ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

FIELD EVALUATION OF A SEAL COAT DESIGN METHOD

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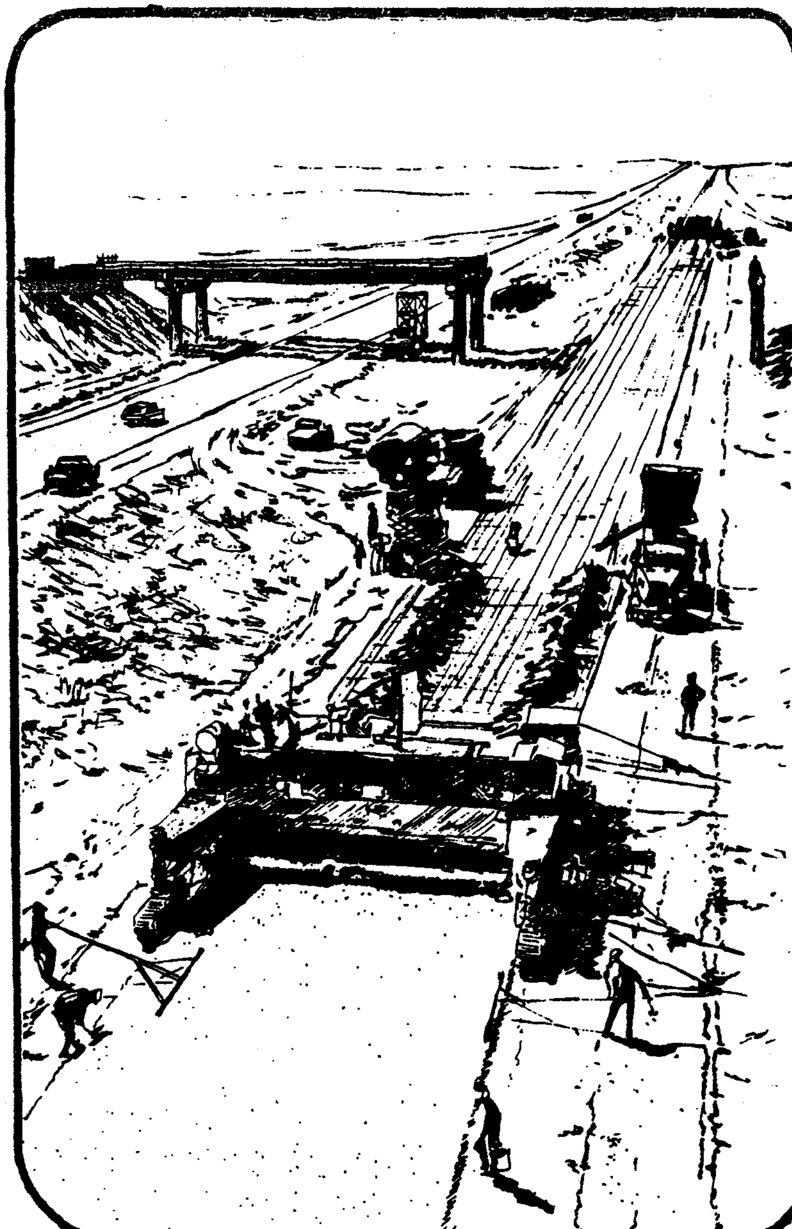

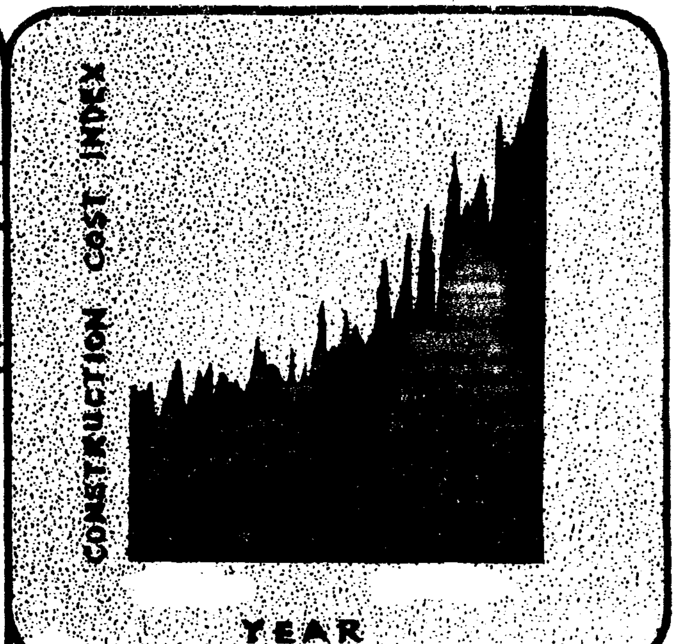

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"ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS IN DESIGN, CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT
OF HIGHWAYS
AND PUBLIC TRANSPORTATION

