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16. ABSTRACT

It has been apparent for a number of years that the methods commonly employed for estimating the quantity of asphalt and screenings and to control the placing of seal coats are not adequate to insure that satisfactory results will be consistently obtained.

Up to the present time, the accomplishment of a successful seal coat has depended upon skill and experience on the part of the engineer, the availability of suitable equipment and materials and above all upon good weather. However, there has never been an over supply of engineers experienced in this particular class of work and as a result of the rapid expansion in the California Highway Program, it is increasingly difficult to find experienced men for all of the numerous cases where seal coat construction is involved. The problem has been recognized for several years and the Materials and Research Department has been engaged in collecting information, making observations on current practice and as opportunity has permitted, has studied the problem involved in the designing and placing of seal coats on road surfaces.

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c. 2 The Design of Seal Coats and Surface Treatments

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IT HAS BEEN apparent for a number of years that the methods commonly employed for estimating the quantity of asphalt and screenings and to control the placing of seal coats are not adequate to insure that satisfactory results will be consistently obtained.

Up to the present time, the accomplishment of a successful seal coat has depended upon skill and experience on the part of the engineer, the availability of suitable equipment and materials and above all upon good weather. However, there has never been an over supply of engineers experienced in this particular class of work and as a result of the rapid expansion in the California Highway Program, it is increasingly difficult to find experienced men for all of the numerous cases where seal coat construction is involved. The problem has been recognized for several years and the Materials and Research Department has been engaged in collecting information, making observations on current practice and as opportunity has permitted, has studied the problem involved in the designing and placing of seal coats on road surfaces.

Pertinent Discussion

In a recent paper entitled "The Use and Abuse of Seal Coats," Mr. C. V. Kiefer, (1), Member of the Engineering and Development Committee, Pacific Coast Division of The Asphalt Institute, presented a pertinent and timely discussion on the subject of seal coats. Mr. Kiefer has set forth in very readable form most of the factors which have an influence upon the success or failure of seal coats.

The purpose of this article is to describe the problem, to point out some of the factors involved and to outline

the first steps of a definite engineering approach. While complete field data are lacking to support all of the conclusions and inferences drawn, nevertheless, it is believed that a start can be made and as more information becomes available, procedures can be adjusted or modified as found to be necessary. In any event, the field engineer or maintenance superintendent should be furnished with an orderly and logical procedure in order that the essential details of seal coat construction can be handled with greater assurance than is possible at the present time.

Some of Factors

Before attempting to present a design method, it will be desirable to discuss some of the factors affecting the quality and over-all performance of seal coats. As in the case of all bituminous road surfaces, seal coats are made up of two ingredients; namely a bituminous binder and stone chips or screenings. While the ingredients are relatively commonplace and simple, nevertheless, there are many variations in properties of both asphalt and stone and it is proposed to discuss some of these variations.

Before we can decide what is important and what is relatively unimportant, it is necessary to recognize the purpose for which a seal coat is being placed. The term "seal coat" implies that the original intent of this type of construction was to *seal* the road surface; that is, to prevent surface water from penetrating the pavement or base. However, all highway engineers will recognize that a surface treatment of asphalt and screenings may be applied to a road to accomplish *one or more* of several distinct purposes.

Distinct Purposes

These may be summarized as follows:

1. To seal the road entrance of moisture
2. To develop a non-skid existing road surface to be as smooth and slip-resistant as possible
3. To apply a fresh surface which will enliven an old or weathered surface and prove wear resistance.
4. To reinforce and build up weak pavement
5. To provide a definite traffic guidance between sections and traffic lanes.
6. To improve luminosity at night.

The above list indicates approximate order of importance of purpose and it is evident that there are commonly four or more reasons for placing such a "seal coat" and therefore, the type of binder, the amount and size of screenings should be selected intelligently if there is a clear conception of the purpose of each particular case.

California Method

A seal coat may consist of more successive layers of binder and screenings but in many cases, at least in California, a seal coat consists of one application of asphalt on the existing surface. The Standard Specifications for the California Division of Highways "Seal Coats": Class "A-Fine," Class "B-Single, Coarse," Class "C-Medium, Coarse," Class "C-Fine," all of which require application of liquid binder with one layer of screening.

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Analysis Chart Indicating the Relationship or Influence of All Factors That May Affect the Choice and Performance of Screenings

