

## Chapter 2

### Design and Control of Bituminous Mixtures Using a Modified Marshall Design Procedure

#### 1. General Scope

The Department has established procedures for the design and control of bituminous concrete based on Marshall Method for more than 30 years. Since the late 1990's, the Department has established a goal of implementing a newer mix design method, referred to as Superpave; based on more current national research (SHRP). (See Chapter 2A). Until such time as full implementation can be realized, the Department will continue to provide and publish for use the Modified Marshall Method. However, it is important to recognize that the Department's ultimate goal is to use only one Hot-Mix Asphalt (HMA) design procedure. Therefore it is anticipated that in the very near future, the Marshall Method will not be referenced for use by the Department, in this context. The Modified Marshall Method will continue to be utilized in its' current context for Cold Bituminous Mixture Designs, until such time that another method is proven more suitable.

The design of bituminous mixture by the Department's Modified Marshall Method involves the proportioning of the aggregates and asphalt to produce a mix that will have the optimum qualities and properties. The purpose is to develop a design, by trial means, which will contain an optimum amount of asphalt, have adequate voids, satisfactory flow properties and possess a planned combination of stability, durability and flexibility, based on the climatic condition, traffic density and loads it is intended to carry.

#### 1.1 Definitions

Stability is a measure of resistance to deformation. It is necessary to have sufficient stability to meet the requirements of traffic without mat distortion, or displacement. There are two forms of resistance, frictional or interlocking and cohesive resistance. Frictional or interlocking resistance is dependent on the aggregate framework. Cohesive resistance develops in the asphalt binder portion of the mix. It depends on the rate of loading, load and temperature. High stability is undesirable if it is due to low VMA (voids in the mineral aggregate) or due to being deficient in asphalt binder. Such surfaces have low resistance to cracking, are brittle in the winter, and tend to ravel under traffic.

Durability is a measure of resistance to disintegration by weather or traffic conditions. The most important factor with respect to durability is the amount of asphalt binder. A bituminous mixture is resistant to action of air and water in direct proportion to the degree that they are kept out of the mix. It is, however, desirable that the mix should contain as high a asphalt binder content that is consistent with stability and voids. This can be achieved with high VMA. This will give the pavement maximum durability and prevent raveling because of a deficiency of asphalt binder. This asphalt binder content is referred to as the optimum.

Flexibility is the ability of the bituminous mixture to bend repeatedly without cracking and to conform to changes in the base course. To have flexibility, a mix must contain

the proper amount of asphalt binder. Open graded mixes are more flexible than dense graded mixes.

Voids are the air spaces within the mixture. It is important that a mix contains sufficient voids to provide spaces for expansion of asphalt binder and a slight amount of additional densification (compaction) under traffic. Very high air voids are also detrimental to the mixture because the hardening of asphalt will be accelerated resulting in brittle pavement and reduced service life.

Voids in the Mineral Aggregate (VMA) is the intergranular space between the aggregate particles in a compacted mixture. This space is partially filled with asphalt binder, the remaining space is the unfilled air void. The VMA in a mixture should be adequate to accommodate sufficient volume of asphalt binder for durability and sufficient volume of air voids as explained earlier.

Flow is an index of plasticity or the resistance to distortion. The amount of asphalt binder that fills the aggregate voids affects the flow. The flow value increases as the asphalt content of the mixture increases. Flow values will increase rapidly with small increases in asphalt in mixes which contain a large amount of filler.

Workability is the property that determines the efficient placement without segregation and compaction of the mixture. Harsh or stiff mixtures can result from (a) excess of coarse aggregate, (b) low VMA, (c) low asphalt content or (d) excess of minus 75  $\mu\text{m}$  (No. 200) fraction.

Friction Number is a measure of the sliding force exerted on a tire when the brakes are locked. Bituminous wearing courses must have the highest possible friction number obtainable with the combination of aggregates available in the area. The type of coarse aggregate has the greatest effect on friction number. Aggregates which polish rapidly and repeatedly produce low friction numbers before the normal service life is complete should not be used. An excessive asphalt content can produce a flushed surface resulting in low friction number.

Optimum Asphalt Content is the content determined by taking into consideration the maximum specimen specific gravity and void requirements. This procedure is explained later. This computed optimum asphalt content may be modified by such specific requirements as climate, traffic density, absorptive aggregate, friction number, workability and flexibility as explained in the procedure. The final recommended optimum asphalt content shall meet all Marshall criteria.

**1.2 Desirable Mix Properties.** The final mix design should be workable and contain the most suitable gradation and amount of asphalt binder to produce a mix that embodies the best possible combination of all parameters.

Mixtures with high VMA are preferred because of the following advantages:

- (a) More asphalt can be incorporated in the mixture to increase durability.

- (b) Lower sensitivity to variation in asphalt content during production. Mixtures with low VMA will flush if slightly excessive in asphalt content, and will be dry and brittle if slightly deficient in asphalt content.
- (c) More flexibility and increased resistance to low temperature shrinkage cracking.