AND

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

FIELD EVALUATION OF A SEAL COAT DESIGN METHOD

by

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Engineering, Economy and Energy Considerations in Design,
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INTRODUCTION

The Texas State Department of Highways and Public Transportation and the Texas Transportation Institute through their cooperative research program have developed a seal coat design procedure. This design procedure is based on a modification of the original Kearby Method (1) and includes separate design curves for seal coats made from lightweight aggregates and normal weight aggregates.

A review of the historical development of this method has indicated that the design procedure has not been verified by a field performance study. Furthermore, field observations on normal weight aggregate seal coats have indicated that the design procedure calls for inadequate asphalt. In an attempt to determine the validity of the design and/or to alter the method, a field study was undertaken. This study consisted of visual evaluation of seal coat trial sections placed as a part of Research Study 2-6-71-83 "Synthetic Aggregates for Seal Coats". Details of this field evaluation and subsequent analysis of data are described below.

HISTORICAL DEVELOPMENT OF EXISTING SEAL COAT DESIGN METHOD

Methods available for the design of asphalt quantity and aggregate spread rate for seal coats and surface treatments have been summarized by the Asphalt Institute (2). Three methods are presented by the Asphalt Institute and they are referred to as design method for one-sized aggregate, design method for graded aggregate and design method for multiple surface treatments. These methods are based on references 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, and 11. The design method for one-sized aggregate is based on Hanson's work (7), the design for a graded aggregate seal coat is based on work performed by Lovering (4) while the method for multiple surface treatments is based on studies by Kearby (1) and Benson and Gallaway (3).

A review of SDHPT practices (12) indicates that the Kearby method also referred to as the "board" method appears to be the most popular method utilized in the state. The Asphalt Institute (2) further suggests that this method be utilized for final design quantities when the aggregate has been selected and available for design. In order to obtain a comparison of the existing design methods, asphalt and aggregate design quantities for SDHPT Grade 4 lightweight aggregate (Item 303) (13) were determined by Hanson's Method as described in reference 2 and by the Modified Kearby Method as developed by Benson and Gallaway and described in reference 14. These values for the extreme fine and coarse side and the median of the gradation specification are shown in Table 1. In general, the aggregate rates determined by the Modified Kearby Method are in agreement with proven field experience gained by SDHPT and the research team. Thus, those aggregate quantities determined by Hanson's method are greater than required. The asphalt quantities resulting from both methods are lower than those generally utilized for synthetic aggregate seal coats in Texas. Therefore, it appears as if adjustments should be made in these design methods for prediction of asphalt quantities for lightweight aggregates.

An additional comparison of existing seal coat design methods was made on aggregates obtained from trial field sections placed on State Highway 95 in District 14 (Table 2) (12). Hanson's and Lovering's design calculations were performed according to the procedure given in reference 2 while the Modified Kearby Method was performed according to the procedure given in reference 14. The fourth method, whose results are shown in Table 2, is a modification of the Kearby Method as prepared by J. W. Livingston of District 19 (Atlanta) of the SDHPT. Of the methods investigated, the Modified Kearby Method again appears to be the best predictor of aggregate quantity while the Lovering and District 19 method give the best prediction of the asphalt quantity. Inaccuracies in determination of aggregate bulk specific gravity may be responsible for the unusually high aggregate quantities predicted by Hanson's method.

In order to more accurately predict the quantities of asphalt required for a particular synthetic aggregate seal coat, a modification of the existing Kearby Method was developed as part of Study 2-6-71-83. These modifications include the development of correction factors for traffic volume and surface condition as well as a shift in the relationship between percentage of embedment and average mat thickness (Figure 1). The design method which was published in 1974 is contained in Appendix A. A single design equation was suggested for use, however, depending on the selection of the aggregate (lightweight), a different relationship between percentage of embedment and average mat thickness was suggested (Figure 1).