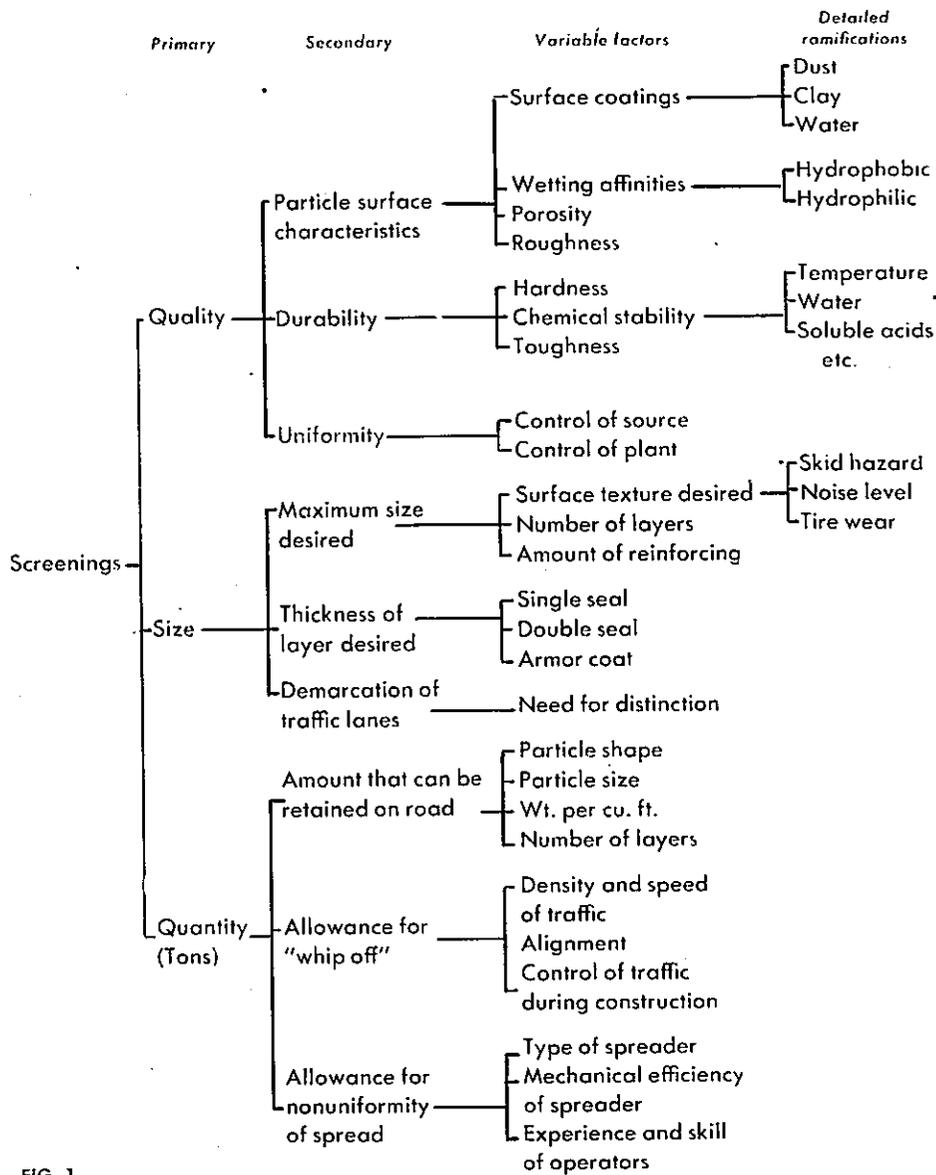


FIG. 1

Items on Figure 1

Up the items on Fig. 1 in first consideration must be given question: What do we mean we stipulate that the screenings of good quality? Common experience indicates that many types of are durable, properly graded and with the proper surface finishes, will be satisfactory for nature of screenings, and it seem to be important whether screenings are in the form of rock, screened gravel or gravel. Good results have been using any of these three types aggregates. However, it is evident "types of stone are not necessarily used in equal amounts and also variance of the seal coat surface will vary somewhat depending the type of aggregate.

important that the screenings ability to retain a film of asphalt in the presence of water. In other the asphalt must wet the stone strip off when subjected to rain water. Mineral aggregates which asphalt can be stripped by film of water are commonly "hydrophilic," meaning that the particles has an "affinity" for water. particles that hold asphalt tenacious even when subjected to water are called "hydrophobic," meaning they avoid water. The question

of adhesion affinities is ordinarily indicated by film stripping tests performed in the laboratory. Certain commercial additives or anti-stripping agents are being sold or proposed for use with the intent of improving the adhesion and thus permit the use of aggregates that otherwise would strip and be unsuitable. So far, these additives have not proved to be universally successful. A number of proprietary compounds are available, but in California practice a selection is made only after laboratory tests have indicated that a certain additive will improve the particular aggregate in question.

Porosity of Stone Particles

The porosity of the stone particles will have an effect upon the amount of oil or asphalt that will be taken up and the surface roughness may also have an influence. However, the question of surface coatings is probably the most serious and the surface films of dust, clay or moisture on the screenings have been responsible for a great many failures in seal coat construction. Like many other factors, these matters are relative, and damp aggregate may cause no trouble when the work is completed and properly cured or conditioned during warm weather. However, the same

amount of moisture in the stone may result in failure when the work is carried on during cold weather or when the humidity is high. The weather condition during the construction period undoubtedly represents the most important single factor contributing to the success or failure of this type of construction.

The question of durability is primarily a problem for laboratory determination and need not be discussed in detail.

Size of Screenings

Uniformity is achieved by the control of plant operations and by efficient operation of the screening facilities.

The second principal factor shown in *Fig. 1* relates to the selection of the size of screenings. In selecting the size, the planning engineer must consider such questions as smoothness of the surface desired, whether or not consideration is given to the irritating noise or rumble in cars and the question of tire wear as well as that of providing an enduring or permanently non-skid surface. In order to make an intelligent selection of screening size, the engineer must give consideration to the primary reasons for placing the particular seal coat, referring to the six distinct purposes listed above in the introduction. It is evident that the selection of stone size will depend to a large degree on the reasons for placing the "seal coat."

At the present time, the choice of screenings for a single course construction on the state highway system generally involves consideration of only two sizes; namely, the *Medium* screenings having a nominal maximum size of $\frac{3}{8}$ " and the *Medium Fine* in which 90 to 100 percent will pass a $5/16$ " screen. Finer screenings have proved troublesome to spread and it is difficult to prevent "padding," or a wavy surface. Coarse screenings of $\frac{1}{2}$ " maximum have been found to develop a noisy uncomfortable surface texture and they are undoubtedly responsible for increased tire wear.

Quality of Screenings

The third primary factor is the question of quantity. In the past, inaccuracy in estimating the quantities have not usually been responsible for

failures. The principal errors have resulted in providing an excessive amount of screenings, which means waste and needless expense. Work in the laboratory of the Division of Highways has followed the lines originally laid down by Hanson in New Zealand, (2), who established the fact that regardless of the amount of screenings placed over a given application of oil, the final layer that adheres would be only one stone in thickness. A series of investigations carried out in California have tended to verify the findings of Hanson. It has been found, for example, that a maximum of 18 pounds of screenings per square yard represented an excellent coverage on the road using $\frac{3}{8}$ " x No. 6 screenings. Experiments conducted in the laboratory indicated that for this size of screenings, 18 pounds per square yard represented a layer one stone thick.

Hanson's Conclusions

Hanson also concluded that for conditions in New Zealand it was necessary to make an allowance of about 10 percent extra material because methods of spreading were not 100 percent perfect and there is a certain amount of loss or "whip off" that occurs when the new surface is subjected to traffic. Under average conditions prevailing during construction in California, it is probable that an estimate of 20 percent allowance is justifiable. The proper allowance for "whip off" should be based upon the type of spreading equipment and perhaps upon the speed and volume of traffic.

Studies conducted by one of the authors, W. R. Lovering (formerly of headquarters laboratory and now Materials Engineer in District I stationed at Eureka) established a relationship between the effective maximum size of screenings and the volume of the same screenings which would produce a layer one stone thick. Hanson established a correlation between the average least diameter of the stone and the quantity of screenings required for coverage. This average least diameter was determined by caliper measurement which is hardly feasible with the screening sizes commonly used in California and an attempt was made to determine a more practical correlation.