An increase in VMA can be achieved by one or more of the following steps:

- (a) The gradation of the fine aggregate should be changed so that the combined mix gradation is deliberately made to deviate further, preferably on the lower side, from the maximum density line (plotted on TR-448A). This can be done by either changing the percentage passing 2.36 mm (No. 8) sieve for the combined aggregate and/or changing the blend proportions of the fine aggregates if more than one are used.
- (b) If the mix contains natural sand as the fine aggregate, incorporate some manufactured angular sand or other crushed stone fine aggregate or slag sand so that different particle shapes are mixed. Usually, 20-25 percent angular fine aggregate is helpful to open up the mix.
- (c) Reduce the Percent Passing 75  $\mu\text{m}$  (No. 200) sieve in the mix.

## 2. Design Procedures

**2.1 Review of Job-Mix Formula (JMF).** The contractor will be solely responsible to design a mix that meets all Department requirements. The contractor will submit the required test results, the composition of the mixtures and the combined aggregate gradation curves proposed for use in the production of the base, binder and wearing courses, to the District Materials Manager/Engineer (DMM/DME) for review prior\* to the scheduled start of work. Submit mix designs to the DME/DMM for review following the procedures outlined in Appendix J. The acceptability of the bituminous concrete produced from any mix design is determined as specified in Publication 408, Section 401.

\*NOTE: As a standard practice it is recommended to allow up to three weeks lead time to allow for resolution of problems concerning mixture acceptability.

Whenever the contractor's gradations and calculations do not check, the DMM/DME shall request the contractor to do additional testing and/or recalculate and submit the correct mathematical solutions. The DMM/DME may request, at his option, to observe testing of a trial mix. He may also request that materials be submitted to the Materials and Testing Division for evaluation of the mix.

**2.2 Development of the Initial Design.** For a design being developed from new sources of materials, past experience shall be used in determining the starting formula, or one that approaches the median of the specification limits. The following is the general outline for development of the initial design:

Step 1. Obtain representative samples of all materials.

(a) Determine Dry Bulk Specific Gravity of coarse and fine aggregates (AASHTO T 85 and AASHTO T 84). At least five determinations should be made for each aggregate type using five samples, and the average value used. If the aggregate supplier has past historical test data, the average of those values can be obtained and used instead.

(b) Determine the Apparent Specific Gravity of mineral filler, if added separately (AASHTO T 133). At least three determinations should be made and the average value used.

(c) Determine Specific Gravity of Asphalt @ 25 °C (77F) (Specific Gravity @ 16 °C (60F) - 0.007). (AASHTO T228).

Step 2. Dry the aggregates and separate them into the specified individual sieve sizes.

Step 3. Make three mixtures using the combined gradation and the asphalt content of the selected starting formula (Refer to Appendices A, B and D and PTM No. 705 for blending and mixing procedures). Extract these samples to determine if the average extracted gradation conforms reasonably with the starting formula gradation. If the aggregate particles are significantly coated with fines, the extracted gradation is usually finer on the smaller sieves because the fines are picked up. This would require appropriate adjustments to the weights of the affected sieve size fractions.

Step 4. Determine the Maximum Specific Gravity for the completed mix (AASHTO T209), and calculate total mass of mix ([490 ml] x [Maximum Specific Gravity]) to produce a compacted specimen 63.5 mm (2-1/2 inches) high.

Step 5. Calculate the required amount of aggregate for the individual sieve sizes and the required amount of asphalt binder to make 27 Marshall specimens ([9 mixture types] x [3 replicates]) with the following variables:

(a) Passing 2.36 mm (No. 8) sieve - 3 to 5 percent less than the starting formula.

(b) Passing 2.36 mm (No. 8) sieve - at the starting formula.

(c) Passing 2.36 mm (No. 8) sieve - 3 to 5 percent more than the starting formula.

(d) Asphalt Content - 0.3 to 0.5 percent less than the starting formula.

(e) Asphalt Content - at the starting formula.

(f) Asphalt Content - 0.3 to 0.5 percent more than the starting formula.

The percent passing 75 µm (No. 200) sieve should be held constant in these mix trials.

Step 6. Prepare these mixtures and compact Marshall specimens (PTM No. 705).

- Step 7. Test the specimens for thickness, specific gravity, voids, VMA, VFA, stability and flow (Refer PTM No. 705, PTM No. 709 and PTM No. 715).
- Step 8. Report the average test data for these nine mixture types on a summary sheet, and plot them on the six graphs given in the Marshall Design Summary Form (TR-448B).
- Step 9. Review the summarized data carefully to establish the percentage passing 2.36 mm (No. 8) sieve to be used in further trials. Besides experience, this should be based on the following considerations: (a) high VMA, (b) mix properties, such as, voids, VMA, stability and flow that are least susceptible to variation in the asphalt content, and (c) workability.
- Step 10. If the VMA values are lower than desirable in these mix trials, change in the combined aggregate gradation and/or source will be necessary to increase the VMA as explained earlier. If the VMA values are satisfactory, Proceed to the next step.
- Step 11. Use the established percentage passing 2.36 mm (No. 8) and a asphalt content corresponding approximately to 4 percent air voids in the further mix trails. Keep the percentage passing 75  $\mu\text{m}$  (No. 200) sieve same as starting formula. This combination will be called second formula.
- Step 12. Make twelve Marshall specimens ([4 mixture types] x [3 replicates]) with the following variables:
- (a) Passing 75  $\mu\text{m}$  (No. 200) sieve -2 percent less than the second formula.
  - (b) Passing 75  $\mu\text{m}$  (No. 200) sieve -2 percent more than the second formula.
  - (c) Asphalt Content -0.4 percent less than the second formula.
  - (d) Asphalt Content -0.4 percent more than the second formula.
- Step 13. Repeat Step 7.
- Step 14. Report the average test data for these four mixture types on a summary sheet along with the data on the second formula for comparison.
- Step 15. Review the summarized data carefully to establish the percentage passing 75  $\mu\text{m}$  (No. 200) sieve based on the considerations given in Step 9.