As indicated above, field verification of the design method was not attempted as part of the cooperative research program. However, Study 2-9-74-214, "Engineering-Economy and Energy Considerations in Design, Construction and Materials", identified the need for such a verification and consequently a field study was performed in March of 1976.

FIELD EVALUATION

In an attempt to obtain verification of the design method, trial field sections placed in 1971 and 1972 as part of Study 2-6-71-83 were visually examined. These trial field sections were selected because extensive construction records were maintained and other data such as traffic volume, surface texture, skid number, aggregate gradation and aggregate samples were available to the study team.

The visual survey was conducted by C. W. Chaffin and A. J. Hill of the Materials and Tests Division of SDHPT and J. A. Epps of the Texas Transportation Institute in March of 1976 utilizing the form shown on Figure 2. Data collected included a visual determination of aggregate embedment depth both in the outer wheel path and between the wheel path. The visual data were summarized and combined with construction data and laboratory measured properties of the aggregate as shown in Table 3. These data together with traffic volume and the condition of the pavement prior to the seal coat operation, which is found in Table 4, formed the basis for the analysis presented below.

ANALYSIS OF FIELD DATA

The equation utilized to determine asphalt quantity by the existing Modified Kearby seal coat design method is shown below.

$$A = 5.61E \left(1 - \frac{W}{62.4G}\right) (T) + V$$

A = asphalt quantity, gals, sq. yd. at 60°F

E = embedment depth, inches

where

E = ed, inches

e = percent aggregate embedment (Figure 1)

d = average aggregate or mat depth, inches

$d = \frac{1.33Q}{W}$, inches

Q = aggregate quantity determined from board test,

W = dry loose unit weight, lbs. per cu. ft.

G = dry bulk specific gravity of aggregate

T = traffic correction factor (Table 5)

V = correction for surface condition (Table 6)

The quantities "T" and "V" are adjustments to the asphalt quantity for traffic and surface condition of the pavement upon which the seal coat is to be placed.

The quantity "$(1 - \frac{W}{62.4G})$" is a calculation which determines the percent air voids in the seal coat aggregate as if it were placed in a container without any form of compaction. Theoretically, this is the volume available for the asphalt to fill.

The quantity "E" is the depth of the asphalt in the seal coat. This quantity is derived from use of Figure 1 which allows the engineer to determine the desired percent embedment depth, "e", based on "d", the expected average depth of the aggregate.

The values of "W" and "G" can be measured in the laboratory; thus, it appears as if "E", "T" and "V" are the variables that may be changed to improve the design equation. The terms "T" and "V" have been defined in the literature cited above. A rather extensive field testing program would be required to reliably change the values of "T" and "V". Thus the current values have been accepted; however, the use of surface texture measurements as an indication of what value to select for "V" has been developed and explained below.

Use of Surface Texture to Determine the Value of "V"

Values of pavement surface texture as determined by the putty test have been obtained on a number of research projects at the Texas Transportation Institute for a variety of pavement types. These data are shown on Figure 3. It should be noted that a great deal of variation exists for the pavement types identified.

The amount of asphalt required to fill the surface texture (voids) in the pavement is calculated and shown on Figure 4 (theoretic requirements). These quantities far exceed those quantities normally considered appropriate (Table 6). Therefore, the relationship between surface texture and the asphalt application rate correction quantity has been altered based on field experience utilizing the range of the correction quantities normally accepted. This relationship is based on the approximate correlation found in Table 6. Additional field experience may alter this relationship.

Adjustment of Percentage of Embedment Versus Mat Thickness Relationship

Probably the most logical relationship to adjust is the relationship between percentage of embedment and mat thickness shown in Figure 1. A methodology was developed and utilized to investigate this relationship and is described below.

Values of "W" and "G" were determined from laboratory tests on aggregates utilized on the various field trial sections. The values of

"T" and "V" were obtained from Tables 5 and 6 by using the field determined traffic and surface texture as shown in Table 8. The value of "A" was obtained from field construction records (12). This value of "A" was adjusted by using field observation data on aggregate embedment depth (Table 3). The asphalt quantity was adjusted to an embedment depth of 80 percent as visual observation data indicated that an 80 percent embedment depth was acceptable from a bleeding standpoint (Figure 5). A bleeding score of 10 indicates no bleeding; whereas a score of 1 indicates extensive and severe bleeding.