"Effective Maximum

A relationship was determined between the "effective" and the loose volume screenings which would produce a layer one stone thick as determined by the size of the screenings which would pass through a certain size of openings. The effective maximum size of the screenings to pass through a certain size of openings. Better correlation was obtained between the "effective" and the loose volume screenings required to produce a layer one stone thick. The effective maximum size may be defined as the size of the mean size of the screenings which would pass through a certain size of openings. The middle 60 percent, the middle 60 percent, the smallest 20 percent of the screenings determined from a plot curve. Screenings from different sources gave somewhat different results, however, indicating that had not been considered. The most important of the factors evaluated are the shape and faces of the rock and the size of the rock particles.

Quantity of

It is felt however, that the effective maximum size of screenings determined by the present methods and equipment, other factors are kept in mind. On the basis of the foregoing, an allowance has been prepared as an estimate of the quantity of any size of screenings required. This chart is a correction for the size of the screenings and an allowance for either 10 or 20 percent "whip off." A correction for variations in weight per cubic foot of the screenings is a final conversion to the volume of screenings required per station. The widths of spread is determined by the volume of screenings possible to compute the lineal feet which would produce a layer one stone thick for any widths of spread. The chart indicates the steps to be followed in determining the quantity of screenings required for any widths of spread.

In order to use the chart, certain determinations must be made. The following information must be obtained: a sieve analysis of the screenings to be used and plotted on a semi-log grading chart.

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PART FOR ESTIMATING THE QUANTITY OF SCREENINGS TO BE APPLIED FOR SEAL PAVEMENT CONSTRUCTION.

Information Required

1. Minimum effective size of screenings and weight per cu. ft.
 2. Proceed in clockwise direction.

3. 1st quadrant determines amount of screenings.
 a. Net amount which will be applied to road surface.
 b. Net amount plus 10%.
 c. Net amount plus 20%.

4. 2nd quadrant converts amount to pounds per sq. yd.

5. 3rd quadrant indicates total quantity required per station.

