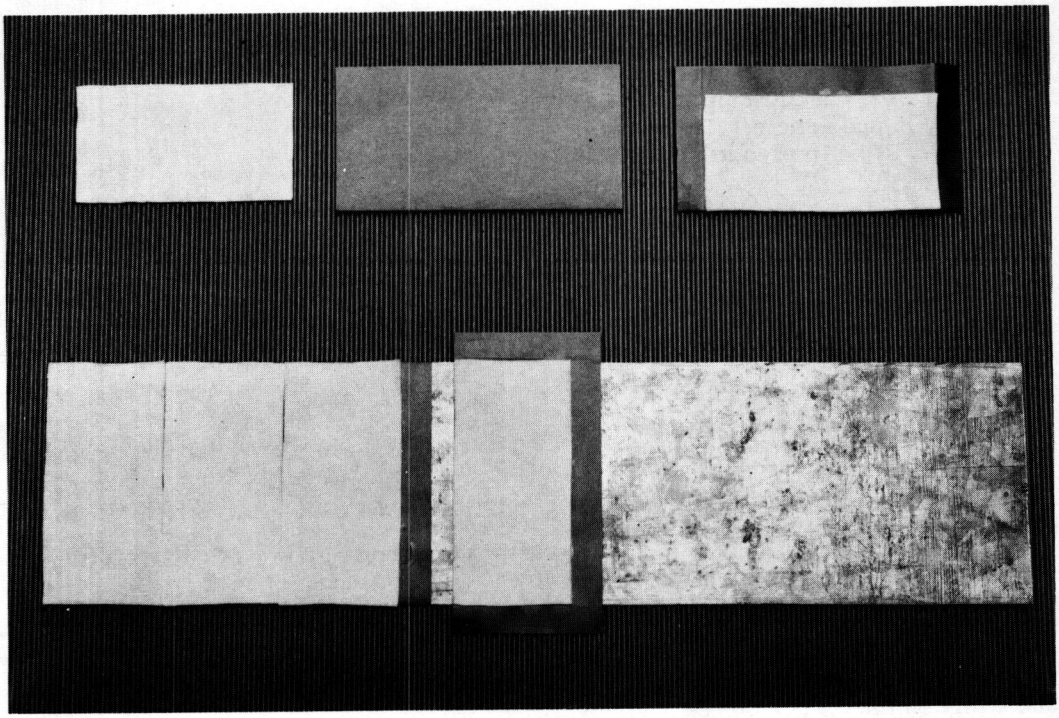

Figure 1. Placing 4- by 8-in. pads on metal strips for transverse spread (Method 1).

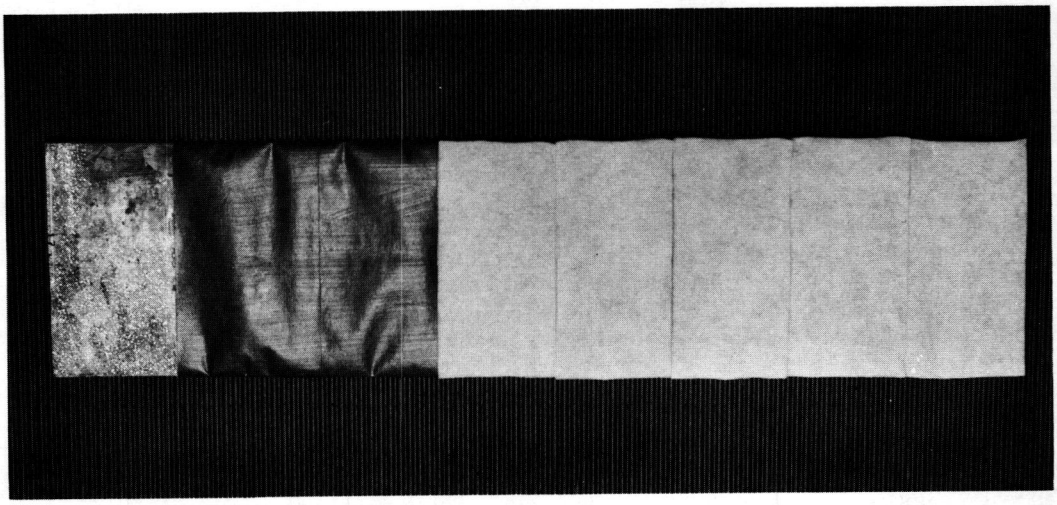

Figure 2. Placing 4- by 8-in. pads on metal strips for transverse spread (Method 2).

California are of smaller particle size than those generally used in many other parts of the United States and are specified as either fine ($\frac{1}{4}$-in. by No. 10) or medium-fine ($\frac{5}{16}$-in. by No. 8) size. Complaints from the traveling public of damage to car windshields by flying screenings, particularly during the whipoff period, has discouraged the use of larger size chips in California. Also the coarser stone creates unpleasant car rumble and increased tire wear.

The purpose of this paper is to report certain laboratory techniques and field studies relating to the construction of seal coats. The outline, as shown in Appendix A, lists

some 20 separate and distinct investigations and studies. Although considerable time has been devoted to some of these factors, it would be difficult to treat all adequately in one article. Therefore, this paper will be limited to the following subjects:

1. Method for checking transverse and longitudinal spreads of asphalt distributors.
2. Temperature study of bituminous binders from time of application of binder to rolling of screenings.
3. Degradation of screenings due to rolling and traffic.
4. Absorptiveness and permeability of pavements.
5. Rate of curing of bituminous binder and adherence of screenings.
6. Seasonal effects on performance of seal coats.

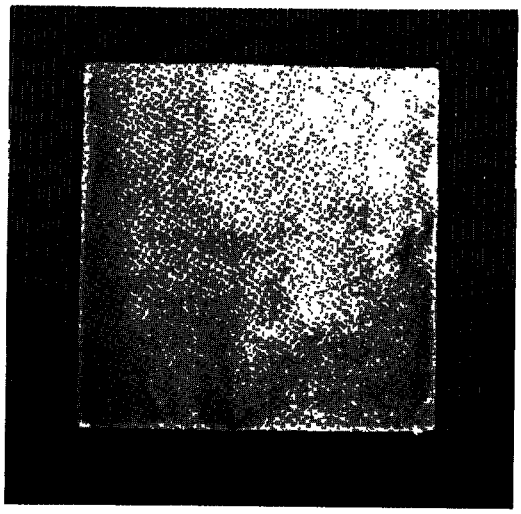

Figure 3. 12- by 12-in. pans with paper liner for longitudinal spread.

Some attempts were not entirely successful. However, they are included in this report to illustrate the difficulties encountered in developing simple and workable field methods. These trials are mentioned with the thought that they may save some time and effort on the part of others who might have similar ideas or who may pursue the experiments further and perhaps devise more simplified and better field methods.

Method of Checking Distributor Spread Rate

The proper and uniform application rate of the bituminous binder may easily be the deciding factor in the satisfactory performance of a seal coat. Excess asphalt may result in bleeding of the surface and insufficient application in raveling of the seal coat. Irregularities in the transverse rate of spread may result in parallel ridges or rough areas due to variations in the quantity of screenings retained.

Failure to apply the binder at the desired rate may be caused by a number of factors, most of which are correctable. Good equipment, kept in proper condition and operated efficiently, is one of the basic requirements for a uniform spread.

For some time, the development of a procedure for determining uniformity of both the transverse and longitudinal spread rates has been of concern. In the determination of transverse spread rate it is desirable to have a complete record across the full width of the roadway, since random measurements may not provide a satisfactory indication of deviations from the desired spread rate.

At present, the street inspector makes random spread rate determinations from tank "stabbings" and visually notes deviations, but neither of these observations are very satisfactory. It is also possible to make the average spread per square yard coincide exactly with the intended rate of application by adjusting a combination of spread, pressure, rate of speed of truck, etc. This still permits sizeable variations in each individual short stretch of application. It would be very desirable for the street inspector to have available a rapid and more accurate method for determining the average spread.

When the field study of seal coats was instigated several years ago, a method of checking distributors reported from England (3) was given considerable consideration. In their procedure, permanent testing stations are set up at convenient locations. The checking procedure consists of collecting the bitumen sprayed into a row of pans set under the spray bar. Each pan covers a transverse width of about 2 in. and is calibrated so that the contents may be either weighed or gauged. This method gives quite accurate results since the sampling pans do have a relatively large capacity. The

method, however, has some distinct disadvantages. A considerable investment in equipment is required. A test on a single distributor could very easily involve the taking of 50 to 100 gal samples and equipment to handle this waste material must be provided. Steam or a large solvent bath would be required to clean the pans and other equipment. A major disadvantage of this system is that it does not indicate the ability of the operator to put down a uniform spread of binder in the field. Also, a distributor in good operation today, may not remain in this condition a day or two hence. This difficulty was overcome to some extent by testing on the job, taking samples on a series of small pads or strips of paper placed directly on the pavement.

Although the British method gives an accurate picture of the quality of the spread, it is not completely satisfactory because of the time and sensitive equipment required. If the street inspector were to make a check of the spread rate, to be practicable the method should be considerably shorter and simpler. With this in mind, several approaches were studied and new methods are still being considered.

One of the more rapid methods tried for checking the spread or film thickness of the binder consists of a small wheel used to measure thicknesses of paint coatings (Fig. 4). However, due to the unevenness of the pavement surface, accurate measurements could not be obtained. Although this was partially overcome by placing a sheet of metal or cardboard on the pavement prior to the passage of the distributor, this method still proved to be unsatisfactory.