NOTE: If the contractor intends to use the same combination of aggregate for which a reviewed job-mix formula (JMF) already exists, the number of trial Marshall specimens can be reduced or eliminated at the discretion of the DMM/DME, following a written request by the producer.

**2.3 Determination of Optimum Asphalt Content (Final Design).** So far, the development of the bituminous concrete design in the initial stages, using varying percentages of aggregates passing 2.36 mm and 75  $\mu$ m (No. 8 and No. 200) sieves, has been outlined. After the percentages passing 2.36 mm and 75 mm (No. 8 and No. 200) sieves have been established, there exists a range of asphalt content which can satisfy the Marshall design criteria specified in Pub. 408. It is necessary to determine the optimum asphalt content to strike a balance between density, stability, % air voids, and % VMA. To have a uniform practice on the determination of optimum asphalt content, the following procedure should be followed.

**2.3.1 Procedure for Determining Optimum Asphalt Content.**

Using the same combined gradation of the aggregates, prepare three Marshall specimens each at five asphalt content levels in 0.5 percent increments. To ensure a more uniform interpretation of the Marshall design, the mixing temperature shall be the maximum temperature  $\pm 3^{\circ}\text{C}$  ( $\pm 5^{\circ}\text{F}$ ) stated on the bituminous material provider's Bill of Lading. The compaction temperature for Marshall design shall be the minimum temperature  $\pm 3^{\circ}\text{C}$  ( $\pm 5^{\circ}\text{F}$ ) stated on the bituminous material provider's Bill of Lading. This is very important because discrepancies in the values of specimen specific gravity (lab density) reported in the JMF Report can vary significantly when these temperatures are varied. The compaction equipment and procedure should be in strict accordance with PTM No. 705, especially the compaction pedestal.

Determine the maximum specific gravity (AASHTO T209) in triplicate of the mixture containing adequate asphalt content (at or slightly above the expected design asphalt content). The maximum specific gravity of the remaining four mixtures can then be calculated.

Determine the following properties (based upon the average of three specimens) of the Marshall specimens at five asphalt content levels:

Specific Gravity of Marshall Specimen	% VFA
% Air Voids	Stability
% VMA	Flow

The data on these properties should be plotted as points corresponding to the asphalt contents used in trials on the six graphs given in the Marshall Design Summary, Form TR-448B (See example). In each graphical plot connect the plotted values with a smooth curve that obtains the "best fit" for all values. Aggregate blends may be encountered that will furnish erratic data such that plotting of the typical curves might be difficult especially in the binder course mixtures. In a majority of these cases, an increase in the number of specimens tested at each asphalt content will normally result in data that will plot as typical curves. Test property curves, plotted as described above, have been found to follow a reasonably consistent pattern. Trends generally noted are outlined in subsection 2.3.2.

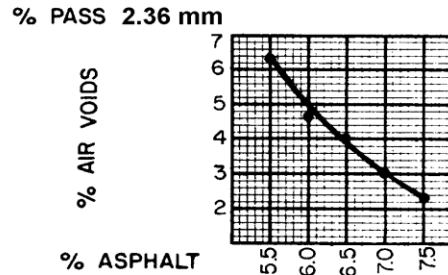
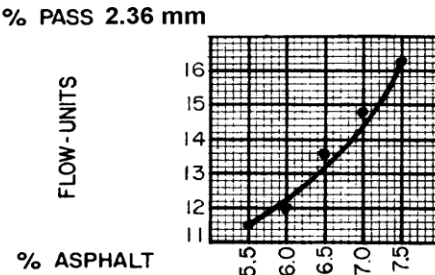
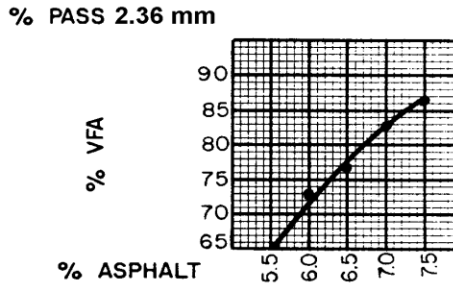
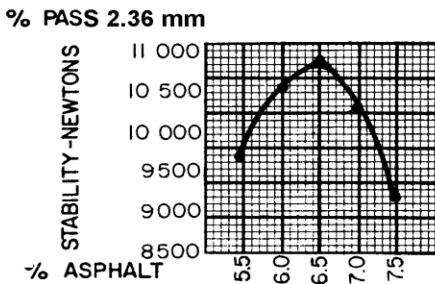
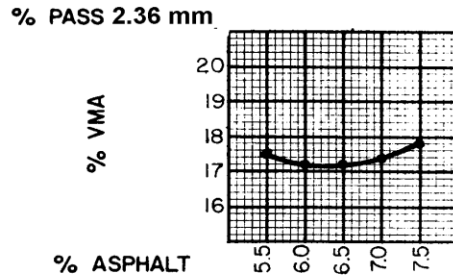
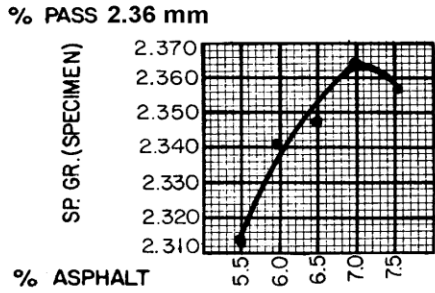
### MARSHALL DESIGN SUMMARY