6. QUANTITY OF SCREENINGS PER STATION

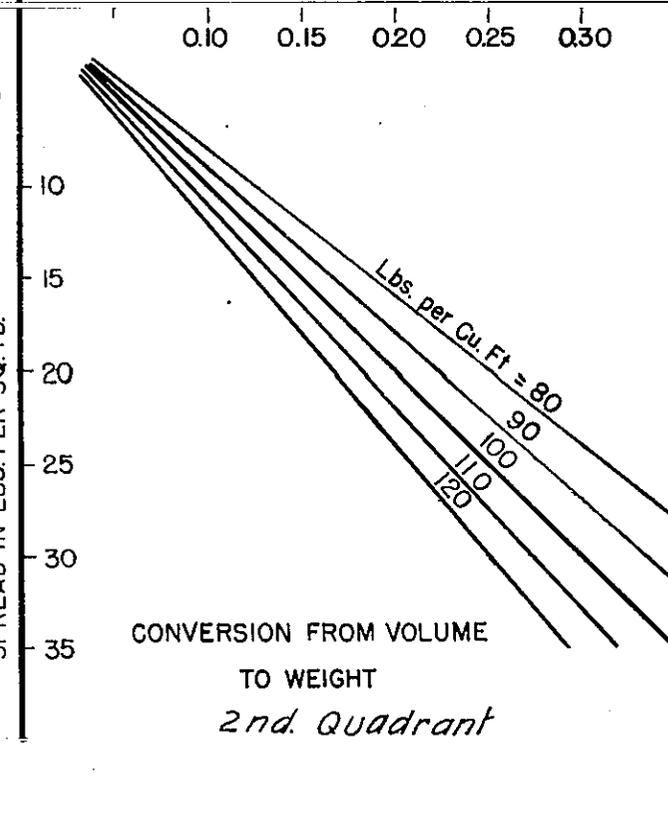
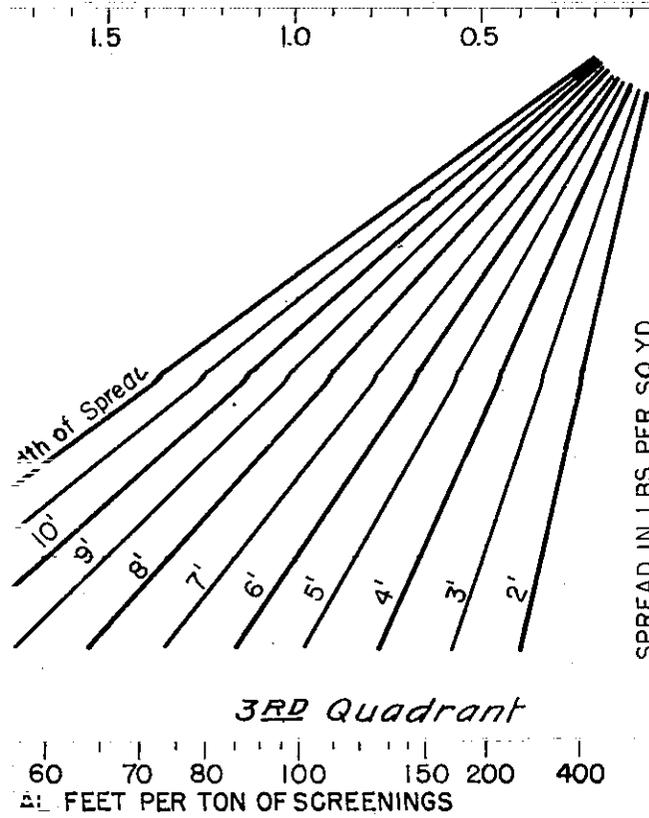
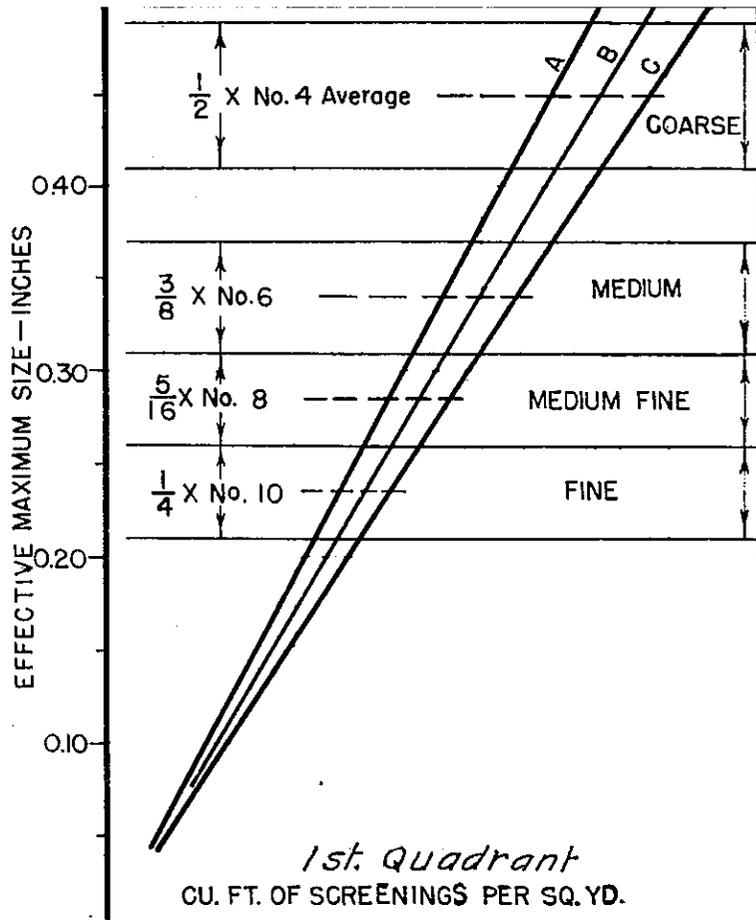
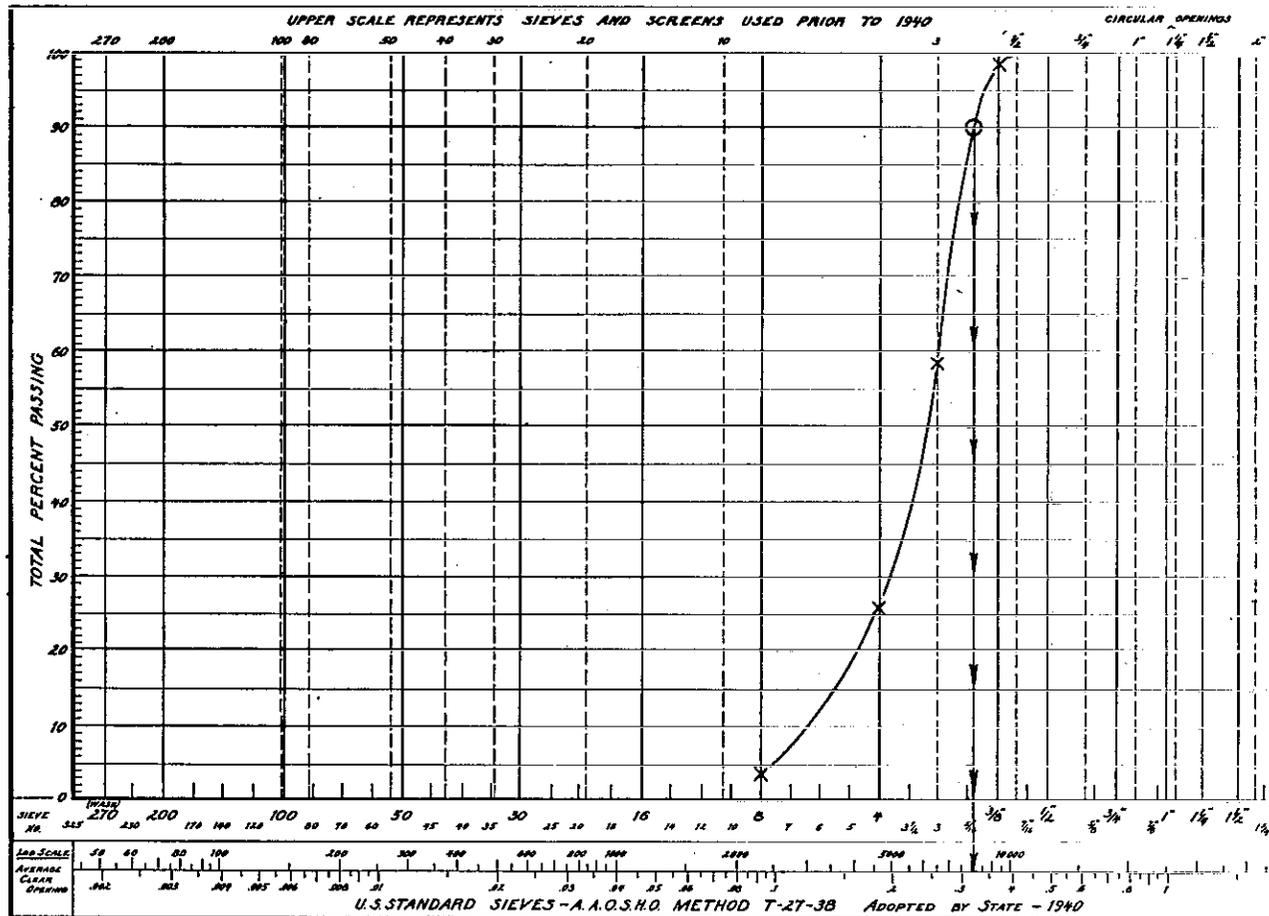


Fig. 2



curve, the effective maximum size in inches is determined by noting the size in inches on the bottom scale that corresponds to the point where the plotted graph crosses the line representing 90 percent passing. *Fig. 3.*

The grading chart, *Fig. 3*, gives an illustration showing a typical curve for a sample of medium screenings of nominal size $\frac{3}{8}$ " x No. 6. In this case the curve crosses the 90 percent line at a point equivalent to a hypothetical screen having 0.32" openings. This represents the effective maximum size of the screenings. Chart, *Fig. 2*, lists the standard specification screenings indicating the range of effective maximum size. The second item of information required is the loose weight per cubic foot of the particular screenings in question. Having the effective maximum size and the weight per cubic foot, the number of pounds of screenings required to cover one square yard can be determined from the chart.

