VIRGINIA METHOD FOR THE DESIGN OF DENSE-GRADED
EMULSION MIXES

by

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(The opinions, findings, and conclusions expressed in this
report are those of the author and not necessarily those of
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An investigation into the Illinois method for the design of dense-graded emulsion base mixes resulted in a report offering several modifications to that procedure. The Bituminous Research Advisory Committee subsequently recommended that the Illinois method, along with the recommended modifications, be adopted for use in Virginia.

Since that time a need has developed for a written document incorporating the modifications into the basic method. That is the purpose of this report.

1. SCOPE

The method and recommended test criteria are applicable to paving course mixtures for low traffic volume pavements containing any grade asphalt emulsion and dense-graded aggregates. This design is recommended for road mixes or plant mixes prepared at ambient temperatures. In developing the procedures an attempt was made to simulate field conditions while retaining as much similarity to hot mix design as possible.

2. MATERIALS

2.1 Aggregates — One of the main purposes of emulsion mixes is economy. Therefore, the use of local aggregates is important. Crusher run aggregate, local sands and reclaimed aggregates are some of the more economical aggregates available in the state and should be considered for use.

Approximately 150 lb. of aggregate are required for the mixture design.

2.2 Emulsified Asphalt — Most emulsions used in the state are cationic; however, if a limestone aggregate is used, an anionic emulsion may be more compatible. If a question of cationic vs. anionic emulsions arises, the potential emulsion supplier may be the person best qualified to provide the answer.

Approximately 1 gal. of asphalt emulsion is required in the mixture design.

3. PROCEDURE

3.1 Trial Residual Asphalt Content — An equation has been derived that gives an approximate residual asphalt content. The information required to use this method is obtained from a washed sieve aggregate gradation.

> NOTE 1: For simplicity, a dry gradation may be substituted for the wet gradation with the realization that the trial residual asphalt content may be lower than optimum.

The residual asphalt content can also be determined experimentally.

3.1.1 Determination by Equation — The equation for calculating the trial residual asphalt content is

$$R = 0.00138AB + 6.358 \log_{10}C - 4.655,$$

where

R = trial residual asphalt content by weight of dry aggregate, in percent;

A = percentage of aggregate retained on No. 4 sieve;

B = percentage of aggregate passing No. 4 sieve and retained on the No. 200 sieve; and

C = percentage of aggregate passing the No. 200 sieve.

R is rounded off to the nearest half percent to yield the trial residual asphalt content.

Example: Retained on No. 4 sieve — 35%

Passing No. 4 and retained on No. 200 sieve — 57%

Passing No. 200 sieve — 8%

$$R = 0.00138 \times 35 \times 57 + 6.358 \log_{10} (8) - 4.655 = 3.84\%$$

Use R = 4.0% for trial residual asphalt content.

To obtain an asphalt emulsion content, it is necessary to divide R by the percentage of residual asphalt contained in the emulsion.

3.1.2 Determination Experimentally — For all mixes using non-virgin crushed aggregate, the following experimental approach to estimating the trial emulsion content is suggested.

3.1.2.1 Dampen a 200-g sample of aggregate and mix for 1 minute.

3.1.2.2 Add sufficient emulsion to achieve 100% coating of the aggregate by mixing for 2 minutes.

3.1.2.3 Calculate the amount of emulsion to obtain the trial emulsion content.

NOTE 2: Experience has indicated that this value may tend to be on the high side of optimum. If the mix appears excessively wet, consideration may be given to reducing the trial emulsion content by 1%.

3.1.2.4 If the trial residual asphalt content is desired, multiply the trial emulsion content by the percent of residual asphalt in the emulsion.

3.2 Coating Test — The selection of the type and grade of emulsified asphalt for use on a particular project is based in part on the ability of the emulsion to adequately coat the job aggregate.

3.2.1 Test When Trial Residual Asphalt Content Determined by Equation — If the equation is used to determine the trial residual asphalt content, then the coating test outlined below is advisable.

3.2.1.1 Determine the moisture content on a combined sample of the air-dried aggregate according to ASTM Test Method D 2216, "Laboratory Determination of Moisture Content of Soil", and record.