OPTIMUM PERCENT ASPHALT AND PERCENT PASS 2.36 mm

DATE \_\_\_\_\_ SPEC ID -2A WEARING \_\_\_\_\_ AGG GRAVEL \_\_\_\_\_

BIT. CONC. PRODUCER \_\_\_\_\_ LOCATION \_\_\_\_\_

DISTRICT \_\_\_\_\_ COUNTY \_\_\_\_\_ SR \_\_\_\_\_ SEC \_\_\_\_\_



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Computation of Optimum Asphalt Content

A. Obtain from the graphs in the Marshall Design Summary (Sheet #1)

Asphalt content at max. sp. gr. (specimen)	7.0 %
Asphalt content at 4% air voids	6.4 %
	6.7 %
Optimum Asphalt Content, average	

B. Referring back to the curves, this Optimum Asphalt Content of 6.7 % would have the following properties:

(i) Stability	10 800	newtons	(ii) Flow	13.7	units
(iii) Air Voids	3.4	%	(iv) VMA	17.2	%
(v) VFA	80.5	%			

Check one of the following:

The above properties meet the Marshall Design Criteria and the Optimum Asphalt Content of 6.7 % is recommended.

The above properties meet the Marshall Design Criteria. However the following adjustment be made (Strike-out not applicable):

Increase/Decrease the asphalt content by \_\_\_\_\_ % on account of low traffic/high traffic, colder climate/warmer climate, absorptive aggregate, high altitude, other \_\_\_\_\_.

The increased/decreased asphalt content of \_\_\_\_\_ percent would still satisfy the Marshall design criteria.

The above properties do not meet the Marshall Design Criteria. Increase/Decrease the Optimum Asphalt content by \_\_\_\_\_ % so as to meet the Marshall design criteria.

C. The recommended Optimum Asphalt content of \_\_\_\_\_ % would have the following properties (read from the curves):

(i) Stability	newtons
(ii) Flow	units
(iii) Sp. Gr. (Specimen)	
(iv) Air Voids	%
(v) VMA	%
(vi) VFA	%



### MARSHALL DESIGN SUMMARY

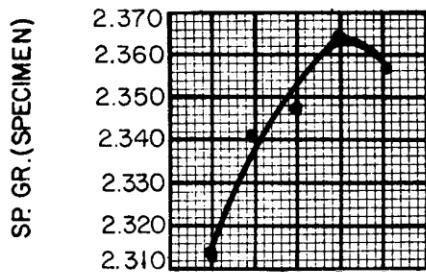
OPTIMUM PERCENT ASPHALT AND PERCENT PASS No. 8

DATE \_\_\_\_\_ SPEC ID-2A WEARING AGG GRAVEL

BIT. CONC. PRODUCER \_\_\_\_\_ LOCATION \_\_\_\_\_

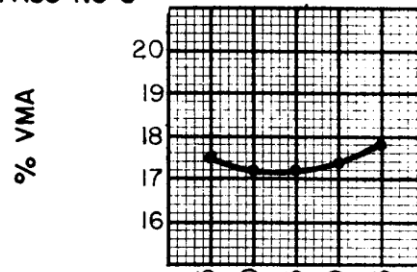
DISTRICT \_\_\_\_\_ COUNTY \_\_\_\_\_ LR \_\_\_\_\_ SEC \_\_\_\_\_

% PASS NO 8



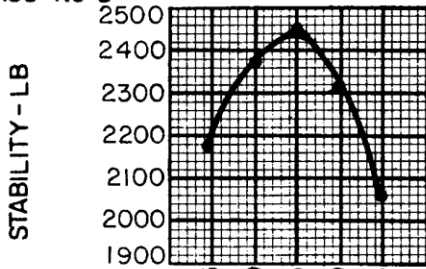
% ASPHALT

% PASS NO 8



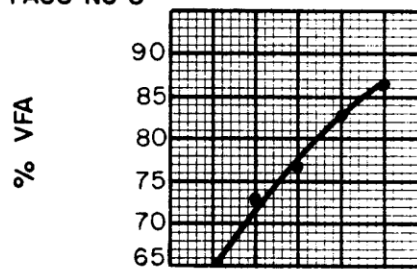
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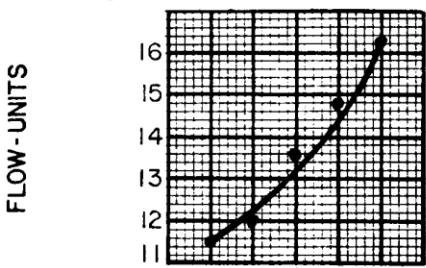
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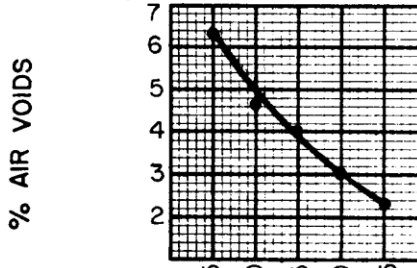
% ASPHALT