SELECTION AND APPLICATION OF BITUMINOUS BINDER

Any bituminous material, whether asphalt or tar, that is suitable for sticking rock particles to the road surface must have certain properties. For seal coat construction, a bitumen should have good adhesion to the existing road surface and to the screenings. It should develop sufficient cohesive strength to hold the screenings in place and should develop this strength rapidly in order to prevent loss of screenings under traffic. The bituminous binder should be able to resist deterioration under conditions of outdoor exposure and not become hard or brittle for a substantial period of time. In addition, the bitumen should have the proper fluidity or consistency to permit ready and accurate application. As the conditions vary between projects, it is evident that no one grade of liquid asphalt will satisfy all of the requirements for every project considering the wide variety of condi-

tions of the existing road of screenings, equipment climatic conditions which countered in California.

Complex

While the selection grade and type of asphalt is a complex problem, it is often complicated by the dislikes of engineers. Engineers have a philosophical view of a poor job and it is only a certain project turns an engineer understandably view of everything is an unlovely result, and it is that the particular type of asphalt involved is blamed and condemned for all.

In order for a seal coat to hold screenings on the road surface, it must adhere to the screenings and develop at least a certain cohesive strength. In the case of asphalt, this cohesion is

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and to some extent by the rate of evaporation is determined by the temperature of the amount and type of volatile oils, temperature of the air, air movement and by the exposed surface.

Temperature Factor

In the case of seal coats, the temperature of the asphalt is determined by the temperature of the pavement to which it is applied. The pavement temperature will, of course, depend upon the recent air temperature and will be definitely influenced by the pavement's ability to absorb heat directly as radiation from the sun. Thus, it is generally true that liquid asphalt is more fluid in the summer months when the temperatures are long and temperatures are high and reach the desired consistency in a shorter period of time. During the winter months, with shorter days and lower temperatures this interval can be greatly extended depending upon the weather conditions. However, it is also true that hot weather may cause asphalt screenings because the asphalt is too fluid. For example, ROMC Cutback has been observed to give good results in late summer or early fall but is not satisfactory in hot weather when the asphalt was too fluid because of the high temperature and still did not set rapidly enough to hold the

Weather Condition Factor

Fig. 4, has been prepared to show the factors that bear upon the choice of the grade and type of bituminous binder and includes the variables which should influence an estimate of the quantity required. The chart indicates that the prevailing weather condition is one factor having a major influence upon the choice of asphalt. It could be expected that a hot weather curing cutback, RC-5, will set more rapidly in consistency at a faster rate than RORC-5.

The latter product contains a higher percentage of solvent, the base asphalt containing a lower percentage of oily content. Thus, it might appear that the latter would be preferable in cold weather work. However, the question of the weather intervenes as a base stock of RC-5 is 85-100 penetration as-

phalt and ordinarily could be expected to reach the brittle point due to weathering in a shorter period of time. The best solution, of course, is to avoid placing seal coats or any other bituminous construction under adverse weather conditions. It has been suggested that a substitute treatment might be employed in the form of a light application of open-graded plant mix placed upon a heavy tack-coat in lieu of the orthodox seal coat when weather conditions are liable to be unfavorable.

Traffic Density Factor

Aside from durability reasons, the density of traffic to be carried is a major factor. With increase in traffic and average vehicle speed, the problem of closing a road to traffic becomes more difficult. While it is essential that traffic be kept off the road until the asphalt reaches a consistency which will hold the stone chips in place, the setting time required will vary depending upon the type and grade of asphalt as well as the prevailing weather. This indicates the importance of using a rapid setting binder when construction must be carried on in the late fall.

The lower portion of the chart, Fig. 4, lists factors which have an influence upon the quantities of bituminous binder. These factors are the character of the screenings, the condition of the existing road surface, also the degree and kind of compaction to which the screenings will be subjected.

Under the heading "Character of Screenings" is included such things as particle gradation, particle shape, particle roughness and porosity. The gradation or sieve analysis of the screenings is an index to the amount of voids which must ultimately be filled with asphalt. The particle shape, that is, whether the stone chips are relatively cubical or flat will also have an influence on the void space. Particle roughness and porosity will take up additional oil compared to normal screenings. Hanson pointed out that the amount of asphalt should range from 0.5 to 0.7 of the voids in the aggregate as placed and compacted on the road.

Particle Shape Factor

While sieve analyses are easily made and the surface capacity of the stone due to roughness and porosity can be

evaluated by noting the amount of light lubricating oil that will be retained by the screenings when drained under standard conditions (4), the factor of particle shape or cubicity is less easy to evaluate. Hanson (2), recognized the effect of cubicity in the screenings and proposed that the least dimension of individual rocks of a representative sample should be measured. Hanson averaged the least dimension of a number of particles and estimated the amount of oil from this average value. However, Hanson was dealing largely with coarse stone ranging from 1/2-inch to 3/4-inch in size and as stated above his method of measuring individual particles by means of calipers does not seem practicable for the smaller sized screenings now used in California.

A method having better possibilities was developed by Egberto F. Tagle (3) of Argentina. This procedure involved the use of slotted screens which provide a particle size analysis based upon least dimension rather than upon maximum size of the rock particle. By comparing this type of grading analysis to the grading produced by standard screens, Tagle derived a factor which he designated the "cubicity factor" and the quantity of oil recommended in Argentine practice was based upon this factor. They also consider that "cubical" shaped particles are most satisfactory.

Oil

In the design chart, Fig. 5, the quantity of oil to be applied is based upon the *maximum effective size* of the screenings derived from a standard sieve analysis rather than upon the cubicity or average least dimension. This method has been selected because it is at the present moment more applicable than are the procedures proposed by either Tagle or Hanson.

Correction for Porosity

The particle roughness and porosity can be determined by methods described in connection with the Centrifuge Kerosene Equivalent Test for establishing the surface factor K_c (4). The design chart, Fig. 5, carries an allowance for porosity of the stone in the third quadrant of the chart. (The factor K_c may be determined by measuring the amount of No. 10 lubricating oil retained by the screenings after they

have been soaked in the oil and then drained under controlled temperature conditions.)