3.2.1.2 Weigh out a sufficient number of batches of the air-dried aggregate for trial mixes. The batch weight should be approximately 2,000-g (oven dry basis).

3.2.1.3 Place one batch of aggregate in the bowl of the mechanical mixer. Incorporate 3% water by dry weight of aggregate in excess of the air-dried water content. Water should be added in a thin stream and the aggregate mixed until the water is thoroughly dispersed.

3.2.1.4 Add the amount of emulsified asphalt (percent by weight of dry aggregate) as determined by the equation. The emulsion should be added in a thin stream to minimize the tendency of the asphalt to ball up with the fine aggregate. A 5-minute mixing process is usually satisfactory. If hand mixing is used, it should be sufficiently thorough to disperse the asphalt throughout the mixture.

3.2.1.5 Calculate the free water content of the aggregate at mixing by combining the moisture content of the aggregate as determined in 3.1.2.1 with the percentage of water added in 3.1.2.3.

3.2.1.6 If mix becomes soupy or segregates upon standing, reduce water added by 1%.

3.2.1.7 Surface dry the mixture and rate the appearance by visually estimating the total aggregate surface area coated with asphalt. For each pre-mix water content at mixing, record the estimate of the coating as a percentage of the total area. Aggregate coating in excess of 50% shall be considered acceptable. If the mixture does not attain 50% coating at any water content, the emulsion shall be rejected from further consideration. If the coating appears borderline, the mixture may be evaluated by the entire mixture design procedure.

3.2.1.8 Cationic emulsified asphalt mixtures generally exhibit increased coating as the pre-mix water content is incrementally increased. At some point, sufficient water is available for optimum dispersion of the asphalt and additional increments of water do not improve the coating. This result shall be the minimum pre-mix water content required for mixing. All subsequent mixing in the design process shall be done at the minimum pre-mix water content.

3.2.2 Test When Trial Residual Asphalt Content Determined Experimentally — If the experimental approach to establishing the trial emulsion content as outlined in 3.1.2 has been used, the requirements of the coating test can be considered to have been fulfilled. There is the possibility that if the aggregate has a high percentage of material passing the No. 200 sieve, insufficient pre-mix water will result in balling of the asphalt with the fines and may produce an insufficient coating. If this occurs, the amount of water used to dampen the aggregate should be increased and another determination made. Emulsions which do not pass the coating test are not considered further.

3.3 Optimum Water Content at Compaction — Mixture properties are closely related to the density of the compacted specimens. Thus it is necessary to optimize the water content at compaction to maximize the desired mixture properties. This must be done for each combination of emulsion type, emulsion grade, and aggregate type considered.

The mixture design procedure utilizes standard Marshall specimens in the evaluation of mixture properties. To obtain reliable results, triplicate specimens are prepared for determination of stability.

The determination of optimum water content at compaction requires determining the Marshall stability at each water content at compaction and plotting these data as illustrated in Figure 1 to define the optimum.

3.3.1 Preparation of Specimens —

3.3.1.1 Prepare three specimens for each water content at compaction to be evaluated. Generally, four increments of water content 1% apart are sufficient to define the stability/water content-at-compaction curve.

3.3.1.2 Thoroughly clean the specimen mold assemblies and the face of the compaction hammer. Place a piece of filter paper cut to size in the bottom of the mold before placing mixture in the mold.

3.3.1.3 Use 3.6 kg of aggregate. Place the pans in a well-ventilated area and determine the temperature of the aggregate. The aggregate should be at room temperature prior to mixing.

3.3.1.4 Make four calculations for each combination of aggregate and asphalt as follows:

$$\text{Weight of air-dried aggregate added} = \frac{a}{100-b} \times 100 \quad - - - - - - (1)$$