The value of "E" is a function of "e" and "d". Since "d" can be obtained from laboratory tests performed on the aggregates, the only unknown in the design equation becomes "e". Thus, the following relationship results.

$$e = \frac{A-V}{5.61(d)\ (1 - \frac{W}{62.4G})\ (T)}$$

Figure 6 illustrates the range of values of "e" that results in a field embedment of 80 percent 4 to 5 years after construction. It should be noted that those seal coats constructed with asphalt cement are separated from those constructed with asphalt emulsion. No explanation is noted for the wide range of values noted between emulsions and asphalt content. For a given amount of residual asphalt, emulsified asphalts appear to be more effective as aggregate binders than pure asphalt cements.

The average, standard deviation, coefficient of variation and minimum and maximum values of "e" for asphalt cement and emulsion seal are shown on Table 9. The average value of "e" for asphalt cement seal coats is

0.33 which compares to about 0.40 from the present design chart considering the mat thicknesses utilized in these field trial sections. The data scatter as shown on Figure 6 and as indicated by the coefficient of variation appears to be excessive. It should be remembered, however, that data from visual ovservations (field embedment depth) are an integral part of the calculation. Additionally, it is not unusual to find field asphalt quantities varying ± 0.03 gallons per square yard (2, 12) and surface characteristic of the pavement upon which the seal coat is to be placed to vary considerably. For example, surface texture measurements from State Highway 6 in District 2 have coefficients of variation of the order of 40 percent. Common coefficients of variation associated with asphalt concrete quality control are of the order of 5 to 20 percent (15).

An example to illustrate the variability of the design asphalt quantity associated with the selection of "e" is given below if one assumes that aggregate "C" has been utilized from District 2 trial field sections. For an "e" of 0.39 the design asphalt content is 0.32 gallons per square yard. If the value of "e" is varied ± one standard deviation (0.07) the resulting design asphalt content varies ± 0.05 gallons per square yard. It is logical to assume that the factors "T" and "V" may be in error and/or the visual evaluation procedure could account for this variation.

VARIATION IN ASPHALT SURFACE DEMAND

As discussed above the equation for determining asphalt quantity includes the term "V" which is a correction factor dependent on the characteristics of the old pavement upon which the seal coat is to be placed. According to the design method included in this report, "V" will vary from -0.06 to +0.06 gallons per square yard according to those factors described on Table 6 and Figure 4. Under most conditions the correction factor "V" is applied for a considerable length of pavement or in most cases for the entire section of highway to be seal coated. Occasionally, a different "V" and "T" will be utilized for 4-lane facilities when traffic volumes and/or lane surface textures differ.

Recent field work in District 23 of the SDHPT has illustrated the importance of altering the quantity of asphalt not only in the longitudinal direction but also the transverse direction (16). Variations in asphalt quantities across the pavement are required due to the effect of traffic. The asphalt demand in the wheel path is usually reduced from that required outside the wheel paths. It is not uncommon to find highways whose wheel paths have a tendency to bleed while slight raveling occurs between the wheel path and/or near the edges of the lane.

Surface texture measurements made by the putty method have been obtained on 120 pavements most of which are pavements containing limestone rock asphalt in either a seal coat or cold mixed cold laid operations. The average difference in surface texture between the wheel path and in the wheel path is 0.010 cubic inches per square inch. The values ranged from +0.076 to -0.097*. The standard deviation for the 120 sections is 0.024. A surface texture difference of 0.010 represents about 0.06 gallons per square yard of asphalt (Figure 4) from a theoretical standpoint.

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*A positive difference indicates that the surface texture between the wheel paths is in excess of the surface texture measured in the wheel path.

In order to achieve the variation in asphalt quantity desired, District 23 has experimented with spray nozzles and methods to measure spray bar outputs. Results to date indicate that a one size reduction in the spray nozzle results is about the desired asphalt variation.

CONCLUSIONS AND RECOMMENDATIONS

Adjustment of the original Kearby Curve (1) by Benson and Gallaway (3) was in the direction of increased asphalt. The adjustment by Epps and Gallaway (12) for lightweight aggregate is also in the direction of increased asphalt. This correlation was made based on increased asphalt embedment depth to insure that the high friction lightweight aggregate would not be overturned and subsequently ravel under the action of traffic. Synthetic lightweight aggregate seal coat trial field sections placed in 1971 and 1972 in four Districts of SDHPT and visually examined in 1976 indicate that on the average the design method proposed for lightweight aggregate results in a slight over-estimate of asphalt quantity.