In considering a correction for porosity using the factor K_e , it must be pointed out that this correction represents the amount of oil that will ultimately be absorbed by the screenings and the rate of absorption will depend upon the consistency of the bituminous binder which, in turn, is a function of temperature. As the temperature of an asphalt film in any sort of road mix or penetration treatment is controlled entirely by the temperature of the road surface or the aggregate, it is evident that absorption may take place very slowly when the road surface is cold and as a result the asphalt applied to compensate for absorbent aggregates may appear to be excessive and bleeding may develop before the excess is absorbed. However, at some future time when the pavement temperature rises, the oil may be absorbed and if a sufficient quantity is not applied in the first instance the absorption may leave an insufficient amount to hold the screenings in place. Therefore, it appears that screenings composed of highly porous stone will be particularly unsuited for cold weather work. It is not the intent to suggest that the ultimate amount of asphalt be applied during cold weather for a seal using porous aggregate. The inevitable result would be that sand would be applied to take up the apparent excess and the surface would dry out sooner or later. It is probable that the best solution is to avoid porous aggregates when possible.

Chart, Fig. 5, includes a correction for the porosity of the old road surface and it should again be emphasized that weather conditions and the presence of moisture may have a definite influence on the rate at which the oil is absorbed.

Summary of Factors

To summarize, it is recognized that the quantity of screenings required to cover the road surface will vary depending upon the size of the screenings and hence, the dimensions of the stone. Thus, a greater weight in volume of screenings will be required to develop a coverage of 1/2-inch screenings than will be required if 1/4-inch size is used. As the screenings vary in weight per cubic foot, a correction must be made

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Analysis Chart Indicating the Relationship or Influence of All Factors That Affect the Choice and Performance of Bituminous Binder

(Assuming That the Bituminous Binder Is of Suitable Quality)

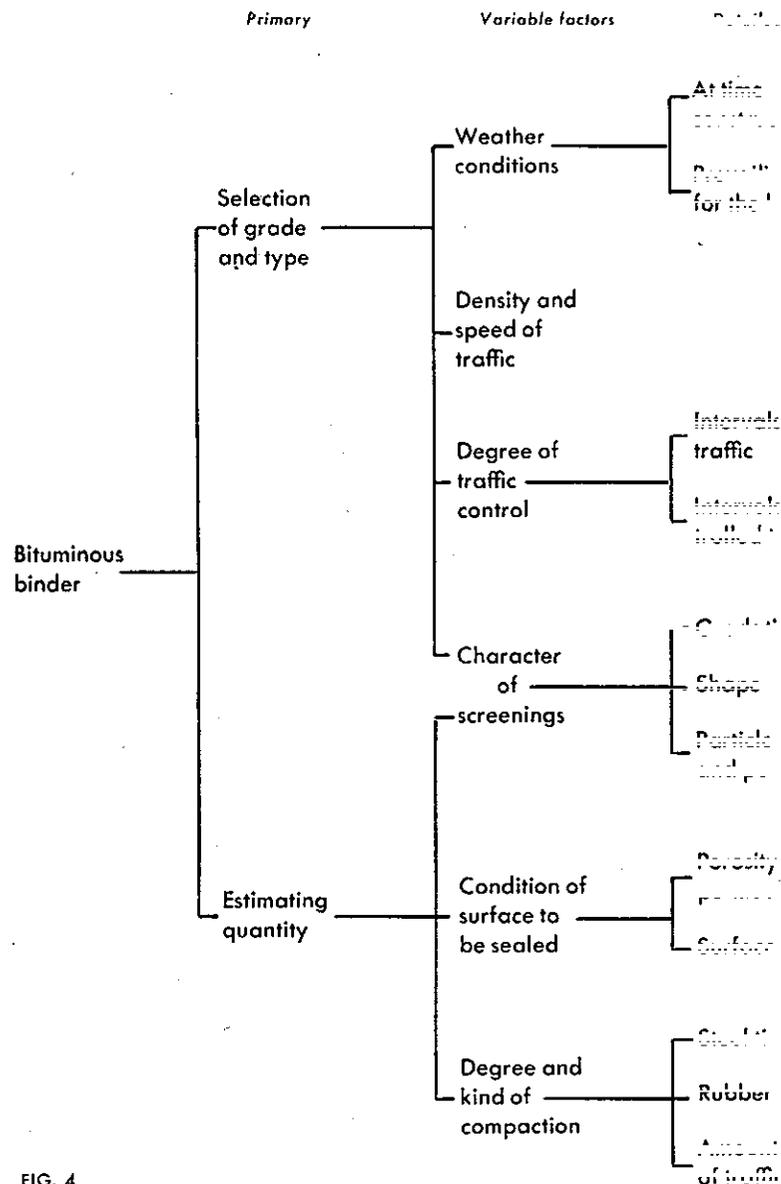


FIG. 4

in the number of pounds per square yard or the number of tons per station to compensate for variations in the volume-weight relationship. The amount of asphalt required is a function of the voids existing in the layer of screenings applied to the road. The total application of asphalt is also influenced by the amount necessary to prime the existing road surface which means that the existing surface must be evaluated in order to determine how much of the application will be taken up as a prime. Finally, there will be

some variability when they are definitely porous. The evaluation of these variables will give an accurate estimate of the application and the total amount required.

Selection of Bituminous Binder

A casual survey of California practice indicates that the best bituminous binders for seal coat applications are around the SC-6 grade. SC-6 of 200-300 penetration will be very satisfactory. How-

PART FOR ESTIMATING THE QUANTITY OF ASPHALT REQUIRED FOR A SEAL COAT.

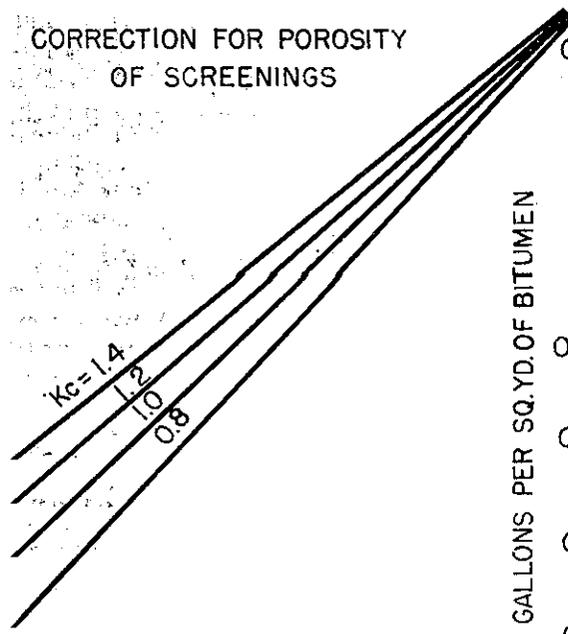
Formation Required

- Effective maximum size of screenings; porosity of screenings; condition of existing road surface.
- Proceed in clockwise direction.
- 1st quadrant gives amount of screenings which must be held by asphalt.
- 2nd quadrant adds amount of asphalt needed for prime existing road surface.
- 3rd quadrant provides allowance for porosity of screenings.