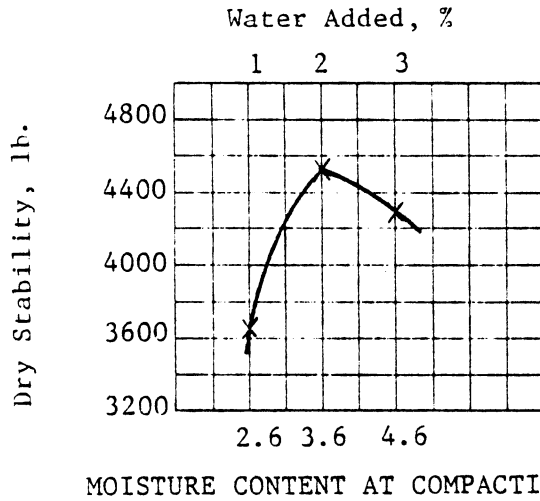$$\text{Weight of emulsion} = \frac{a \times c}{d} \quad - - - - - - - - - - - - - - - (2)$$

$$\text{Weight of pre-mix water added} = a(f-b-\frac{e \times c}{d}) \; 100 \quad - - - - - - (3)$$

$$\text{Weight of water loss for compaction} = a(\frac{f-g}{100}) \quad - - - - - - - - (4)$$

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EMULSION DESIGN CHART
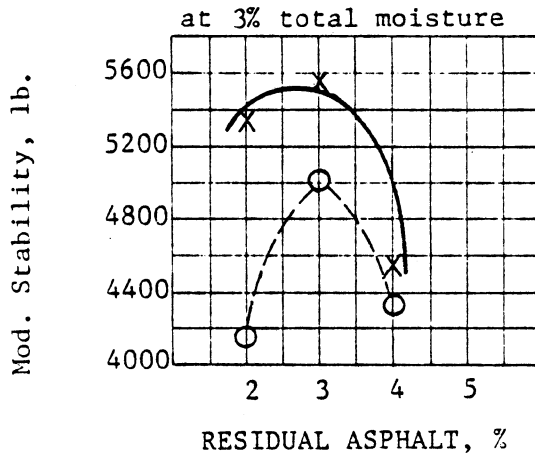
Asphalt   Chevron

Aggregate   Limestone

Water Added, %

Dry Stability, lb.

3.0% Residual

4.6% Emulsion

MOISTURE CONTENT AT COMPACTION, %

X   Dry
O   Soaked

at 3% total moisture

Mod. Stability, lb.

RESIDUAL ASPHALT, %

% Moisture Absorbed

RESIDUAL ASPHALT, %

% Stability Change

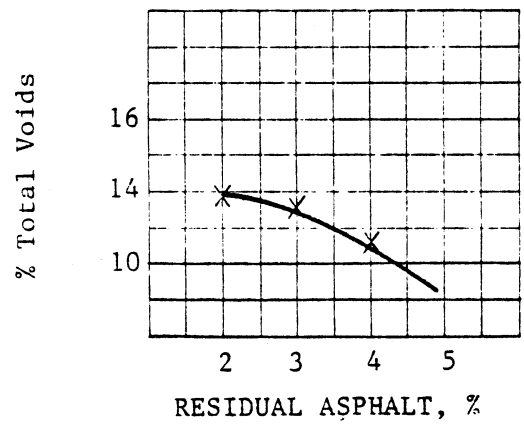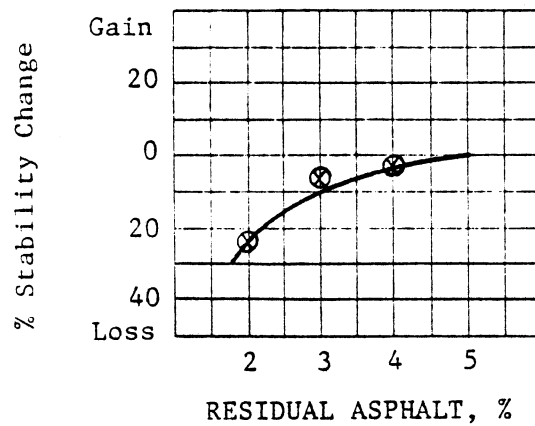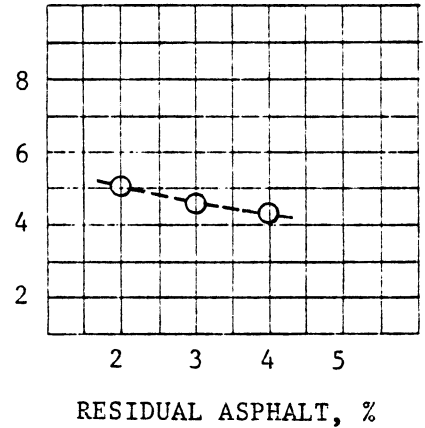RESIDUAL ASPHALT, %

% Total Voids

RESIDUAL ASPHALT, %

Figure 1. Typical emulsion mix design chart.