Field data from normal weight aggregate seal coats have not been obtained and in absence of these data it appears feasible to utilize the design curve developed for synthetic lightweight aggregates for the design of seal coats containing normal weight aggregates as well. A suggested design method is contained in Appendix A.

Consideration should be given to varying the asphalt quantity both longitudinally and transversely if demanded by the pavement upon which the seal coat is to be placed. This variation is included in the proposed design equation by the factor "V". Surface texture measurements may provide a basis for determining the magnitude of this correction factor.

Additional field verification is required particularly for normal weight aggregate seal coats. Districts are encouraged to utilize the suggested design method together with surface texture measurements to establish seal coat asphalt and aggregate requirements. Visual evaluation at various time intervals after construction should be made by a survey team to establish seal coat performance. Seal coat projects should be selected such that the aggregate depth (mat thickness) extends beyond the range of 0.25 to 0.35 as data from the study presented herein covers aggregate gradations in this range.

Data presented on Figure 6 indicate that different design curves should be used for emulsions and asphalt cement binders. Additional field data need to be collected prior to establishing this relationship. In this interim it is suggested that several districts place trial sections using the approach given below.

1. Use the same design curve as for asphalt cements
2. Adjust for the amount of water present in the emulsion
3. Multiply by a factor of 0.80
4. Adjust for spray temperature

For example, the design method indicates that 0.30 gallons per square yard of asphalt cement will be required for a particular project. If the emulsion proposed has 30 percent water, the corrected quantity would be

$$\frac{0.30}{0.70} = 0.43 \text{ gallons per square yard}$$

Multiplying 0.43 x 0.80 gives the amount of emulsion to be sprayed on the surface (0.34 gallons per square yard). If the emulsion were to be sprayed at 140°F, the temperature correction would be 0.98. Thus, $\frac{0.34}{0.98}$ or 0.35 gallons per square yards of emulsion would be sprayed at 140°F.

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APPENDIX A

SYNTHETIC AGGREGATE SEAL COAT DESIGN METHOD

The design method described below is based on field experience gained by representatives of the Texas Highway Department and the Texas Transporation Institute on synthetic aggregate seal coats since 1961. The method is based on Kearby's original research as modified by Benson and Gallaway. Modification on the original design method includes changes in the relationship between mat thickness and percent of embedment and correction for traffic volume and existing surface condition.

LABORATORY TESTS

Dry Loose Unit Weight

The dry loose unit weight determination shall be made in accordance with Tex-404A, except that the aggregate shall be tested in an oven-dry condition.

Bulk Specific Gravity

The bulk specific gravity should be determined by the method given in Appendix B.

Board Test

Place sufficient quantity of aggregate on a board of known area such that full coverage, one stone in depth is obtained. A half square yard area is a convenient laboratory size. The weight of the aggregates applied in this area is obtained and converted to the units lbs. per square yard. Good lighting is recommended and care should be taken to place the aggregate only one stone in depth.

CALCULATIONS

The quantity of aggregate expressed in terms of square yards of road surface per cubic yard of aggregate and the quantity of asphalt in gallons per square yard can be found as described below.

<u>Asphalt Quantity</u>

$$A = 5.61E \quad 1 - \left(\frac{W}{62.4G}\right) \quad (T) + V$$

<u>Aggregate Quantity</u>

$$S = \frac{27W}{Q}$$

where:

S = quantity of aggregate required, sp. yds. per cu. yd.

W = dry loose unit weight, lbs. per cu. ft.

Q = aggregate quantity determined from board test, lbs. per sq. yd.

A = asphalt quantity, gals./sq. yd.

E = embedment depth obtained from Figure A-1 as follows:

E = ed

where:

e = percent embedment (Figure A-1)

d = average mat depth, inches

$$= \frac{1.33Q}{W}$$

G = dry bulk specific gravity of aggregate

T = traffic correction factor obtained from Table A-1

V = correction for surface condition obtained from Table A-2

Note: Asphalt quantities calculated by these methods are for asphalt cement. Appropriate corrections should be made where utilizing cutback and emulsion.

SAMPLE CALCULATION

Given:

(W) Dry loose unit weight of aggregate = 52.4 lbs./cu. ft.

(G) Dry bulk specific gravity of aggregate = 1.57

(Q) Quantity of aggregate (board test) = 9.7 lbs./sq. yd.