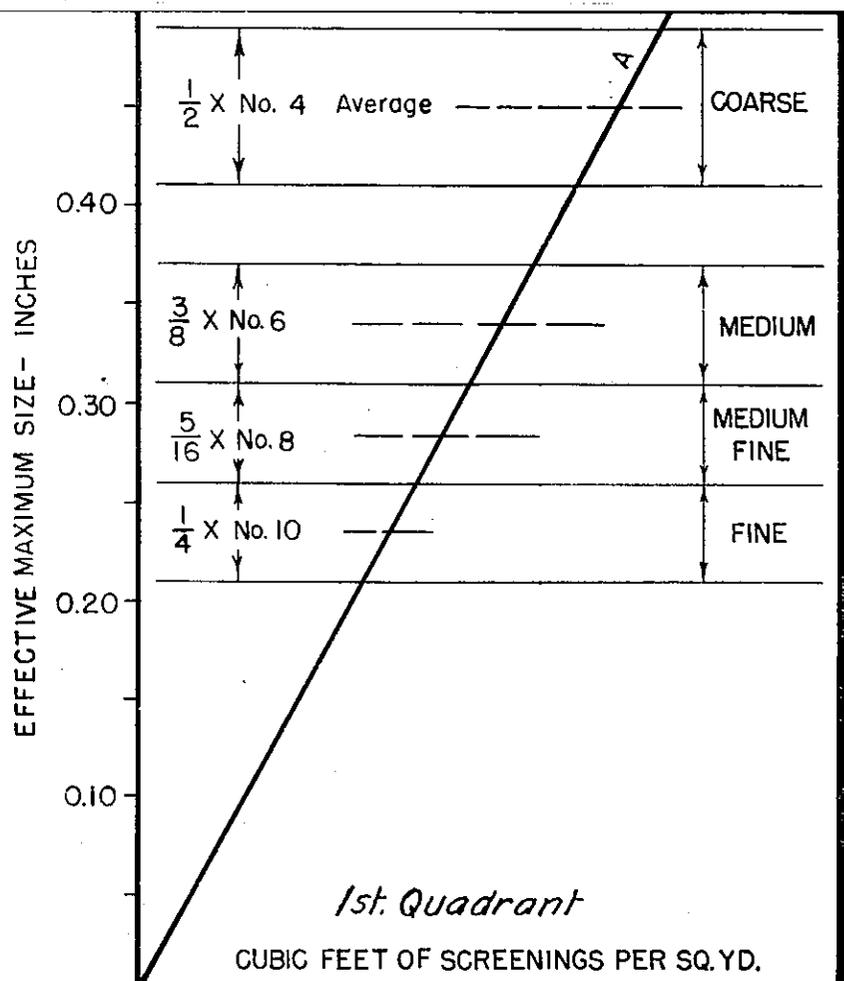
correction for grade type of asphalt.

APPLICATION OF BITUMEN IN GAL. PER SQ. YD.