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where

a = weight of dry aggregate,

b = percent water content of air-dried aggregate,

c = desired residual asphalt content (percent weight dry aggregate),

d = percent residual asphalt in the emulsion,

e = percent water in emulsion (100 - d),

f = percent pre-mix water content at mixing (weight dry aggregate), and

g = percent water content at compaction (weight dry aggregate).

Example:

Weight of dry aggregate = a = 7,200 g

Water content of air-dried aggregate = b = 0.5%

Desired residual asphalt content = c = 4.0%

Residual asphalt in the emulsion = d = 65%

Water in emulsion = e = 35%

Pre-mix water content at mixing = f = 5.0%

Water content at compaction = g = 3.5%

Eq. (1) Weight of air-dried aggregate added = $\frac{7,200}{100-0.5}$ x 100

= 7,236 g

Eq. (2) Weight of emulsion = $\frac{7,200 \times 4.0}{65}$ = 443 g

Eq. (3) Weight of added pre-mix water = 7,200 $(5.0 - 0.5 - \frac{35 \times 4.0}{65})$

/100 = 169 g

Eq. (4) Weight of water loss for compaction = 7,200 $(\frac{5.0 - 3.5}{100})$

= 108 g

The data should be entered on a form similar to that shown in Table 1.

Table 1. Emulsified Asphalt Mixture Data Sheet
(Use for specimens containing a single residual asphalt content)

ASPHALT			AGGREGATE	
Type & Grade			Source Id.	
Asphalt in Emulsion	%		Type	
Asphalt Spec. Gra. (B)			Bulk Spec. Gra. (C)	
Residual Asphalt in Mixture (A)	%			
MIXING AND COMPACTION			TESTING	
Total Mix Water	%		Dry Spec. Test Date	
Added Mix Water	g		Rotate Soak Spec. Date	
Water at Comp.	%		Soak Spec. Test Date	
Compaction Date				

COMPACTED SPECIMEN DATA	Dry			Soaked		
	1	2	3	4	5	6
Bulk Density						
Weight in Air (D)						
Weight in Water (E)						
Weight SSD (F)						
BSG - compacted mix (G)						
Dry BSG - compacted mix						
Thickness						
Stability						
Dial						
Load						
Adjusted Stability (L)						
Flow						
Moisture Content						
Weight of failed specimen (H)						
Weight of oven-dry specimen (I)						
Tare (J)						
Moisture content (K)						
Moisture absorbed	✕	✕	✕			
Maximum Total Voids - %				✕	✕	✕

Source: <u>A Basic Asphalt Emulsion Manual</u>, The Asphalt Institute, <u>Manual Series No. 19 (MS-19)</u>, March 1979.

3.3.1.5 Place the air-dried aggregate in the mixing bowl. Calculate the total amount of free water that needs to be added to achieve the optimum pre-mix water as determined earlier. Add the water to the aggregate and mix for 1 minute, or until the water is thoroughly dispersed throughout the aggregate. Add the correct amount of emulsion to the moistened aggregate. Mix for 2 minutes, or until the emulsion is thoroughly dispersed throughout the aggregate. (Excessive mixing may tend to strip the asphalt from the aggregate and should be avoided.)

3.3.1.6 If the desired water content at compaction differs from the optimum mixing water content, aeration is required. Remove all material from the mixing bowl and blade and place in an aeration pan. Distribute the mixture in the pan such that the depth does not exceed 1 inch. Record the weight of the mixture and pan. Calculate the required weight loss to reach the desired compaction water content by equation (4).

Subtract the required weight loss from the recorded weight of mixture and pan and record the remainder. Place the mixture in the curing oven at $140 \pm 5^\circ$F. Stir and weigh the mixture every 15 ± 0.5 minutes until the weight is within 20 g of the required weight loss. Remove the mixture from the oven and place in a well-ventilated area. Cool the mixture to room temperature and weigh. (A fan may be used to accelerate the cooling process.) Stir and weigh the mixture every 10 ± 0.5 minutes until the calculated required water loss is reached. The mixture is now ready for compaction.