Using the same basic principle, a large wheel (about 6-in. diameter) was made by cutting the surface of a cone into the outside of a cylinder (Fig. 4). As the cylinder is rolled over the surface the depth of binder is indicated by the point on the cone which contacts the surface of the binder. This apparatus has the same fault as the preceding in that it gives an irregular reading on rough pavement surfaces.

Another variation involved the use of a short straightedge mounted on two handle bars so that one end of the straightedge is flush with the surface and the other a certain distance above the surface (Fig. 4). It is so calibrated that when placed flat on a surface the point at which the binder contacts the straightedge indicates the rate of spread. Erratic results were obtained due to irregularities in the pavement surface.

After many trials, the best solution seemed to be the use of a modified paper strip method for transverse spread measurements and the use of metal pans for the longitudinal spread. Although this operation is time consuming, it is the best found so far and it does provide quite accurate information. Therefore, this method is described in the following pages for possible adoption for field use. A detailed description and list of equipment required for performing this test is given in Appendix B.

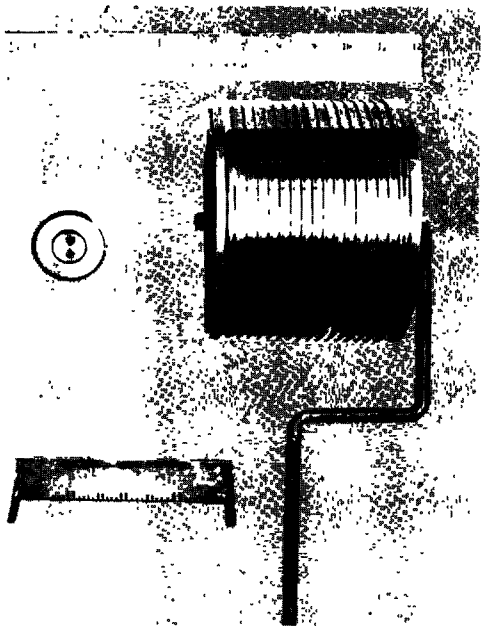

Figure 4. Gauges for measuring thickness of oil film.

The procedure as developed has been used on about a dozen seal coat contracts during the past two years. The tests are carried out during the normal operation of the distributor.

The transverse spread is determined from samples caught on 4- by 8-in. cotton pads (or 2- by 8-in. if greater accuracy is desired), glued to sheets of paper which in turn are attached to strips of sheet metal and placed transversely across the pavement (Figs. 5 and 6). The cotton fibers prevent the binder from flowing. The pads with the attached sheets of paper are removed after passage of the distributor and weighed to determine quantities.

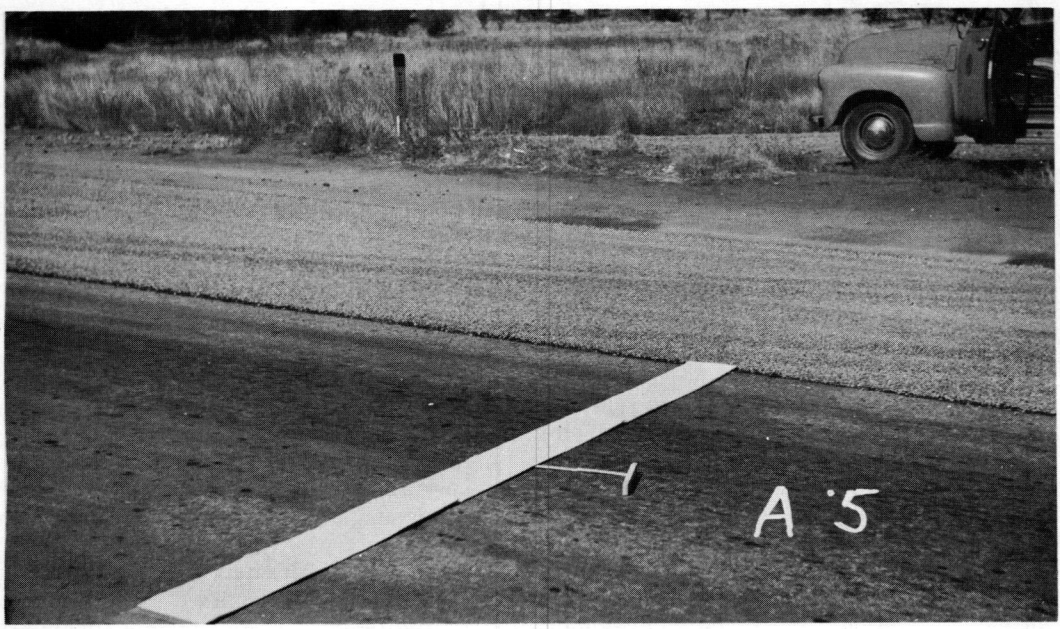

Figure 5. Transverse sample pads in position.

Figure 6. Distributor just before passing over sample pads.

Ordinary paper, it was found, would not work with the type of binder, especially asphalt emulsion that was used since the asphalt tends to spread or flow off the sample pad. The small cotton pads made especially for cleaning multigraph machines worked very well in retaining the binder (see Figs. 1 and 2). The pads cost about $0.018 each. Since 36 pads are required for a 12-ft width of pavement, the cost in pads for each sampling is $0.65. Considerable hand labor is involved in fastening the pads to the paper and sheet iron backing as well as in removing the samples and weighing them.

Longitudinal spread measurements are obtained by taking samples in 12- by 12-in. shallow metal pans (Fig. 3) placed at 100- to 150-ft intervals along the highway. They are lined with heavy wrapping paper and a ¼-in. lip around the edge of the pan helps to hold the paper liner in place and also prevents the collected binder from running out. Quantities are determined by weight.

The advantage of the paper strip method is that it can be performed in the field as often as deemed necessary with little interference during sealing operation. After the samples have been weighed they can be disposed of with a minimum of inconvenience.

The question of what is a permissible deviation is appropriate. This rests on two factors: (1) the best that can be expected from an average distributor operated by an average crew, and (2) the maximum deviation from the desired spread that can be permitted without danger of distress or failure in the finished product. Final answers to

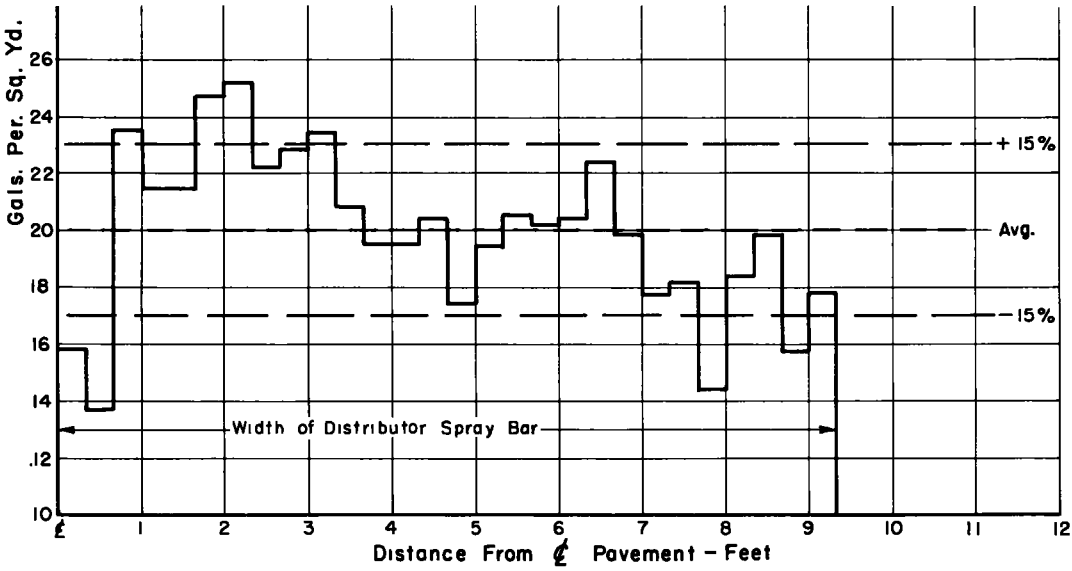

Figure 7. Transverse variation in spread rate of binder, Distributor A.

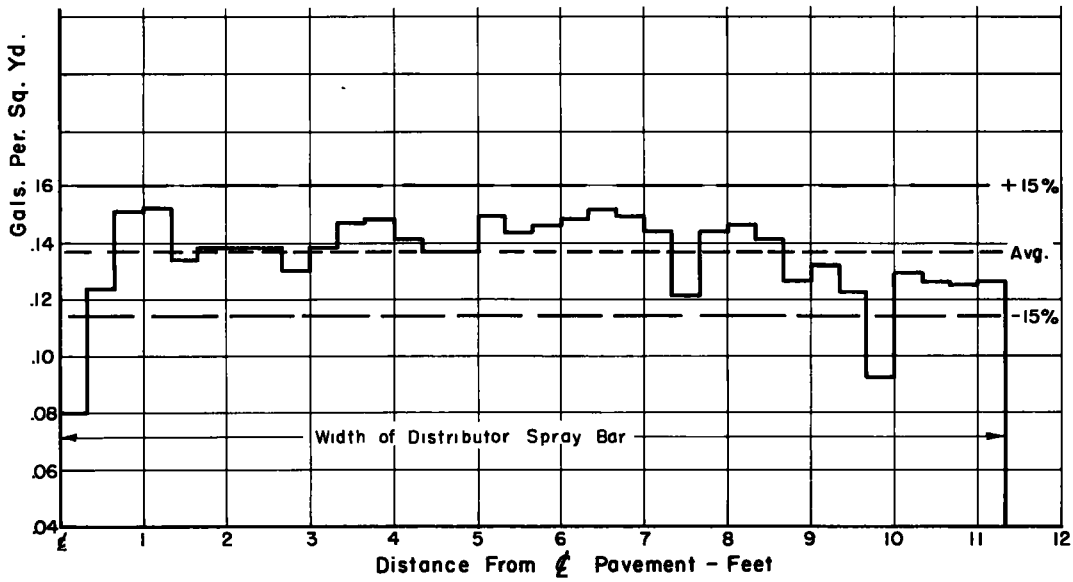

Figure 8. Transverse variation in spread rate of binder, Distributor B.