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% ASPHALT

% PASS NO 8



% ASPHALT

Computation of Optimum Asphalt Content

A. Obtain from the graphs in the Marshall Design Summary (Sheet #1)

Asphalt content at max. sp. gr. (specimen)	7.0 %	
Asphalt content at 4% air voids	6.4 %	
	6.7	%
Optimum Asphalt Content, average	6.7	%

B. Referring back to the curves, this Optimum Asphalt Content of 6.7 % would have the following properties:

(i) Stability	2430	pounds	(ii) Flow	13.7	units
(iii) Air Voids	3.4	%	(iv) VMA	17.2	%
(v) VFA	80.5	%			

Check one of the following:

The above properties meet the Marshall Design Criteria and the Optimum Asphalt Content of 6.7 % is recommended.

The above properties meet the Marshall Design Criteria. However the following adjustment be made (Strike-out not applicable):

Increase/Decrease the asphalt content by \_\_\_\_\_ % on account of low traffic/high traffic, colder climate/warmer climate, absorptive aggregate, high altitude, other \_\_\_\_\_.

The increased/decreased asphalt content of \_\_\_\_\_ percent would still satisfy the Marshall design criteria.

The above properties do not meet the Marshall Design Criteria. Increase/Decrease the Optimum Asphalt content by \_\_\_\_\_ % so as to meet the Marshall design criteria.

C. The recommended Optimum Asphalt content of \_\_\_\_\_ % would have the following properties (read from the curves):

(i) Stability		pounds			
(ii) Flow		units			
(iii) Sp. Gr. (Specimen)					
(iv) Air Voids		%			
(v) VMA		%			
(vi) VFA		%			

### 2.3.2 Property Trends.

Specific Gravity (specimen). The specific gravity of the compacted specimen increases with increasing asphalt content up to a certain point, after which it decreases. If no peak is obtained, attempt additional asphalt content(s) on the higher side.

Stability. The stability value increases with increasing asphalt content up to a maximum after which the stability decreases. The curve for stability is similar to the curve for specific gravity except that the peak of the stability curve is normally (but not always) at a slightly lower asphalt content than the peak of the specific gravity curve. Cases are not uncommon where no stability peak is obtained, the stability continues to increase as the asphalt content is increased. In some cases, a relatively flat stability curve with no defined peak is obtained.

Flow. The flow value increases with increasing asphalt content at a progressive rate except at very low asphalt contents. The curve is usually concave upwards.

Voids in Mineral Aggregate (VMA). The VMA generally decreases to a minimum value then increases with increasing asphalt contents. The rate of increase in VMA with increasing asphalt contents is comparatively higher in the mixtures with inherently low VMA.

Voids Filled with Asphalt (VFA). The VFA increases with increasing asphalt content. There is a maximum VFA for each aggregate blend and compaction effort. The VFA cannot be increased above this maximum without increasing or otherwise changing the compaction effort. The VFA curve is usually convex upwards.

Air Voids. The percent of air voids decreases with increasing asphalt content, ultimately approaching a minimum void content in much the same manner as the VFA discussed above approaches a maximum value. The air voids curve is usually concave upwards.

Optimum Asphalt Content. From the curves plotted on Form TR-448B read the asphalt contents at maximum specific gravity and 4% air voids. The average of these 2 asphalt contents read from the curves shall be the optimum.

**2.3.3 Final Checks.** Refer back to the curves to see if this optimum asphalt content meets all the Marshall design criteria as follows:

Stability	5300 N (1200 lbs.) minimum for wearing and binder
Flow	6-16 units
% Air Voids	3-5
% VMA	15 minimum for ID-2 Wearing, 14 minimum for ID-3 Wearing and 12 minimum for ID-2 Binder is recommended

If the computed optimum asphalt content does not meet the above Marshall design criteria, decrease or increase the asphalt content just enough to get into the specified range of Marshall properties such as percent air voids. A percent air voids of 4.0 is considered optimum; however, no design submitted with less than 3.0 percent air voids will be acceptable to the Department.

The final design should meet the Marshall criteria in all respects. The Marshall properties corresponding to the selected asphalt content can be determined from the six curves and recorded on the JMF Report.

**2.4 Undesirable Mix Characteristics.** Although a mix may satisfy all Marshall design criteria, it can be unacceptable because of the following considerations:

**2.4.1. Brittleness.** Mixes with abnormally high values of Marshall stability and abnormally low flow values are undesirable because pavements of such mixes tend to be more rigid or brittle and may crack under heavy volumes of traffic. This is Particularly true where base and subgrade deflections are such as to permit moderate to relatively high deflections of the pavement. The thickness of asphalt film around the aggregate is very low in such mixes. Adjustments in the aggregate gradation (particularly the percentages passing 2.36 mm and 75  $\mu\text{m}$  (No. 8 and No. 200 sieves) should be made to increase the VMA so that more asphalt can be incorporated in the mix. This can be done by deviating further from the maximum density curve (Fuller's curve). If the minus 75  $\mu\text{m}$  (No. 200) content is high, a reduction in this fraction will increase the aggregate voids.