> NOTE 3: If coating of the aggregate is not sensitive to the water content at mixing as determined in the coating test described in 3.2 through 3.2.1.8, the aggregate may be mixed at the desired water content at compaction, emulsion added, and the mixture compacted immediately. Experience has indicated that this is likely.

3.3.1.7 Assemble the base plate, Marshall forming mold, and collar extension in the normal manner. Cover the base plate with a piece of filter paper cut to size and place $1,000 \pm 5$ g of mixture in the mold assembly. Spade the mixture with a small spatula 15 times around the perimeter. Place a second piece of filter paper cut to size over the top of mixture. Repeat this process for the remaining mold assemblies.

Place the first mold assembly on the compaction pedestal in the mold holder and apply 25 blows with the compaction hammer. Remove the collar and base plate, reverse the mold, reassemble, place the assembly on the compaction pedestal, and apply 25 compaction blows. Repeat the process for the remaining mold assemblies. Remove the collars, base plates, and filter paper from all specimens. Specimens are now ready for curing.

3.3.1.8 Cure specimens at room temperature in the forming mold in front of a fan for 24 hours, with the specimens set on edge for equal ventilation on both sides. Remove the specimens from the mold approximately 2 hours prior to testing at room temperature. A water bath should not be used unless the specimens are sealed in a plastic bag to prevent moisture absorption.

3.3.2 Testing of Specimens —

3.3.2.1 Test with normal Marshall procedure, except that the specimens shall be tested at room temperature and therefore not be immersed in a water bath.

3.3.2.2 The stability graph likely will not peak. Therefore, determine the maximum stability as that occurring at a flow of 15.

3.3.2.3 Average the results from each set of three specimens at each moisture-added content.

3.3.2.4 Prepare a plot of Marshall stability vs. water content at compaction (Figure 1). Select the approximate peak of the curve as the optimum water content at compaction. If the curve does not peak, additional water content at compaction points may be needed.

> NOTE 4: It is suggested that both the residual
> asphalt and asphalt emulsion contents be writ-
> ten beside the plot of stability vs. moisture
> content at compaction. This will aid in
> associating water-added with moisture content
> at compaction.

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3.4 Optimum Residual Asphalt Content—

3.4.1 In determining the optimum residual asphalt content for a particular aggregate and asphalt combination, a series of test specimens are prepared over a range of residual asphalt contents. Test mixtures are prepared in 1% increments of residual asphalt content with one or two increments on either side of the trial asphalt content. If further definition of test results is required, increments farther away from the trial residual asphalt content are used. If the trial asphalt content has been determined accurately, four residual asphalt contents should define the optimum residual asphalt content.

3.4.2 Preparation of Specimens —

3.4.2.1 Prepare six specimens for each residual asphalt content.

3.4.2.2 Thoroughly clean the specimen mold assemblies and the face of the compaction hammer. Place a piece of filter paper cut to size in the bottom of the mold before placing mixture in the mold.

3.4.2.3 Use 7.2 kg of aggregate. Place the pans in a well-ventilated area and determine the temperature of the aggregate. The aggregate shall be at room temperature prior to mixing.

3.4.2.4 Use calculations as given under 3.3.1.4.

3.4.2.5 Use the optimum water content at compaction as determined in 3.3 through 3.3.2.4 in all further steps in sample preparation. As the residual asphalt content increases, the amount of water in the emulsion also increases. Therefore, reduce the amount of water added as the residual asphalt content is increased.

> NOTE 5: To emphasize this point, it is suggested that the total moisture content be written on the plot of Modified Stability vs. Residual Asphalt Content. Vary the residual asphalt content by approximately 1% on successive batches to yield a peak of the Modified Stability vs. Residual Asphalt Content Curve. (This may require 4 or more data points.)

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3.4.2.6 If aeration is necessary, follow procedure 3.3.1.6.