TABLE 1

SPREAD RATES FOR DISTRIBUTOR A

Pad No.	Data for Figure 7			Data for Figure 9			
	Total Weight of Pad, grams	Net Weight Bitumen, grams	Net Weight Bitumen, gal/sq yd	Variation			Cumulative Percent of Spread Width
				± from Average, gal/sq yd	Percent from Average	Percent Average Ascending Order	
1	21.7	14.8	0.158	0.040	20.2	0	0
2	19.7	12.8	0.137	0.051	25 8	0.5	3 7
3	29.0	22 1	0.235	0.037	18 7	2 2	7 4
4	27.0	20.1	0.215	0.017	8.6	2.2	11.1
5	27.0	20.1	0.215	0.017	8.6	2.2	14.8
6	30.0	23.1	0.247	0.049	24.8	2.5	18.5
7	30.5	23.6	0.252	0 054	27.2	3 0	22 2
8	27.7	20.8	0.222	0 024	12.1	3 0	25 9
9	28 2	21.3	0 228	0.030	15.1	3 5	29.6
10	27.7	21 8	0.234	0.036	18.2	5 1	33.3
11	26.3	19.4	0.208	0 010	5.1	7.6	37.0
12	25.0	18.1	0.194	0.004	2.2	8.1	40.7
13	25.0	18.1	0.194	0.004	2.2	8.6	44.4
14	26.0	19.1	0.204	0 006	3.0	8.6	48.1
15	23.3	16.4	0.175	0.023	11.6	9 6	51.8
16	24.9	18 0	0 193	0.005	2.5	10.6	55 5
17	26.1	19 2	0 205	0.007	3.5	11.6	59.2
18	25 8	18.9	0 202	0 004	2.2	12.1	62 9
19	25.9	19.0	0.204	0.006	3.0	13 1	66.6
20	27.9	21.0	0 224	0.026	13.1	15.1	70 3
21	25.4	18 5	0 198	0.000	0	18.2	74 0
22	23.4	16 5	0.177	0.021	10.6	18.7	77.7
23	24.0	17.1	0.182	0.016	8.1	20.2	81.4
24	20.4	13.5	0.144	0.054	27.3	24.8	85 1
25	24.0	17 1	0 183	0.015	7.6	25.8	88 8
26	25.5	18.6	0 199	0.001	0.5	25.8	92.5
27	20.6	13.7	0.147	0.051	25 8	27.2	96 2
28	23.6	16.7	0.179	0.019	9.6	27.3	100 0
29	10.8	3.9	0.042	These samples at the edge have been omitted.			
30	7 3	0.4	0.004				

Average spread rate 0.198 gal per sq yd

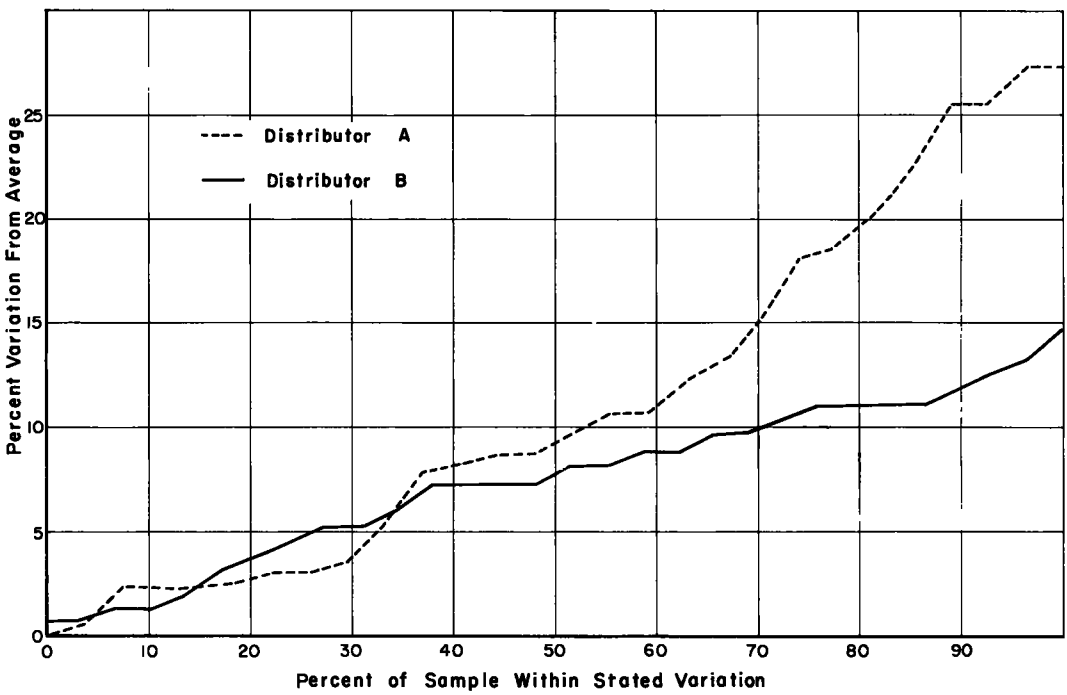

Figure 9. Variation in transverse spread rate from stated average.

these questions can be given only after study of many seal coat jobs. For example, the English recommended a maximum allowable variation of ± 15 percent from the average spread. Argentine engineers have reported that they control variation within 10 percent. For illustration purposes the transverse spread of two different distributors are shown in Figures 7 and 8. The spread rates, as shown in Figure 7, were taken from a distributor that had all the outward appearance of being in very poor condition, and an inspection of the curve will verify this fact. The distributor with a spread pattern as shown in Figure 8 was clean and in every way seemed to be in good operating condition and as will be noted in the curve only one sample other than at the edge of the pavement varied from the ± 15 percent of the average.

In order to compare variations in spread rates, these results have been recalculated on a percentage basis (see Table 1 for example) and plotted as shown in Figure 9. The curves provide a measure of the percentage of the samples that fall within a given limit, above or below the average. In plotting these curves it has been customary to calculate the average spread, after adding in the binder falling onto the feathered edge.

Attention was recently directed to a seal coat job which exhibited the appearance of rich, closely spaced, longitudinal ridges within a day or two after construction. Hot oil, grade SC-6 and fine screenings ¼ in. by No. 10 were used. Regular transverse spread tests using the 4-in. pads were made and in order to obtain a closer pattern of the actual spread the 4-in. pads were cut in half and thus made it possible to determine the spread rate for each 2-in. interval. The bituminous binder showed very little flowing on the pads and thus permitted the cutting of the paper strips. The values obtained are plotted in Figure 10. As can be seen from the chart there is considerable variation in the transverse spread. This spread pattern was then compared with the actual appearance on the road and it was noted that the majority of rich spots coincide very closely with the high spots on the graph. Instead of adhering to the binder, the screenings were completely submerged in the excess asphalt. Although the spread rate was excessive according to standards used, this irregular spread pattern presented a very unsightly appearance of the finished seal coat. Many of these rich streaks have to some extent been ironed out by traffic. A photograph, Figure 11, taken three months after construction still very clearly illustrates the uneven distribution pattern.

It is believed that the ± 15 percent variation from the average spread might be per-

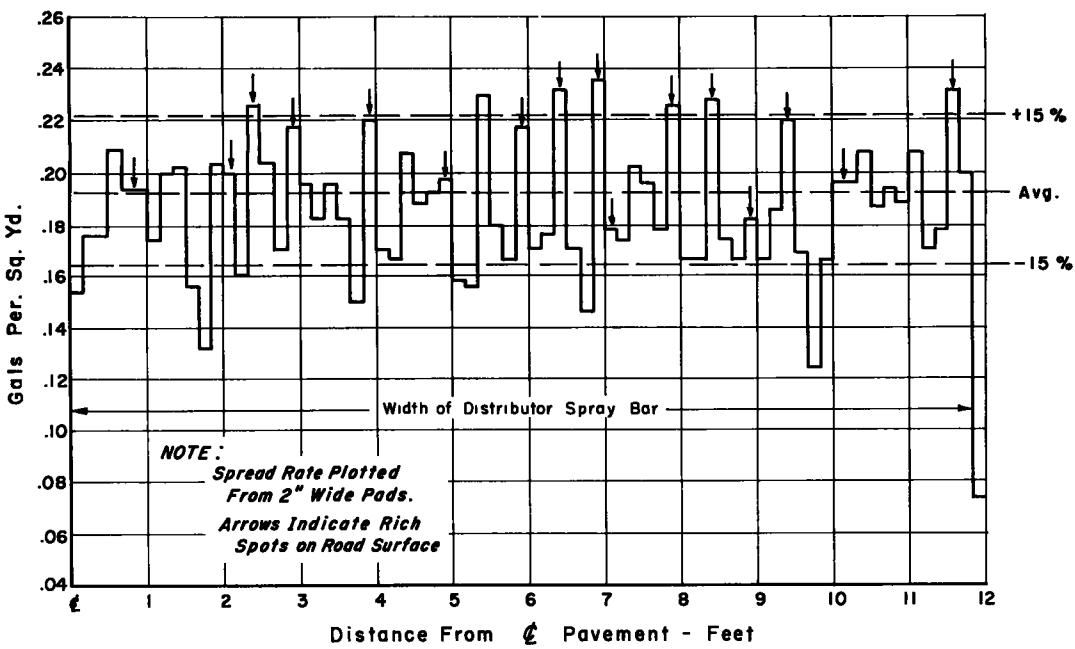

Figure 10. Transverse variation in spread rate of binder, Distributor C.