**2.4.2. Sensitivity.** Mixes with aggregate gradation close to the maximum density curve (Fuller's curve) are very sensitive to slight variations in asphalt content. The appearance of such mixes can change from dry to gummy if the asphalt content is increased by a slight amount (as low as 0.5 percent). These mixes may result in pavements difficult to compact which may also ravel or flush. For these reasons, such mixes should be adjusted by one of the methods previously given to increase the VMA.

**2.4.3. Tenderness.** These mixes tend to pull and shove during the compaction operations resulting hairline cracking, usually consisting of transverse hairline cracks several inches apart, sometimes accompanied by longitudinal cracking. A poor aggregate gradation often is a leading contributor to tender (slow-setting) or unstable mixes. Tender mixes are frequently typified by:

(a) An excess of the middle-size fraction in the material passing 4.75 mm (No. 4) sieve. A hump in the grading curve caused by the excess sand could appear on nearly any sieve below 4.75 mm (No. 4) and above 150  $\mu\text{m}$  (No. 100). This condition is most critical when occurring near 600  $\mu\text{m}$  (No. 30) sieve. A change in the gradation of the fine aggregate(s) is necessary to remove the hump.

(b) Close proximity of the aggregate gradation to the maximum density line and/or major portion of gradation line relatively straight. These mixes have low VMA. Some easily compatible gravel mixes attain the desired maximum density (lowest possible VMA) with one or two passes of the roller, and then

start to decompact and deform. A change in the gradation of the mix is necessary to alleviate this situation.

- 2.5 Stability.** Although the asphalt content at peak stability is not utilized to calculate the optimum asphalt percentage, stability criteria must still be met. Designs should not be recommended with stabilities less than 6900 N (1550 lb) for wearing and binder to allow for normal operational variation so that 90% of the time we may be assured of being above the specification minimum of 5300 N (1200 lb).

If stability adjustments jeopardize other Marshall criteria in the design so that it does not meet requirements, adjustments to the aggregate gradation may be in order. Normally, incorporation of angular fine aggregates in the mixture increases the stability.

### **2.6 Design of Mixtures with PG 58-28 Asphalt Cement.**

(a) When PG 58-28 asphalt cement is to be used in lieu of PG 64-22 on one project only or in patching operations, make three Marshall specimens at the JMF asphalt content. If the properties, such as, stability, flow, air voids, and VMA meet the specified Marshall design criteria, use this asphalt content. If not, proceed to the following step (b).

(b) When PG 58-28 asphalt cement is to be used in lieu of PG 64-22 on more than one project, optimum asphalt content must be determined using PG 58-28. Using the same combined gradation of the aggregate, prepare three Marshall specimens each at five asphalt content levels in 0.5 percent increments (a total of 15 Marshall specimens) and follow the procedure given earlier to determine the optimum asphalt content.

## **3. Approved Job-Mix Formula**

- 3.1 General.** The JMF is developed specifically for the plant from the reviewed laboratory design. This may require small adjustments to fit the plant and thus ensure production within the tolerance limits. The selected laboratory design must be reproducible within the tolerances specified in the applicable section of the specifications (Pub 408). This design when proven in production can then be considered an approved JMF as long as the material sources, aggregate gradations, asphalt content and test values remain within the specifications and specified design tolerances.

If the approved JMF was developed with PG 64-22 asphalt cement and the source of this asphalt is changed, it is not necessary to change the JMF. However, if some other grade of asphalt cement, such as PG 58-28 is used it is necessary to re-determine the optimum asphalt content only (15 Marshall specimens at five asphalt contents).

- 3.2 Verification of the Job-Mix Formula.** JMF verification is conducted according to Publication 408 Section 401.2. If initial JMF verification is unsuccessful, the following process is recommended for further evaluation of the JMF:

- 3.2.1.** The contractor must verify the JMF with a minimum of three random samples taken from the plant production using PTM No. 1.

- 3.2.2. Evaluate the mix composition (gradation and asphalt content) and all Marshall test data, such as, voids, VMA, stability, flow, etc. If it checks with the previously reviewed JMF mix, production may begin.
- 3.2.3. If the Marshall test data do not meet the design criteria because the mix composition is substantially different than the JMF, corrective action must be taken at the plant to obtain the desired mix composition and then re-evaluate the Marshall test data.
- 3.2.4. If the mix composition conforms to the JMF but the Marshall Data do not meet the design criteria, perform additional testing of each material component in the mix for change in properties and/or verify all test equipment is in proper working order, calibrated within specifications, and test procedures are performed properly. Provide a summary report which includes findings and recommendations to the DMM/DME for review prior to performing any work with such a design.

**4. Quality Control Requirements For Mix Designs During Production.** Prepare and Submit a QC Plan to the DMM/DME for review and approval as specified in Chapter 1, Section 2.1 and Publication 408 Section 401.2. Perform all tests as required therein at the specified frequencies. Control and documentation of mixture maximum specific gravity (G<sub>mm</sub>) during production shall be performed as specified in Appendix I.