3.4.2.7 Compact specimens in manner described under 3.3.1.7.

3.4.2.8 Use the following accelerated curing and soaking procedure that has been developed for use in Virginia.

a. Cure six specimens in the mold in oven at $140^{\circ}F \pm 5^{\circ}$ for 16 hours. (This is most easily done overnight.)

b. Remove the specimens from the oven and let stand until they reach room temperature (usually about 1 hour in front of fan).

c. Remove all specimens from mold and determine their bulk specific gravities.

d. Test three specimens in the Marshall mold as normally done, except that they shall be tested at room temperature.

e. Place three remaining specimens in a vacuum chamber in water 1/2 in. deep, vacuum saturate for 5 minutes, turn off vacuum, and let them stand in water for 2 hours.

f. Remove specimens from water, dry the surface, weigh, and test as in d above.

3.4.2.9 Place failed specimens in preweighed pans, taking care to make sure all of the failed specimen is put into the pan. Weigh the specimen and pan, record the weight in row H of form in Table 1, and put specimen and pan in oven at $250^{\circ}F \pm 10^{\circ}$. Remove after 24 hours and record weight in row I. The weight of water absorbed can be determined by subtracting the average moisture content of the specimens before soaking from the average moisture content of the specimens after soaking.

4. TEST DATA AND ANALYSIS

4.1 Preparation of Data — The stability, flow, voids, bulk density, and moisture content are prepared as follows:

4.1.1 Measure stability values and correct for volume by measuring the thickness of the specimen and using Table 2.

Table 2. Stability Volume Corrections

Volume of Specimen, cm^3	Approximate Thickness of Specimen, in.	mm	Correction Factor
200 to 213	1	25.4	5.56
214 to 225	1-1/16	27.0	5.00
226 to 237	1-1/8	28.6	4.55
238 to 250	1-3/16	30.2	4.17
251 to 264	1-1/4	31.8	3.85
265 to 276	1-5/16	33.3	3.57
277 to 289	1-3/8	34.9	3.33
290 to 301	1-7/16	36.5	3.03
302 to 316	1-1/2	38.1	2.78
317 to 328	1-9/16	39.7	2.50
329 to 340	1-5/8	41.3	2.27
341 to 353	1-11/16	42.9	2.08
354 to 367	1-3/4	44.4	1.92
368 to 379	1-13/16	46.0	1.79
380 to 392	1-7/8	47.6	1.67
393 to 405	1-15/16	49.2	1.56
406 to 420	2	50.8	1.47
421 to 431	2-1/16	52.4	1.39
432 to 443	2-1/8	54.0	1.32
444 to 456	2-3/16	55.6	1.25
457 to 470	2-1/4	57.2	1.19
471 to 482	2-5/16	58.7	1.14
483 to 495	2-3/8	60.3	1.09
496 to 508	2-7/16	61.9	1.04
509 to 522	2-1/2	63.5	1.00
523 to 535	2-9/16	64.0	0.96
536 to 546	2-5/8	65.1	0.93
547 to 559	2-11/16	66.7	0.89
560 to 573	2-3/4	68.3	0.86
574 to 585	2-13/16	71.4	0.83
586 to 598	2-7/8	73.0	0.81
599 to 610	2-15/16	74.6	0.78
611 to 625	3	76.2	0.76

NOTES:
1. The measured stability of a specimen multiplied by the factor for the thickness of the specimen equals the corrected stability for a 2-1/2 in. (63.5 mm) specimen.
2. Volume-thickness relationship is based on a specimen diameter of 4 in. (101.6 mm).

Source: A Basic Asphalt Emulsion Manual, The Asphalt Institute, Manual Series No. 19 (MS-19), March 1979.

4.1.2 Average the stability and flow values for all dry specimens at a given asphalt content. Average the values for all wet specimens at a given asphalt content, also.