Figure 11. Appearance of seal coat three months after construction, Distributor C.

missible for asphaltic emulsion in the transverse pattern where the variations in depth of spread tend to even out by the flowing together of the binder. For paving asphalts or heavier grades of liquid asphalts which chill rapidly and assume the temperature of the pavement almost immediately, as shown later under temperature studies, the transverse variation should perhaps not exceed 10 percent from the average spread. In the longitudinal spread the limits should be more restrictive, possibly not over 10 percent for all types of binders since any variation of this nature would be more extensive and would tend to affect the over-all success of the seal coat.

If this method were adopted as a routine procedure, sampling of the transverse and longitudinal spread would require more personnel than is customarily assigned to seal coat jobs. Furthermore, there is some doubt as to whether the average construction engineer would have the patience to glue the little cotton pads in just the right places. Depending upon local conditions and policies it is thought that a trained laboratory crew equipped for making these tests should calibrate the distributor trucks.

What can be expected from the sampling of distributor spreads? The answer is: little or nothing unless the engineer takes the necessary steps to see that serious deviations are corrected, or if necessary, unsatisfactory asphalt distributors be barred from the job.

It might be mentioned that the mere presence of laboratory personnel checking the spread rates, seems to put the contractor as well as the engineer on the alert. Apparently, due to this "influence," an improvement in operation covering all phases of seal coat construction was noted on several jobs.

Temperature Studies During Seal Coat Operations

The general consensus of opinion of engineers dealing with seal coat construction is that the chips should be applied immediately or as soon as possible after the bituminous binder has been spread. This applies particularly to hot oil.

In order to study the rate of temperature change of the bituminous binder after application on the road, the variation on one job was determined by means of thermocouples glued to the pavement surface and connected to a micromax recorder powered by a storage battery (Fig. 12). Temperatures were taken as frequently as one minure intervals. The oil used was an RC-5 and applied at a temperature of 255 F. The screenings were slightly damp. The air temperature ranged between 90 and 100 F and the pavement temperature between 115 and 140 F.

An inspection of the data in Figure 13 and Table 2 indicates that the temperature of the bituminous binder after application drops almost immediately (within one minute) to the pavement surface temperature. The temperature of the binder is further lowered upon application of the screenings. This drop depends somewhat upon the temperature of the screenings themselves whether they are taken from the outside of the stockpile warmed by the sun, or from the damp and cool center of the pile. The temperature of the bituminous binder then will slowly increase until it nearly reaches the pavement temperature.

On the particular job studied the chip spreader consisted of a 12-ft Buckeye Spreader operated from the rear of the truck. Although considerable difference in time elapsed between application of the oil and the screenings, no adverse results were noted in this particular case. It should be noted, however, that the studies were made under ideal weather conditions and very good traffic control and it is quite possible that the results might have been quite different in case of adverse conditions. Today,

Figure 12. Micromax with thermocouples glued to pavement surface.

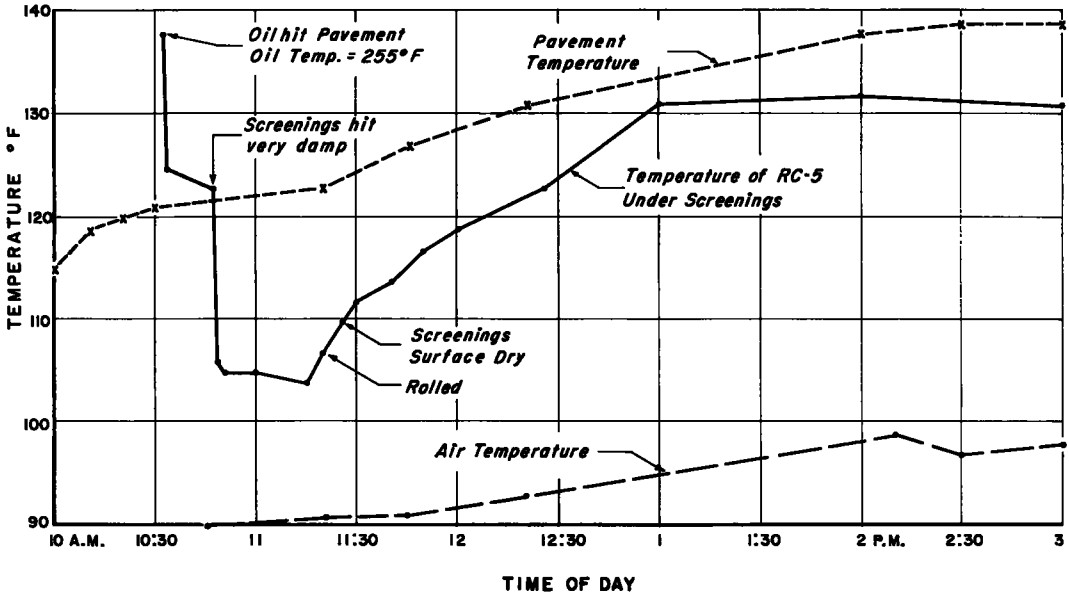

Figure 13. Temperature-time study for RC-5 binder; weather clear, hot, slight wind.

TABLE 2

SHOWING CHANGES IN TEMPERATURE OF RC-5 BINDER DURING SEAL COAT CONSTRUCTION

Time	Air Temperature	Original Pavement Temperature	Oil Temperature		Remarks
			In Distributor	On Pavement	
10:00		115			July 16, 1952 a.m. spread
10:10		119			
10:20		120			
10:30		121			
10:32			255	138	Oil hit surface
10:33				125	
10:34				124	
10:35				125	
10:45	90				
10:47				123	Screenings hit surface
10:48				106	
10:50				105	
11:00				105	
11:15				104	
11:20	91	123		107	Rolled
11:25				110	Surface appeared dry
11:30				112	
11:40				114	
11:45	91	127			
11:50				117	
12:00				119	
12:20	93	131			
12:26				123	
1:00				131	
2:00		138		132	
2 10	99				
2:30	97	139			
3:00	98	139		131	
4:00	98	135			

when most contractors in this state use the mechanical Spread-master the time interval between application of the bituminous binder and screenings can be reduced, by proper coordination, to less than one minute. However, if the Spread-master is operated too fast, as may be accomplished by the installation of special sprockets, the momentum imparted to the falling screenings will have a tendency to make them roll or turn over after hitting the binder covered surface instead of sticking immediately upon hitting the pavement. This tendency is greatest when particles strike on unbroken emulsion. The bituminous covered stone tends to adhere to vehicle tires and recently one bad

failure was attributed to loss of screenings by this mechanism.

The studies would indicate that the change in temperature of the road surface after the application of screenings is of greater importance than the ambient temperature which is usually specified as a control. In other words, ideal conditions would be increasing temperature on cool days and decreasing temperature on extremely hot days.

This study would also suggest that equipment similar to the Spread-master, but equipped with heating units to warm the screenings and a blower to remove dust would greatly enhance the success of seal coat performance. This would be especially beneficial when the bituminous binder consists of paving grade asphalt or the more viscous liquid asphalts, and the seal coat is being placed under somewhat less than favorable weather conditions. Heated screenings were used on two or three small experimental jobs with excellent success (4).

Degradation of Screenings Due to Rolling and Traffic

There is no question that a certain amount of degradation of aggregates occurs under the roller and progresses with time due to traffic, but how much? Generally, the degradation shows some relationship to the hardness of the aggregate which is commonly measured by the Los Angeles Rattler or Deval Wet Shot Test, and most specifications contain maximum limits of loss under these tests. In some states or areas where a few types of aggregates predominate, this relationship might not be too difficult a matter to determine and papers showing satisfactory correlation have been published on this subject.

The California Division of Highways generally uses crushed aggregates having a good service record and are normally obtained from commercial sources. However, in taking advantage of local aggregates whenever possible, particularly in outlying areas, a wide variety of stone types ranging from lightweight volcanic cinders to crushed river gravel have been used. Trying to correlate the Los Angeles Rattler or Wet Shot Test results with the degree of degradation of these aggregates having decidedly varying surface and hardness characteristics, being placed under varying conditions of construction, degrees of rolling, and traffic, is not a simple matter. By recovering screenings from the pavement at various intervals of time an attempt has been made to establish some correlation.

The rate of chip spread on various jobs was determined by removing the screenings from 18- by 18-in. or 24- by 24-in. areas immediately after rolling but before the binder had set. A grading analysis was made on these samples and the surface area calculated.

It was found that the percent increase in surface area due to breakdown during rolling under actual field conditions was comparatively small on all jobs and did not amount to over 75 percent increase when compared to the surface area of the samples taken from the spreader box.