Traffic = 700 vehicles per day per lane

Roadway Surface Condition = slightly pocked, porous oxidized

Quantity of Aggregate

$$S = \frac{27W}{Q} = \frac{27(52.4)}{9.7} = 146 \text{ sq. yds./cu. yd.}$$

(square yards of roadway surface per 1 cubic yard of aggregate)

Quantity of Asphalt

$$A = 5.61E\left(1 - \frac{W}{62.4G}\right)(T) + V$$

$$d = \frac{1.33Q}{W} = \frac{1.33(9.7)}{52.4} = .246 \text{ inches}$$

e = 40 percent from Figure A-1

E = ed = .40(.246) = 0.0985 inches

T = 1.05 from Table A-1

V = +0.03 from Table A-2

A = quantity of asphalt cement, gallons per square yard at 60°F

$$A = 5.61\ (0.0985)\left(1 - \frac{52.4}{62.4(1.57)}\right)\quad (1.05) + 0.03$$

A = 0.30 gallons of asphalt per square yard of roadway surface

If an emulsion with 30 percent water was to be utilized, the quantity of emulsion would be

$\frac{0.30}{.70}$ = 0.43 gallons of emulsion per square yard of roadway surface

If the emulsion were to be sprayed at 140°F, the temperature connection factor would be 0.98. Thus, $\frac{0.43}{0.98}$ or 0.44 gallons of emulsion per square yard of roadway surface would be sprayed at 140°F.

If an asphalt cement were to be sprayed at 340°F, the temperature connection factor would be 0.9057. Thus, $\frac{0.30}{0.9057}$ or 0.33 gallons of asphalt cement per square yard of roadway surface would be sprayed at 340°F.

Table A-1. Asphalt Application Rate - Correction Due to Traffic.

	Traffic - Vehicles Per Day Per Lane				
	Over 1,000	500 to 1,000	250 to 500	100 to 250	Under 100
Traffic Factor (T)	1.00	1.05	1.10	1.15	1.20

Table A-2. Asphalt Application Rate Correction Due to Existing Pavement Surface Condition.

Description of Existing Surface	Asphalt Quantity Correction gal/sq. yd.
Flushed asphalt surface	-0.06
Smooth, nonporous surface	-0.03
Slightly porous, slightly oxidized surface	0.00
Slightly pocked, porous, oxidized surface	+0.03
Badly pocked, porous, oxidized surface	+0.06