## **5. HOT-MIX RECYCLING DESIGN PROCESS**

STEP 1 - Obtain ten representative samples of the reclaimed asphalt pavement (RAP) material or milled material from different locations in the stockpile. Remove at least 150 mm (six inches) of the material from the surface of the stockpile before obtaining the sample to minimize segregation effects. Scalp off and discard the material retained on 50 mm (2 inch) sieve. Sample size at least 5 kg (10 lbs.) each after scalping. Split each sample into two portions. Identify the samples (No. 1 thru 10). Save ten split samples [at least 2.5 kg (5 lbs.) each] for sending to the Materials and Testing Division (Step 4). Retain the other ten split samples at the plant for testing and designing the recycled mix.

STEP 2 - Run extraction on the retained ten samples of the RAP. Use 1.02 as the specific gravity of the aged asphalt. Report the extraction results on Table 1. Save the remaining portions of the retained samples for subsequent mix designs at the plant (Step 6).

STEP 3 - Select the percentage of RAP to be recycled, and determine the percentages of virgin aggregate(s) to meet the specification requirements. Determine typical properties of all virgin asphalt cements (PG 58-28, PG 64-22, etc.) from the asphalt supplier. Fill out Tables 2 and 3.

STEP 4 - Submit the following to the Materials and Testing Division (Bituminous Laboratory) for determining the grade of virgin asphalt cement to be used in recycling:

1. Ten split samples of the RAP (at least 2.5 kg (5 lb) each) with Sample Identification Form 447. Number the samples 1 through 10.
2. Tables 1, 2 and 3.
3. Current JMF for the mix using 100% virgin aggregates.

STEP 5 - The Materials and Testing Division (MTD) will evaluate the aged asphalt in the RAP after Absorb recovery, and using the data from Tables 1, 2 and 3 and the current JMF, the MTD will recommend the grade of virgin asphalt for recycling.

NOTE: If 15 percent or less RAP is used in the BCBC and ID-2 Binder mixes, the performance grade of neat asphalt binder specified in the current JMF can be used and there is no need to submit the RAP samples to the MTD.

Table 1. RAP MIX COMPOSITION (HOT RECYCLING)

SIEVE SIZE	Fine Aggregate (s)										MEAN X	STD. DEV.	
	1	2	3	4	5	6	7	8	9	10			
% Pass.													
50 mm (2")													
37.5 mm (1½")													
25 mm (1")													
19.0 mm (¾")													
12.5 mm (½")													
9.5 mm (⅜")													
4.75 mm (#4)													
2.36 mm (#8)													
1.18 mm (#16)													
600 µm (#30)													
300 µm (#50)													
150 µm (#100)													
75 µm (#200)													
% AC													



Table 2. PROPOSED RECYCLED MIX DATA (HOT RECYCLING)

A. Bituminous Concrete Producer \_\_\_\_\_  
 Plant Location \_\_\_\_\_  
 Name of Representative & Phone No. \_\_\_\_\_  
 Location of RAP Stockpile \_\_\_\_\_  
 Project for Recycling: District \_\_\_\_\_ SR \_\_\_\_\_ TR \_\_\_\_\_  
 Use of Recycled Mix: Main Line/Shoulders/Patching ADT \_\_\_\_\_

B. Details of Virgin Aggregates:

Source	Pa. No. (57/8/F.A.)	Type (Stone/Gravel/Slag)	SRL
1.			
2.			
3.			
4.			
5.			

C. Proposed Mix Composition:

	Percentages in		
	BCBC	ID-2 BINDER	ID-2 WEARING
RAP			
Virgin Aggregate No.			
Virgin Aggregate No.			
Virgin Aggregate No.			
TOTAL			

D. Proposed Virgin Asphalt Cements (Supply data for all grades):

	AC-20	AC-10	AC-5	AC-2.5
Supplier & Location				
Penetration @ 25 °C (77°F)				
Viscosity @ 60 °C (140°F), poises				
Viscosity @ 135 °C (275°F), cSt				

Table 3. PROPOSED BLENDS AND JOB-MIX FORMULA (HOT RECYCLING)  
 Mix Type: BCBC/ID-2 Binder/ID-2 Wearing (circle applicable)

SIEVE	RAP			NO. 1			NO. 2			NO. 3			Total % in Blend	Specification Range
	% Pass X A = % in Blend	% Pass X B = % in Blend	% Pass X C = % in Blend	% Pass X D = % in Blend	% Pass X E = % in Blend	% Pass X F = % in Blend	% Pass X G = % in Blend	% Pass X H = % in Blend	% Pass X I = % in Blend	% Pass X J = % in Blend	% Pass X K = % in Blend			
75 µm (200)														
150 µm (100)														
300 µm (50)														
600 µm (30)														
1.18 mm (16)														
2.36 mm (8)														
4.75 mm (4)														
9.5 mm (3/8)														
12.5 mm (1/2)														
19.0 mm (3/4)														
25.0 mm (1)														
37.5 mm (1-1/2)														
50 mm (2)														

A, B, C, D = Decimal Fraction of each aggregate in blend

STEP 6 - Obtain a sample of the MTD recommended asphalt grade from the asphalt supplier (it is advisable to keep these samples on hand in advance to save time).