TABLE 3

DEGRADATION BY ROLLING AND TRAFFIC

Job No	No. of Test Sites	Type of Roller	L.A. Rattler, percent loss		Wet Shot Percent Loss	Rolling: Average Surface Area sq ft/lb			Pavement Age Month	Traffic: Screening Quantity				Percent Increase in S A by Traffic
											After Traffic			
			100 Rev	500 Rev		Orig.	After Rolling	Percent Inc.		After Spread lb/sq yd	lb/sq yd	Percent Decrease	Decrease Minus Whipoff	
A	2	S	6.8	27.0	12.1	6.1	7.6	24	28	16.4	7 9	51	36	169
B	4	S	3.2	13.8	7 6	3.7	6 2	67	12	24.1	7 7	68	53	248
C	2	S	4.2	21.0	18.0	6.0	7.8	30	9	12.5	8.8	30	15	133
D	5	S & P	4 8	20.8	12 4	9.4	10.0	6	9	15.0	11 9	27	12	65
E	2	S & P	2 6	12.8	3.7	6.5	7 6	17	9	12.7	12 4	2	-	73
F	1	S	4.6	20.0	20.9	5.7	8 4	47	9	13.0	9 5	27	12	61
G	3	P	4 3	24.4	21.3	6.8	8.7	28						
H	3	P	5 0	21.2	13.6	7.1	10.1	42	9	17.0	10 0	41	26	91
I	4	P	5 8	23.6	11.1	9.1	8.8	-	9	14.2	7 8	45	30	148
J	2	P	4.2	21.8	10.6	5.6	9 8	75						
K	3	P	3 2	14.2	6.4	5.2	8 0	54						

S = Steel wheel roller, P = Pneumatic.

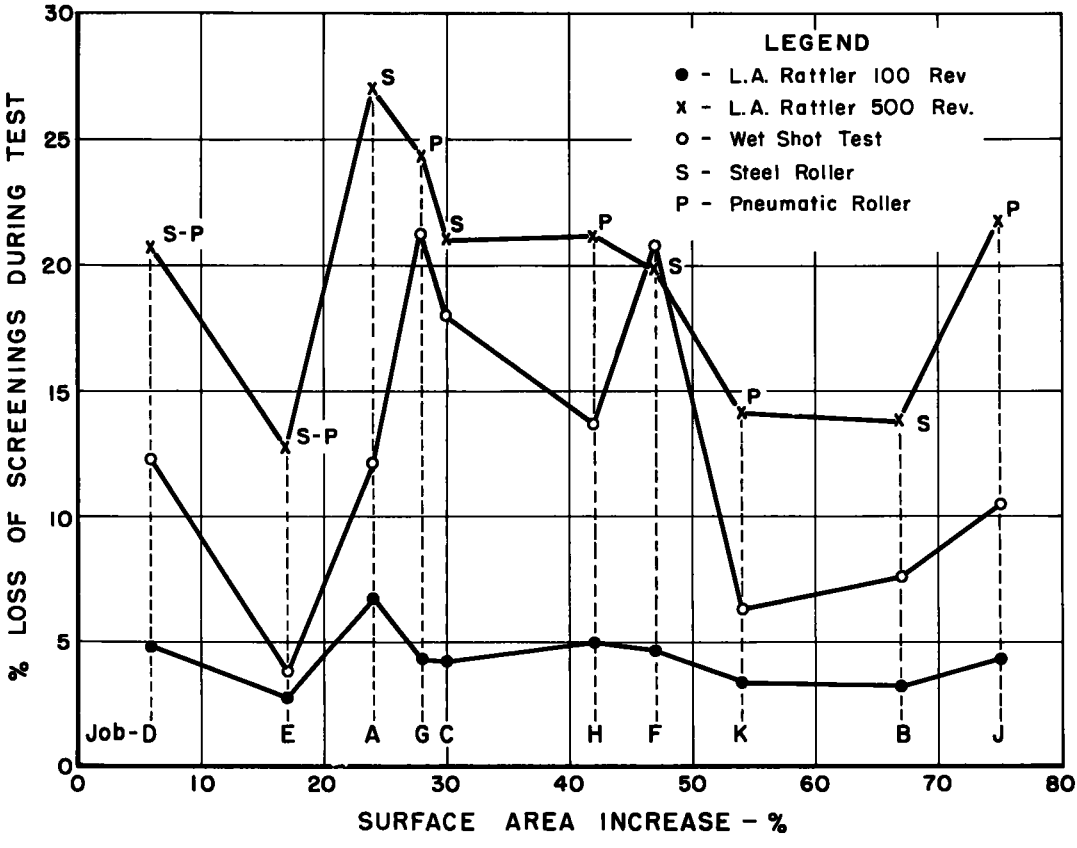

Figure 14. Comparison of hardness test versus degradation under rolling.

The Los Angeles Rattler and the Deval Wet Shot Tests were performed on aggregates from 11 different projects. The data and relationship between these tests and the breakdown or increase in surface area after rolling are shown in Table 3 and Figure 14. There is no apparent trend in either the results from the Los Angeles Rattler at 100 or 500 revolutions or the Wet Shot Test.

The results on the increase in surface area in relation to the Los Angeles Rattler Test are somewhat at variance as reported by others (5). It should be pointed out, however, that in this investigation the screenings as used, are considerably finer than are commonly reported from other states and the amount of rolling less, consisting of only two or three passes of a light steel or pneumatic type roller.

A heavier roller will break more particles during rolling and probably less subsequent degradation takes place under traffic; whereas, a light roller will degrade the aggregate less but with further breakdown occurring under traffic. The same applies to soft and hard particles.

To further study degradation under traffic, samples from the above jobs were removed after certain intervals. The total weight per square yard and surface area of the screenings remaining on the pavement were determined.

The results of the Los Angeles Rattler and Wet Shot Tests were compared with the decrease in quantity of screenings and the increase in surface area. The only apparent relationship was noted when the Rattler results at 100 and 500 revolutions were compared with the decrease in the quantity of screenings, as shown in Figure 15. The results indicate a rather marked change in degradation under traffic for small changes in Los Angeles Rattler test values and at levels far below those normally considered critical.

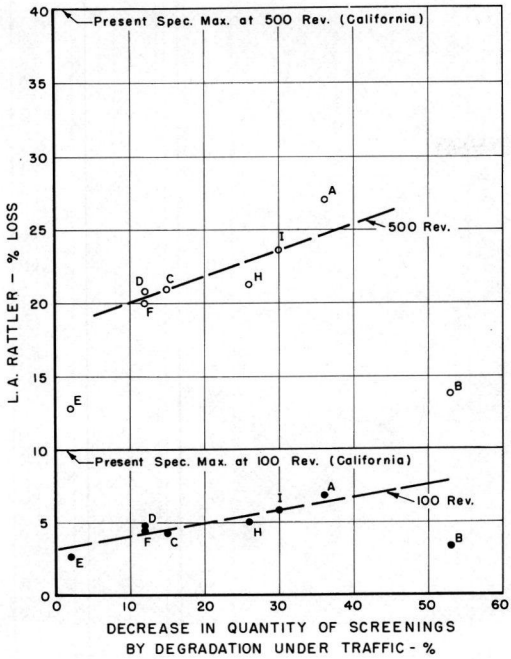

Figure 15. Degradation under traffic versus loss in Los Angeles Rattler.

Absorptiveness and Permeability of Bituminous Pavements

In order to calculate the optimum bitumen demand, some allowance has to be made for the surface characteristics of the existing pavement such as absorptiveness, permeability, and texture. The surface may be porous to such an extent as to absorb some of the binder, leaving an insufficient amount to bond the chips. This applies particularly to road mixed jobs which often use local, absorptive aggregates and as a result in many cases are under oiled. Empirical curves for this purpose are provided in "The Design of Seal Coats and Surface Treatments" (2). However, the field engineer must estimate the porosity of the existing surface by visual means and select the proper curve. The success of this type of examination depends on the experience of the observer and other factors which cannot be determined visually and may lead to an improper estimate of the degree of absorptiveness. Therefore, a simple field test method that will provide an average value for the absorption factors is needed for seal coat construction.

In attempts to provide simplified methods a number of ideas were tried. One method involved the use of a stack of filter papers placed on the pavement surface wetted with a light lubricating oil or kerosene. It was hoped that the number of soaked filter papers should be in inverse ratio to the absorptiveness of the pavement. However, nonuniform contact due to uneven pavement surface resulted in inconsistent values. Absorbent cotton, held down with a weight, showed some improvement, although high areas prevented securing good contact.

Various solvents and water, with and without a wetting agent, were spread on different types of pavement textures and the relative rates of absorption noted. It was observed that water containing a wetting agent was absorbed at a fairly fast rate by the pavement surface. Water was finally selected as the liquid for the test procedure to which was added 0.5 percent of a detergent.

The relatively high rates obtained on some of the pavement surfaces although indicating some degree of absorption, really are more a measure of the porosity or permeability of the pavement than true absorption of the surface layer. However, this seems to be a practical method which at least measures some of the factors involved and establishes the need for sealing the pavement. With this in mind, this procedure was used to evaluate the permeability of pavements.