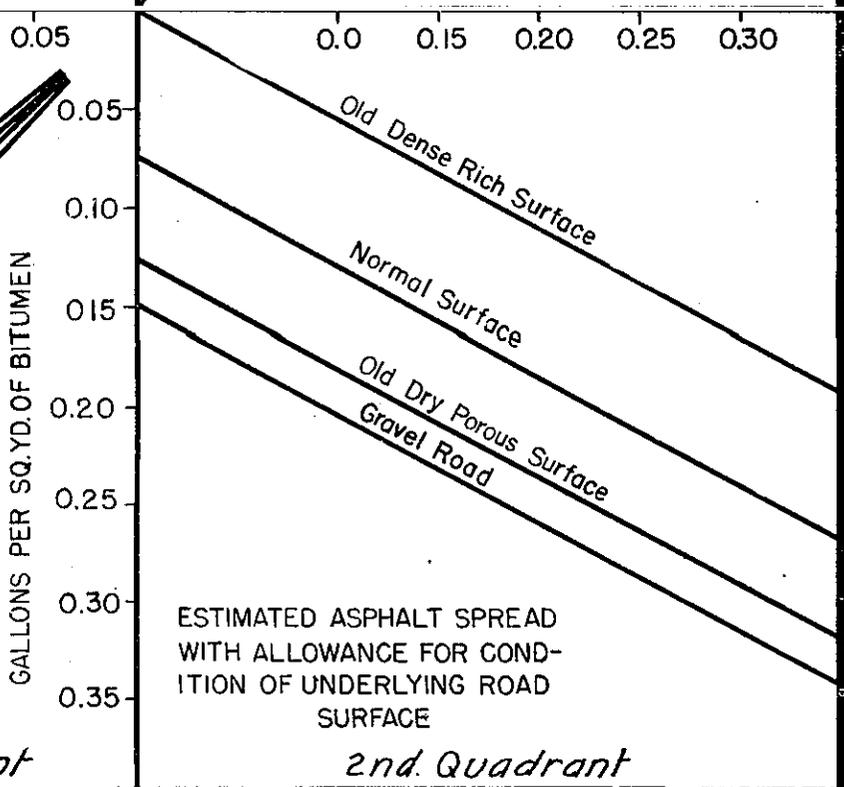
CORRECTION FOR POROSITY OF SCREENINGS



3rd Quadrant

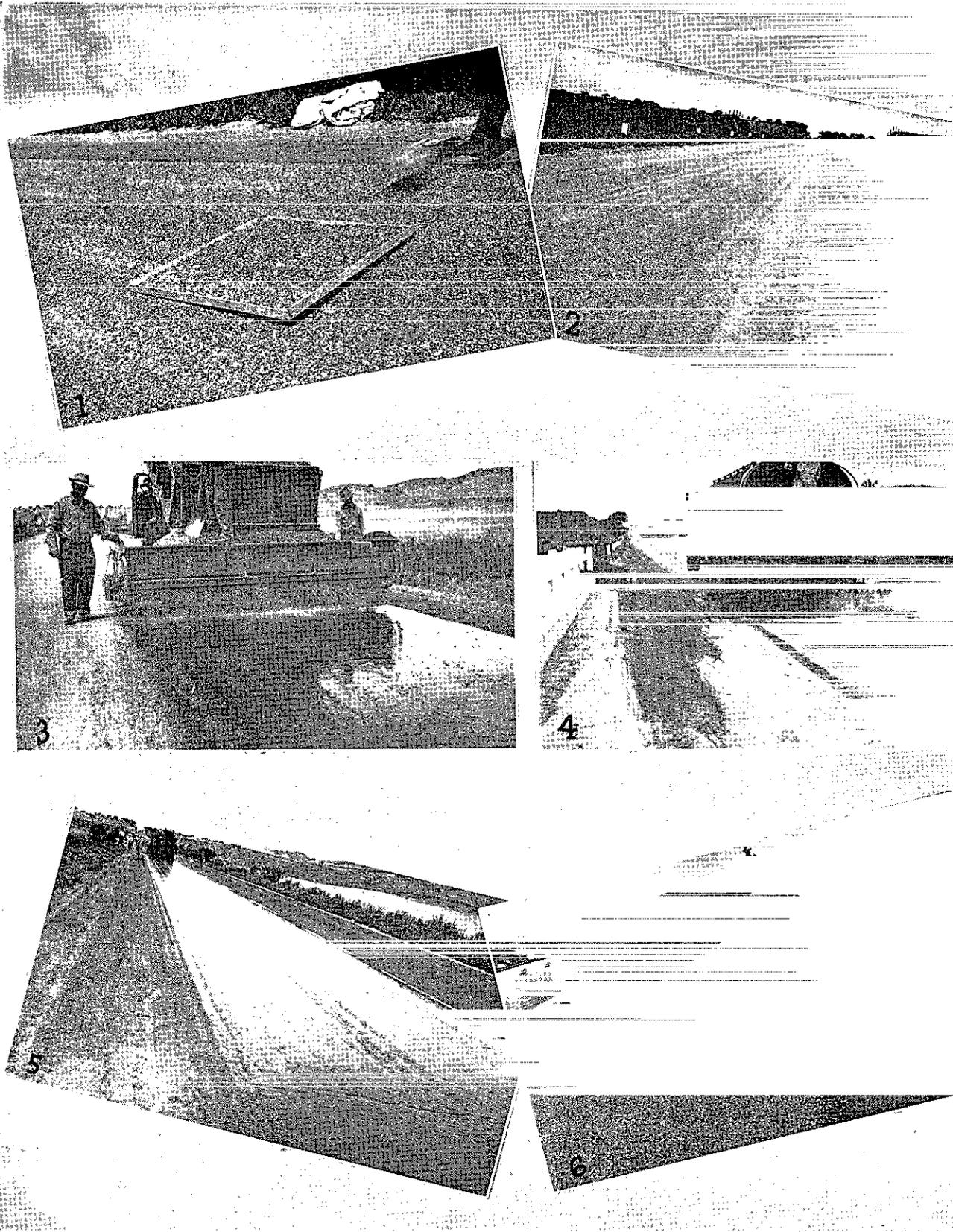


1st. Quadrant



2nd. Quadrant

Fig. 5



1—A tray representing one square yard placed on pavement to determine uniformity of distribution of screening spreader. 2—A newly
 3—Screenings being applied to the surface with a mechanical spreader. 4—Distributor truck starting spread of asphalt. 5—Freshly applied
 following passage of distributor. 6—Screenings being rolled with a tandem roller

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asphalt distributor could not in order to apply the desired. The quantity of SC-6 be cut down to the desired causing skipping or streaks sprays. For this reason, the has often been diluted with and many projects have been with MC-3, 4 or 5, or with 3, 4 or 5, all of which represent of soft asphalt and a kerosene of cutter stock.

to avoid loss of screenings slow setting of kerosene cut-back types have been preferred in. However, the standard of rapid curing cutbacks are from base stock of 85- asphalt and in order to advantage of a softer base asphalt special grade of cutback is the California Standard Specification and designated as RORC-5 of 200-300 penetration asphalt cutback with a small amount of solvent.

Emulsified Asphalt

method for reducing the and thus permitting light application to be made with a high degree of uniformity is the use of emulsified. A great deal of satisfactory

seal coat construction has been accomplished by the use of emulsions. From evidence now available, it does not appear that it is necessary to make any distinction in the quantities of asphalt used whether soft paving grades, cutback or emulsion.

Ordinary emulsions of the penetration or mixing type have a viscosity ranging from 20 to 100 seconds. Emulsions of this type have a tendency to run off the road on steep grades, especially on superelevated curves. In order to avoid this difficulty, special emulsions have been developed giving a viscosity range from 200 to 400 seconds or even greater. These emulsions have noticeably less tendency to run off the road. However, the high viscosity of emulsions can be achieved in different ways and in certain cases an increase in viscosity has been accompanied by a slower setting which resulted in the loss of screenings.

It is hoped that the foregoing outline will help to clarify the problem and that the charts and method of calculation will serve to remove some of the uncertainties involved in current practice.

The procedure proposed is not considered to be complete or final and may

be subject to correction or modification when more data are available.

It is desired to acknowledge the helpful comments and suggestions of Mr. T. H. Dennis, Maintenance Engineer; Mr. Nelson Bangert and Mr. Clarence Woodin of Headquarters Maintenance Department, Mr. G. A. Tilton, Jr., Assistant Construction Engineer; Mr. C. E. Bovey, Assistant District Engineer at Stockton, and Mr. C. V. Kiefer, member of the E & D Committee, Pacific Coast Division of the Asphalt Institute.

References

- (1) C. V. Kiefer, *Second Nevada Asphalt Forum held at Carson City, Nevada, November 18, 1948. Published in The Crushed Stone Journal, June, 1949*
- (2) F. M. Hanson, M.M., *Bituminous Surface Treatment of Rural Highways, Proceedings of the New Zealand Society of Civil Engineers, 1935.*
- (3) Egberto F. Tagle, Buenos Aires, Argentina, *Personal Communication.*
- (4) F. N. Hveem, *The Centrifuge Kerosene Equivalent as Used in Establishing the Oil Content for Dense Graded Bituminous Mixtures, Proceedings of the A. A. P. T., 1942. Reproduced in California Highways and Public Works, 1942.*