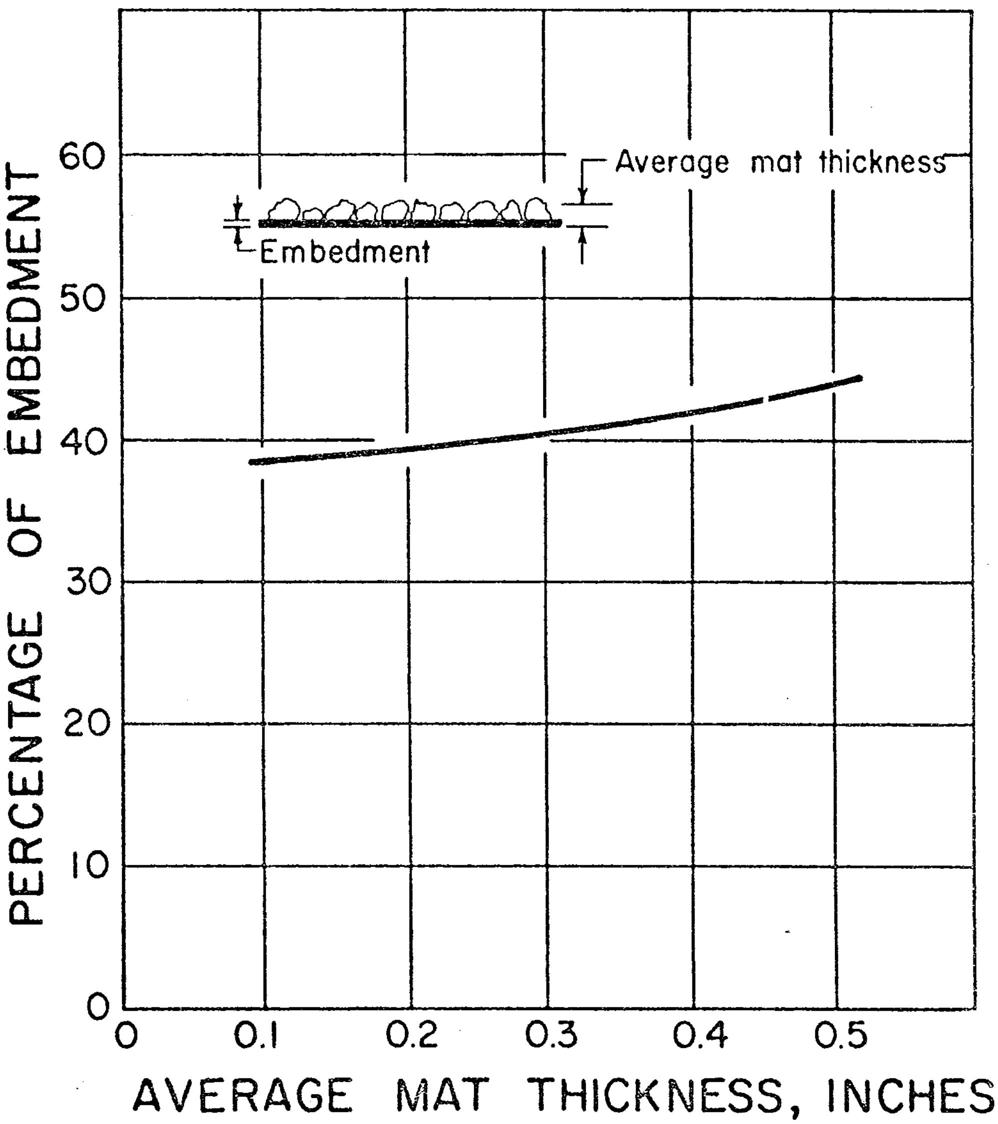

Figure A-1. Relation of percent embedment to average mat thickness for determining quantity of asphalt for lightweight aggregate seals.

APPENDIX B

BULK SPECIFIC GRAVITY

The value of the bulk specific gravity of the aggregate is required to calculate the asphalt cement requirement in seal coats. The bulk specific gravity of normal weight aggregates can be determined by ASTM method C127 "Specific Gravity and Absorption of Coarse Aggregate". The specific gravity of synthetic (lightweight) aggregates or aggregates with high water absorption should be determined by the test method described below.

Scope. This method of test is intended for use in determining dry bulk specific gravity of synthetic coarse aggregate.

Apparatus. The apparatus shall consist of the following:

(a) Balance--A balance having a capacity of 3 kilograms or more and a sensitivity of 0.1 gram or less.

(b) Container--A glass small mouth quart Mason jar fitted with a pycnometer cap.

Sample. A sample of sufficient size to yield approximately 400 grams after being oven dried shall be selected, by the method of quartering, from the aggregate to be tested.

Procedure.

(a) The test shall be conducted at a temperature of $72 \pm 5°F$.

(b) The sample shall be dried in an oven at a temperature of 105°C for a minimum of 24 hours. The sample shall then be allowed to cool to room temperature in a desiccator.

(c) The weight of the pycnometer jar and cap shall be determined to the nearest 0.1 gram.

(d) The weight of the pycnometer completely filled with distilled water shall be obtained to the nearest 0.1 gram. Match marks shall be used on the jar and cap to insure that the same volume is obtained throughout the test.

(e) The dry sample shall be placed in the pycnometer and the total weight determined to the nearest 0.1 gram.

(f) The jar shall be filled with distilled water. The top shall then be placed on the jar with the match mark coinciding and water added to fill the jar and top completely. The pycnometer with sample and water shall then be weighed to the nearest 0.1 gram. With a little practice, the first weighing can be accomplished two minutes after the water is first introduced into the container. Weighings shall then be made at intervals of 4, 6, 8, 10, 20, 30 60, 90, and 120 minutes from the beginning of the test, taking care to agitate the sample by rolling and shaking the jar and then add water as required to return the water level to the reference level before each weighing is made.

Calculations. A curve with time (to at least 10 minutes) as the absicissa and weight of pycnometer plus sample plus water as the ordinate shall be plotted on rectangular coordinate paper. This curve shall be extended back to include zero time and the weight of pyconometer plus sample plus initial water read from the curve. The dry bulk specific gravity shall be calculated by dividing the oven dry weight of the sample by the bulk volume of the sample determined at zero time.