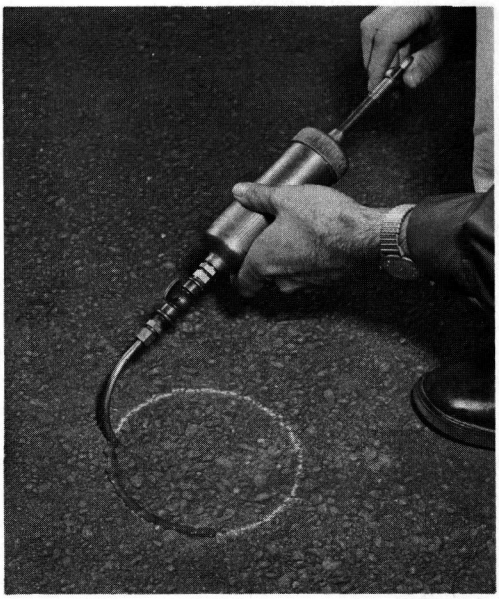

Figure 16. Forming grease ring.

In order to confine the liquid to a definite area on the pavement, a ring made by extruding a light grade of cup grease from a grease gun formed a very satisfactory dam or impermeable barrier.

A grease gun fitted with a short piece of ¼-in. copper tubing is used to spread the ring, about ⅛ in. high, following a previously drawn outline of a 6-in. diameter circle (Fig. 16).

Water containing 0.5 percent of a detergent, sold under the trade name "Vel," is poured within the grease ring from a known quantity of the liquid. (It is planned to substitute a definite chemical for the Vel.) As fast as the solution is absorbed by the pavement it is replaced (Fig. 17). The procedure has been to limit the period of absorption to 2 min.

At the end of the period the amount of the solution in milliliters absorbed per minute is determined and used as a measure of the permeability of the existing surface. A detailed test procedure is given in Appendix C.

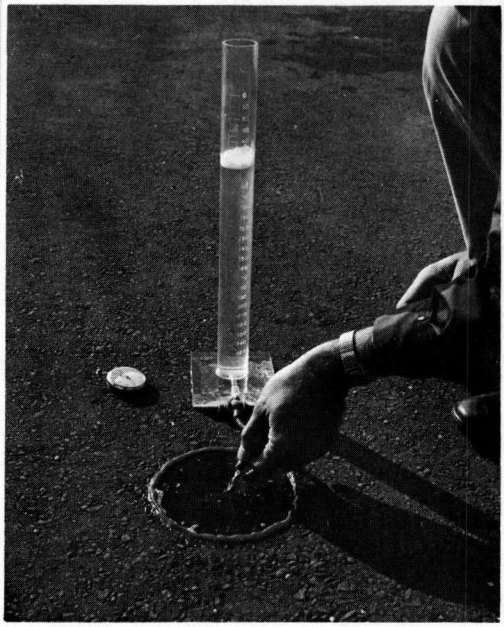

Figure 17. Applying water solution to pavement surface.

It should be pointed out that some of the relatively high porosities obtained on pavements do not necessarily indicate that rain water will percolate at such a rate. Once the interconnected void spaces in a mix are filled with water, a relatively slow rate of further percolation is established. This is borne out by the fact that some pavements, although possessing a relatively high rate of porosity, did not exhibit an unusually high moisture content in the well-compacted base material.

Although this test is used to determine whether or not a pavement is porous and will benefit by a seal coat, a scale of allowable permeability values has not yet been established. The readings obtained are relative and further field work is necessary.

Other adaptions of this test have been made in exploring pavement failures by adding a small amount of water soluble dye and tracing cracks in surface courses or cement treated bases.

A limited number of trials also indicate that this test procedure might be suitable for determining the degree of compaction obtained on newly placed bituminous surfaces. The amount of solution permeating is some indication of the voids or density of the mix.

Rate of Curing of Bituminous Binder

The retention of screenings by the bituminous binder immediately after placing or within a few hours thereafter depends to a large extent upon the "setting up" qualities of the bituminous binder. There seems to be no question that screenings from different sources or different types or grades of binder react differently under identical curing conditions.

A test procedure developed in the laboratory and used for the last 15 years makes it possible to determine the rates of setting of the bituminous binder under controlled conditions by mixing the binder with Ottawa sand and measuring the extrusion rate on the so-called Cohesiograph (6). This method, however, is not applicable to field use and it was felt that a more rapid means should be provided the engineer so he can be reasonably sure that the binder has set sufficiently to resist whipoff by traffic.

In the field the rate of setting is influenced by the types of aggregate used, relative humidity, amount of sunshine, wind velocity, and the pavement temperatures.

Some indications of the rate of setting or drying can be provided by use of the

Livingston Atmometers (7), which have been employed in the field at various times for the past 20 years (Fig. 18). A porous porcelain bulb evaporates water at a given rate depending upon the combined drying effects of air temperature, wind and relative humidity. Good drying weather shows an evaporation rate of roughly 10 ml or more per hour; whereas, during cloudy or overcast days and nights this evaporation rate usually drops to zero. However, the bulbs are sensitive to dust and dirt and cleaning very often changes their evaporation rate. A number of attempts have been made to construct self-recording evaporation devices (Fig. 18) using this principle but an instrument sufficiently free from trouble to make it practicable for field use has not as yet been developed.

Such an evaporation measuring device, although no assurance against possible whip-off by fast uncontrolled traffic, at least does indicate very positively to the resident engineer whether or not he has good drying weather. This device, of course, is most useful when asphaltic emulsion is used as the bituminous binder. Hot oil or asphalt may not "set up" in the summertime under ideal drying conditions due to extremely high ambient and comparatively high night temperatures.

For some time experimentation has been made, as time permits, with a method for testing adherence of chips by means of a small hand-operated centrifuge. In this test, specimens of seal coat were prepared and spread on the lids of gallon paint cans which, after the desired period of curing, were centrifuged at 7.4 x G with the plane of the specimen at right angles to the direction of force. This test, although showing definite differences between a short and long cure, was entirely too severe and test results could not be correlated with actual field conditions. In the present studies the method was reconsidered and tests were made with 6- by 6-in. square plates placed at an angle of 15 percent with the horizontal (Fig. 19). In this way the keying effect of the particles or rock is tested as well as the bond, also different portions of the plate are subjected to a varying amount of centrifugal force. The inner edge of the plate nearest the cen-

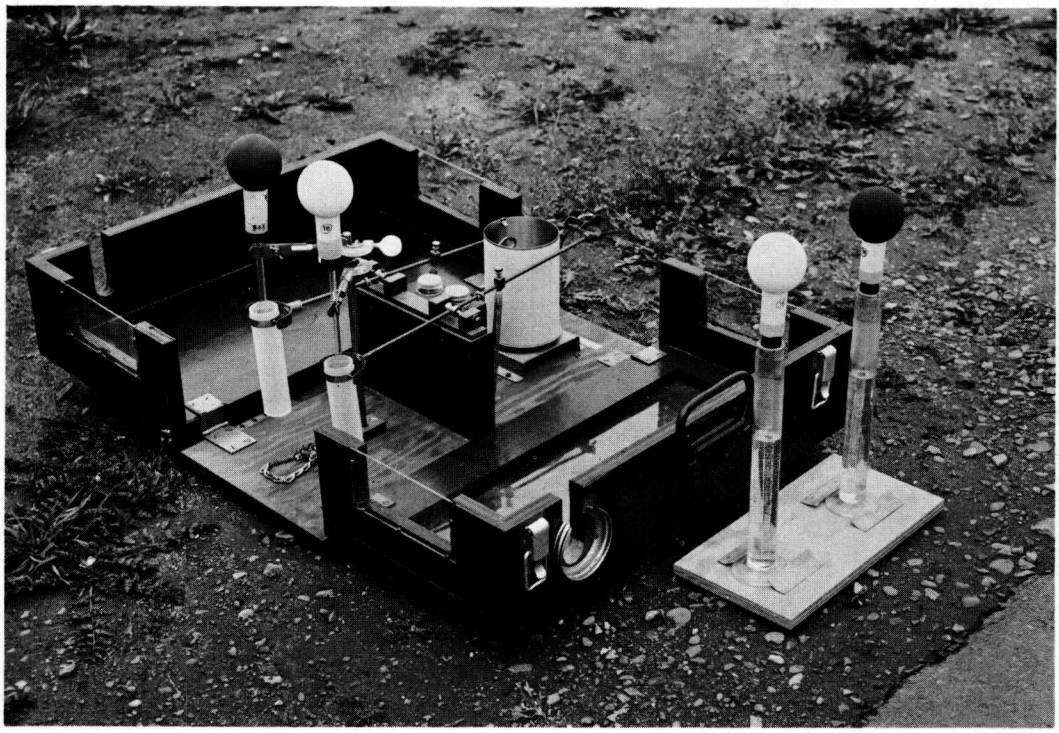

Figure 18. Atmometers; foreground - manually operated, background - self-recording device (box open to show mechanism).

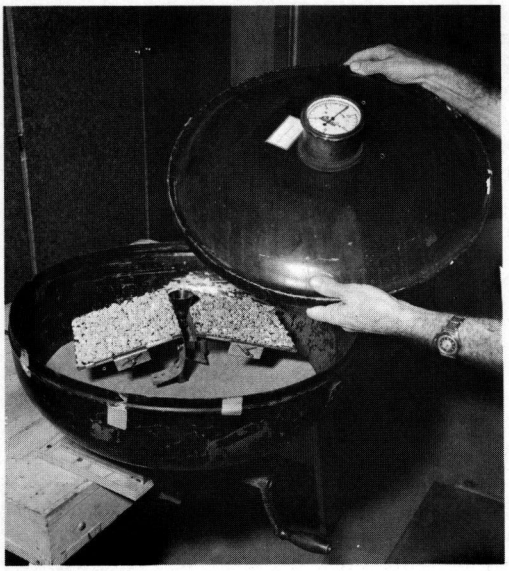

Figure 19. Hand operated centrifuge to determine adherence of screenings.