4.1.3 Make the following calculations to complete the mix design.

$$\text{Bulk Sp. G.} = \frac{D}{F-E} \quad\text{-----------------------(5)}$$

$$\text{Moisture content } (k) = \frac{(H-I) - (F-D)}{I} \times 100 \quad\text{--------(6)}$$

$$\text{Moisture absorbed} = \frac{k\ \text{soaked}}{3} - \frac{k\ \text{dry}}{3} \quad\text{----------(7)}$$

$$\text{Maximum total voids} = \frac{\dfrac{A/100 + k/100 + 1}{G} - \dfrac{1}{C} - \dfrac{A/100}{B}}{\dfrac{A/100 + 1 + k/100}{G}} \times 100 \quad\text{----(8)}$$

$$\text{Percent stability loss} = \frac{\dfrac{L\ \text{dry}}{3} - \dfrac{L\ \text{soaked}}{3}}{\dfrac{L\ \text{dry}}{3}} \times 100 \quad\text{-----(9)}$$

4.1.4 Prepare a separate graphical plot for each factor by plotting these data vs. residual asphalt content and connecting the points into a smooth curve as shown in Figure 1.

4.2 Trends and Relations of Test Data — The test property curves as previously plotted have been found to vary considerably between aggregate types and gradations, but typical curves are shown in Figure 1. General trends are described as follows:

4.2.1 The 1-day dry stability will generally show a peak at a particular moisture content at compaction. Sometimes this curve is very flat and no peak is apparent, indicating a range of possible compaction moisture content. If this occurs, the moisture content resulting in the maximum dry bulk density may be used as long as the stability does not drop off significantly.

4.2.2 The soaked stability will generally show a peak at a particular residual asphalt content, while the dry stability will generally show a continually decreasing curve with increasing residual asphalt content. Some mixes may show a continual increase in soaked stability over the range of asphalt contents evaluated, which indicates the increased beneficial effect of additional asphalt on the soaked stability.

4.2.3 The percent loss of stability (computed by [dry stability-soaked stability] 100/dry stability) generally decreases as the residual·asphalt content increases.

4.2.4 The dry bulk density usually peaks at a particular residual asphalt content.

4.2.5 The percent moisture absorbed during the soak test decreases with increased residual asphalt content.

4.2.6 The percent total voids (air plus moisture) decreases as the residual asphalt content increases.

4.3 Optimum Asphalt Content — The optimum asphalt content should provide a mix with the following properties.

4.3.1 A mixture must provide an adequate stability when tested in a soaked condition to provide adequate resistance to traffic loads during wet seasons.

4.3.2 The percent loss of stability of the mixture when tested soaked as opposed to dry should be minimized. A high loss is indicative of the mixture having a high moisture-susceptibility and may cause disintegration during wet seasons.

4.3.3 The total voids within the mixture should be within the specified range to prevent either excessive permanent deformation and moisture absorption (for too high void content), or bleeding of the residual asphalt from the mixture (for a low void content).

4.3.4 Moisture absorption into the mixture should be below the maximum specified value to minimize the potential of stripping or weakening the bond between the residual asphalt and aggregate.

4.3.5 The residual asphalt should provide adequate coating of the aggregate and should be resistant to stripping or abrasion.

4.4 Selecting the Optimum Residual Asphalt Content — The
optimum residual asphalt content is that value that provides the
maximum soaked stability, but it is adjusted either up or down
depending on moisture absorption, percent loss of stability,
total voids, and coating of aggregates. Design criteria for
each of these values are given in Table 3. If the residual
asphalt content at the peak of the soaked stability curve pro-
vides for adequate moisture absorption, percent loss of stability,
total voids, and aggregate coating, it is selected as the optimum
asphalt content. This value must meet minimum stability require-
ments, however, as given in Table 3, or the mix is rejected. If
one or more criteria cannot be met, the mix should be considered
inadequate.

Table 3. Emulsified Asphalt-Aggregate
Mixture Design Criteria

Test Property	Minimum	Maximum
Stability, lb. at 72°F		
Paving Mixtures	500	—
Percent Total Voids		
Compacted Mix	2	16
Percent Stability Loss		
After soak at 72°F	—	50
Percent Absorbed Moisture		
After soak at 72°F	—	6
Aggregate Coating (percent)	50	—

The moisture contents of the aggregate at mixing and at
compaction may have a significant effect on the above criteria
for emulsified asphalt-aggregate mixtures. While there is a
fairly broad range of moisture contents that may be acceptable,
it is generally desirable to use a minimum of water. This
minimal amount is determined by the coating of the aggregate
by the residual asphalt. The optimum moisture contents at mix-
ing and compaction, therefore, need to be determined and then
controlled to help meet the criteria in Table 3.