TABLE 4

Screening Source	79 F Dry RH 46 Percent		Remarks
	Moisture Lost in Emulsion, percent	Screenings Retained, percent	
A	29	90	Soft, absorbent. Failed in L. A. Rattler Test.
B	40	81	
C	35	27	
D	31	18	
E	33	10	Mostly quartz. Failed in stripping test.

ter of rotation is subjected to about 2 x G and the outer edge to about 12 x G. The specimens are centrifuged for one minute.

It is believed that this test might be used in the field to determine the time at which the seal coat may be opened to traffic. Plates or asphalt sheeting (simulating a roadway surface) can be placed directly on the pavement during sealing operations and be tested at certain intervals directly on the job site. However, some allowance will be necessary to correct for the amount and speed of traffic as well as for superelevation and grades where whipoff is usually most severe.

Some of the data obtained with the centrifuge have been quite interesting. In testing various kinds of screenings it was found that under identical curing conditions and using the same asphalt emulsion the percentage of screenings retained varied considerably as shown in Table 4.

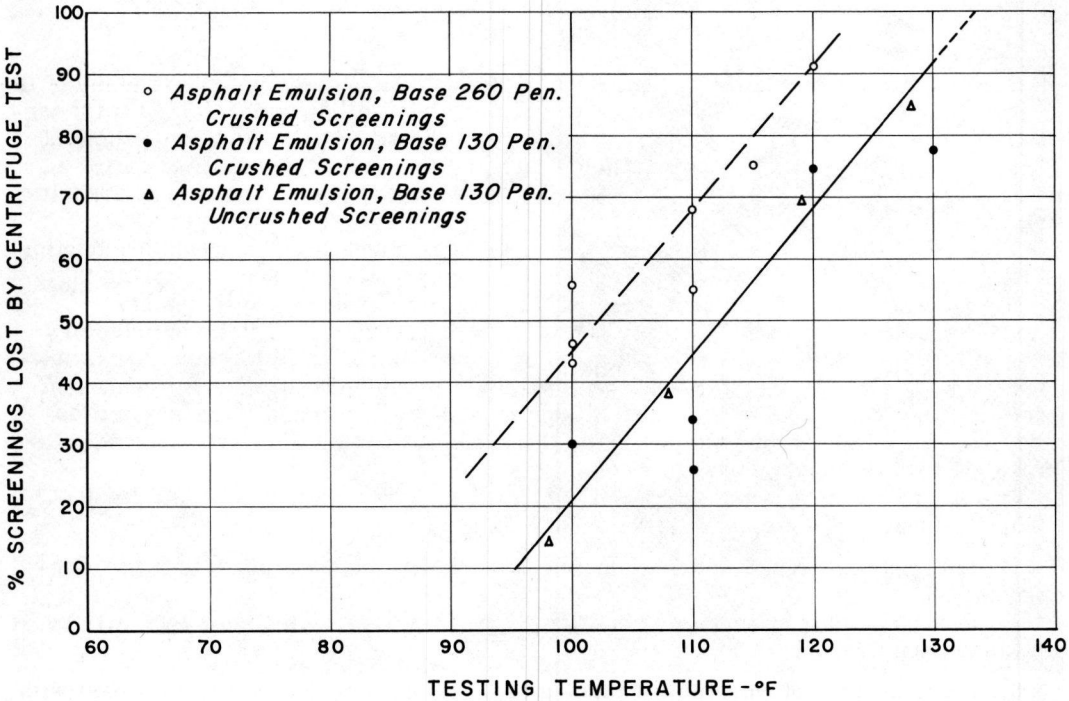

Figure 20. Effect of test temperature on screenings loss.

In seal coat work the general policy in California is to use as soft a binder as possible. Some difficulty has been encountered occasionally with "setting up" of the binder during the summertime where high daytime temperatures coupled with comparatively high nighttime temperatures prevail. To overcome this problem it is necessary at times to revert to a somewhat heavier base stock. A few tests made with the centrifuge on an asphaltic emulsion with a base stock of 130 and 260 penetration asphalt indicate that the degree of whipoff appears to be related to the penetration of the base stock (see Fig. 20).

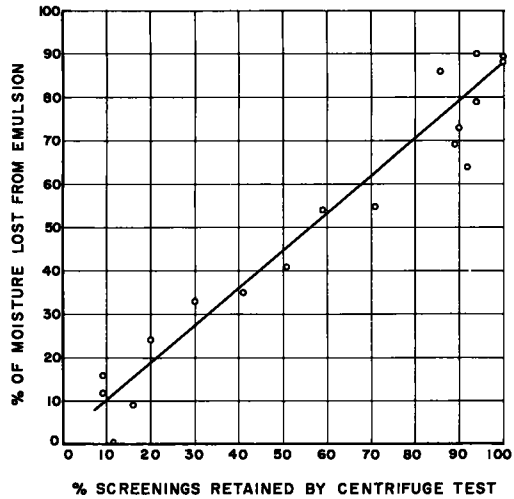

Figure 21. Relation of percent moisture in emulsion to retention of screenings.

The test also appears to correlate with the rate of break of the asphaltic emulsion or, in other words, the amount of water retained by the emulsion. Figure 21 illustrates a fairly constant relation between the percentage of screenings retained and the percent of moisture remaining in the emulsion.

Studies made so far indicate that this method has some promise, at least for laboratory work, to test the adhesiveness of different types of screenings or the bituminous binder with or without admixtures such as rubber or anti-stripping agents employing various curing temperatures, effect of moisture, humidity, etc.

These studies are to be continued and it is hoped that a procedure will be developed which will, when correlated with field performance, provide an answer for the engineer on one of the most difficult problems; namely, when is it safe to open the seal coat to traffic?

Seasonal Effects on Performance of Seal Coats

Even with the introduction of better tools and methods and the solving of many of the present problems there still remains the weather as the major variable and least controllable factor affecting the success or failure of the seal coat. However, some of the potential failures can be avoided by prohibiting the placing of seal coats after a certain calendar date. This is particularly true when the binder consists of asphaltic emulsion.

Most seal coat work in California is now performed under contract and every effort is made to award the contracts early so that the work can be performed during the summer season and thus minimize the detrimental effects of cold fall weather.

Although the daytime temperatures in the fall may still appear to be satisfactory for good sealing, the night and early morning temperatures are low, humidity is increased and an occasional shower, particularly at the higher altitudes all represent conditions not conducive to good seal coat performance. A chart, Figure 22, illustrates a definite trend towards possible failure of seal coats as the fall season approaches with its variable weather conditions.

Based on California weather conditions, the following tentative schedule for the placing of seal coats has been established:

1. Seal coat construction using emulsified asphalts should be terminated by September 1st.
2. Seal coat construction using cutback asphalts of the rapid curing type may be extended until October 15th.

If conditions are unfavorable for placing of a seal coat such as along the coast with its summer fog or on the Redwood Highway along the northwest coast where much of

the pavement is shaded by the big Redwood trees, an open-graded, hot, plant-mix seal of about ½-in. thickness is recommended. This open-graded seal, of course, does not "seal" the underlying pavement against the entrance of surface water and therefore some judgment on its application should be exercised. Many miles of this plant-mixed open-graded mix have been placed in northern California with excellent success. The cost is somewhat higher than ordinary seal coat work but may well compensate by reducing the chance of failure.

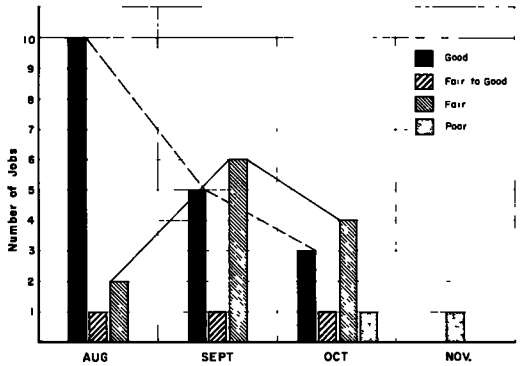

Figure 22. Seal coat studies; final condition of seal coats compared with construction dates.

SUMMARY

The subjects discussed in this paper may be summarized as follows:

1. A method for determining the uniformity of transverse and longitudinal spread rates of bituminous distributors is presented. Although not considered the ideal solution, it is the best available field method developed to date which will provide accurate information. A variation in transverse spread of ± 10 to ± 15 percent of the average rate can be tolerated. The longitudinal spread variation should not exceed ± 10 percent.
2. Hot road oil or asphalt, after spreading, will assume the temperature of the pavement almost instantaneously. Its temperature will further be influenced by the temperature of the screenings. At the time of seal coating and shortly thereafter, the surface temperature of the pavement seems to be of greater importance than minimum ambient temperatures which are generally specified.
3. Degradation studies on screenings made following rolling did not show any correlation between increase in surface area and loss in the Los Angeles Rattler or Wet Shot Test. The study was made on eleven jobs picked at random under varying field conditions and employing miscellaneous rolling equipment. The degradation occurring under traffic showed some relationship to the Los Angeles Rattler Test.
4. A rapid field test, employing water to which a detergent is added for determining the relative permeability of pavements, is described.
5. A centrifugal test method for field use to determine the adherence of screenings is discussed. Coupled with proper traffic control, it should provide the engineer with the answer as to when it is safe to open a newly placed seal coat to traffic.
6. Besides the subjects discussed, the weather is one of the most important but the least controllable factor. In order to minimize seal coat failures due to weather conditions, no seal coat work should be performed after a certain calendar date.

ACKNOWLEDGMENTS

The work described herein was performed under the general direction of F. N. Hveem, Materials and Research Engineer, California Division of Highways, who over the years has shown a keen interest in improving tests and methods which will assure better seal coats.

Acknowledgment is made to John Skog for his many contributions and assistance. G. R. Kemp participated in collecting some of the field data. The writer wishes to especially acknowledge the work of R. M. Hammond for developing some of the mechanical devices and working out the details of the laboratory and field methods discussed.

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Appendix A

OUTLINE OF LABORATORY AND FIELD STUDIES RELATED TO SEAL COAT CONSTRUCTION

I. Laboratory Investigations.
   A. Develop method for measuring shapes of screenings and their effect on retention and skid resistance.
   B. Develop method for measuring rate of polish and wear of screenings and their effect on skid resistance.
   C. Studies and measurements of the rate of cure of bituminous binders used in seal coats and the effect on screening retention.
   D. Development of better test methods for measuring the effect of water on seal coat durability.
   E. Develop method for measuring absorptive capacities of old pavements.
   F. Devise and test new binder compositions to obtain an adhesive having the following desirable properties:
      1. Uniform spreading qualities at average temperatures.
      2. Rapid set after application of screenings under unfavorable climatic conditions.
      3. Low temperature susceptibility and good durability of binder in terms of hardening rate.

II. Field Studies
   A. Investigations just prior to seal coat operations on original surface to be sealed.
      1. Permeability and absorptiveness studies.
      2. Surface roughness studies for possible increase of spread rate of bituminous binder.
      3. Skid resistance studies.
   B. Investigations during seal coat operations.
      1. Distributor spread rate accuracy and uniformity by various methods.
      2. Screenings spread accuracy and uniformity by various methods.
      3. Study of effect of time intervals between bitumen and screenings application and rolling.
      4. Degradation studies. Selection of short test sites where rolling will be increased in definite steps, using steel and pneumatic rollers and combination of both, followed by removal of screenings for analysis.
      5. Temperature studies involving pavement surface, air temperature, chilling of bitumen, screenings temperature and relationship between these variables. Effects of warm night temperatures on screening retention.

6. Rate of set of bituminous binder, especially asphalt emulsion in relation to weather condition. Determine drying or setting up condition by use of atmometer or automatic recording units.

C. Investigations following seal coat operations.
   1. Immediate.
      a. Condition of seal coat during curing period. Changes in consistency of binder during curing stages and its relation to screenings loss. Effect of temperature and evaporation conditions on such curing rates.
      b. Initial determination of skid resistance following final curing stage and completion of whipoff.
   2. Long range.
      a. Periodic condition survey including skid resistance studies and development of wear and polish tests under traffic. Effects of water. Appearance of seal coat due to possible maldistribution of asphaltic binder.
      b. Rate of hardening of bitumen.

Appendix B

TENTATIVE METHOD OF FIELD TEST FOR THE DETERMINATION OF DISTRIBUTOR SPREAD RATE

Scope

This description covers the procedure for determining the transverse and longitudinal spread rate in gallons per square yard of bituminous distributors by weighing small samples which are caught on uniformly sized paper strips.

Procedure

Part I. Transverse Spread Rate Determination.

A. Apparatus.
   1. Balance sensitive to 0.1 g.

B. Materials.
   1. Cotton pads 4- by 8-in. These pads are especially made for use in cleaning multigraph machines and have clean sharp edges. They are currently purchased from Bauer and Black Company, San Jose, California, under part number 200-847.
   2. 5- by 10-in. sheets cut from heavy wrapping paper.
   3. 8- by 60-in. plates cut from 20 gauge galvanized iron sheets.
   4. Masking tape, $^1/_2$-in. width.
   5. Suitable adhesive for fastening cotton pads to paper. Latex, rubber cement, or asphalt emulsion have been used.

C. Preparation of test panels.
   1. First method.
      a. Cotton pads are attached to the paper strips with the adhesive leaving a 1-in. margin on three sides, see Figure 1.
      b. The paper strips, with cotton pads attached, are then fastened to the metal plates by folding the ends over the plate and attaching with masking tape. Each strip overlaps the exposed paper on the previous strip, see Figure 1.
   2. Second method.
      a. Paper strips (without cotton pads) are attached to the metal plates, each sheet overlapping the adjacent sheet 1 in.
      b. After all paper strips are attached to the metal plates the top surface is coated uniformly with the adhesive. The cotton pads are then placed on the paper so that each pad covers exactly the exposed 4- by 8-in. paper surface. Figure 2 shows

the paper strips on the metal plate and part of the cotton pads in place.

3. Several of the pads with the paper backing should be weighed after they are thoroughly dry, to determine the average tare weight.

D. Sampling.

1. Just before the distributor passes, the test panels are placed across the lane to be sealed, see Figure 5. Figure 6 shows the distributor spray bar just prior to passing over the test panels.
2. As soon as the distributor has passed, the test panels shall be removed from the pavement and the paper and cotton pads removed from the metal backing. As each pad is removed it should be folded so as to cover the binder and prevent loss of volatiles before the sample has been weighed.
3. Weigh each sample pad to the nearest 0.1 g.

E. Calculations.

1. Subtract the average tare weight from the gross weight of each pad and multiply the results by 0.0107 to obtain the spread rate in gallons per square yard.
2. Determine the average spread rate in gallons per square yard by dividing the total quantity of binder collected on the pads by the number of pads.

F. Precautions.

1. Traffic should not be allowed to drive over the test panels. The relatively slow moving distributor truck does not usually disturb the panels.
2. In a very hot climate the work of removing and weighing the sample pads should be done in the shade and with as little delay as possible. If much delay occurs a control sample should be prepared with a known weight of binder and weighed at intervals to determine the evaporation loss rate and a correction made.

G. Reporting of results.

1. The uniformity of transverse distribution is determined by plotting the quantity of binder on each pad against the transverse distance of the pad from the inner edge of distributor spread. The average spread rate and the variation value of ± 15 percent from the average shall also be drawn on the chart.

Part II. Longitudinal Spread Rate Determination.

A. Apparatus.

1. Balance sensitive to 0.1 g.

B. Materials.

1. Square pans 12- by 12-in. with a ¼-in. lip (see Fig. 3).
2. Heavy wrapping paper for liners. Pans may be used without liners but time is saved if they are lined with paper. The paper may be held in place with masking tape.

C. Sampling.

1. Determine tare weight of pans to ± 0.1 g.
2. Place pans approximately 100 ft apart and equidistant from the centerline or edge of the pavement.
3. After the distributor has spread the binder, remove pans and immediately weigh to ± 0.1 g.

D. Calculations.

1. Subtract the tare weight of the pans from the gross weight and multiply the results by 0.00238 to obtain the spread rate in gallons per square yard.
2. Calculate the average and determine the variation from the average for each pan.

E. Precautions.

1. Care should be taken to place all of the pans an equal distance from

either the centerline or edge of the pavement in order that the same jets of the distributor will pass over all the pans.

2. The pans should be placed so that the distributor tires do not pass over them.

F. Reporting of results.

1. Record the average longitudinal spread rate in gallons per square yard and the variation from the average for each individual pan used in the test. The variation from the average shall not exceed ± 10 percent for any one pan.

Appendix C

TENTATIVE METHOD OF TEST FOR MEASURING THE PERMEABILITY OF BITUMINOUS PAVEMENTS

Scope

This method is intended to serve as a rapid field test to determine the relative permeability of bituminous pavements.

Procedure

A. Apparatus

1. Screw type grease gun with regular tip replaced by a valve and a short piece of curved ¼-in. copper tubing.
2. Plastic graduated cylinder. Any cylinder with a capacity from 250 to 500 milliliters is suitable. The cylinder is fitted at the base with a valve from which extends a piece of tubing, 8-in. long and ¼-in. diameter.
3. One standard 250 ml graduated cylinder (glass or plastic) for refill purposes.
4. Template for making a 6-in. diameter circle and yellow marking crayon.
5. Suitable container for holding the "Vel" solution.
6. Stop watch.

B. Materials

1. Medium weight chasis grease.
2. Detergent which is sold under the trade name of "Vel." (It is planned to substitute a definite chemical for the Vel.)
3. Supply of distilled water.

C. Preparation of Test Solution

1. Prepare test solution by mixing 5 g of Vel powder per liter of distilled water.

D. Test Procedure

1. With the crayon and template, draw a 6-in. diameter circle on the pavement to be tested.
2. Extrude grease from the grease gun on the circle. The diameter of the grease on the ring should be about ¼ in. (Fig. 16).
3. Run the finger around the outside edge of the grease ring, pushing a small amount of grease into the pavement. This will form a sealed reservoir for the testing solution.
4. Fill special plastic graduated cylinder and regular graduated cylinder with the Vel solution.
5. Start stop watch and run solution from the plastic graduated cylinder onto the area within the grease ring, keeping this area covered constantly with the solution for two minutes. Refill plastic cylinder if necessary (Fig. 17). Note: At the end of the test the pavement in the grease ring should have an unflooded wet appearance.
6. At the end of the two minute test period, determine the total amount of solution used.

E. Calculations

1. Divide the total quantity of solution used during the test period by two and record the relative permeability in milliliters per minute.

F. Precautions

1. The test should not be performed when the air temperature is below 55 F because of the possible marked increase in viscosity of the Vel solution at lower temperatures.

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