Prepare 15 Marshall specimens at five different asphalt contents (use half percent increments) bracketing the current JMF asphalt content (based on 100% virgin aggregates). To facilitate the mixing of the RAP, it should be heated in an oven (for not more than 1+ hours) at  $127 \pm \text{five } ^\circ\text{C}$  ( $260 \pm 10^\circ\text{F}$ ) unless directed otherwise. Heat the virgin aggregate(s) to a suitable temperature so that the resulting mix temperature is  $127 \pm 3 ^\circ\text{C}$  ( $260 \pm 5^\circ\text{F}$ ). Compact the Marshall specimens at  $127 \pm 3 ^\circ\text{C}$  ( $260 \pm 5^\circ\text{F}$ ).

Obtain the Marshall design data and report in Table 4. Plot the data on the six graphs (TR-448B) of the Marshall Design Summary.

Submit Table 4 and TR-448B to the District Materials Engineer for review of the JMF.

It may not always be possible to establish the optimum asphalt content based on the average of the two asphalt contents at maximum specimen specific gravity and 4% air voids. In such cases, it is recommended to select the asphalt content which essentially gives the air voids content equal to the current JMF using 100% virgin aggregates.

If it is intended to vary the percentage of the RAP during production, develop the recycled mix designs using RAP in increments of five percentage points, such as, 10, 15, 20, 25 and 30 percent. If it is desired to use 12% RAP, the asphalt content can be interpolated from the design values at 10 and 15% RAP.

Table 4. MARSHALL DESIGN SUMMARY (HOT RECYCLED MIX)

Producer \_\_\_\_\_ Plant \_\_\_\_\_ Date \_\_\_\_\_  
 Recycled Mix Type \_\_\_\_\_ Virgin Asphalt Source & Grade \_\_\_\_\_  
 Temperatures Used in Mixing: RAP \_\_\_\_\_ Virgin Aggregate \_\_\_\_\_ AC \_\_\_\_\_  
 Mix Temperature \_\_\_\_\_ Compaction Temperature \_\_\_\_\_

% AC from RAP*			
% Virgin AC			
% Total AC			
Specimen Sp. Gr.			
Maximum Sp. Gr.			
% Voids			
% VMA			
% VFA			
Stability, Newtons (lbs.)			
Flow, Units			

\* % AC from RAP = % AC in 100% RAP X Decimal Fraction of RAP in Mix.

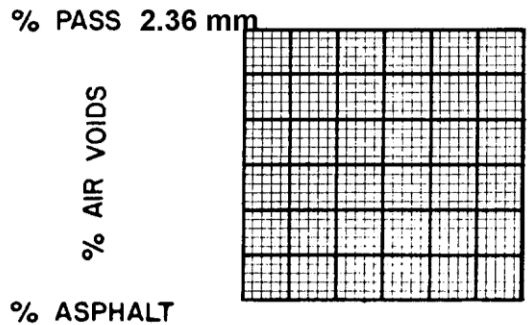
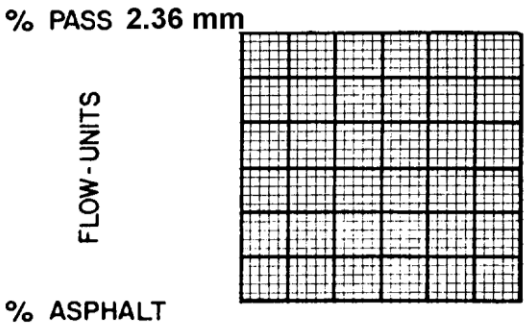
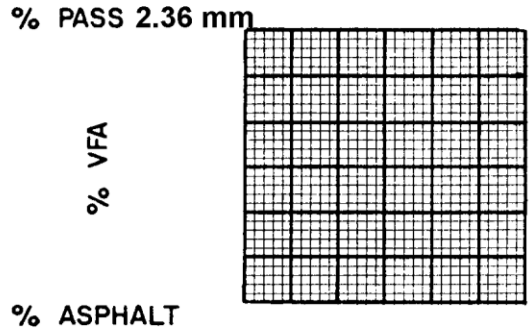
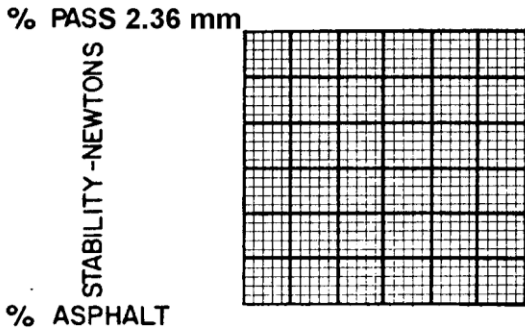
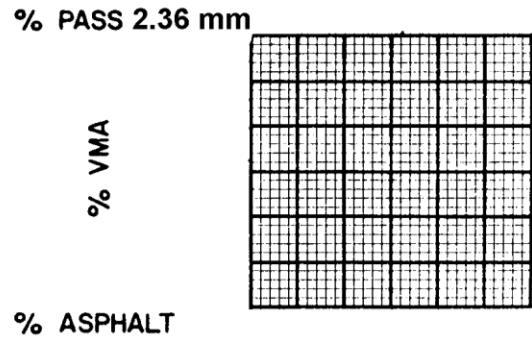
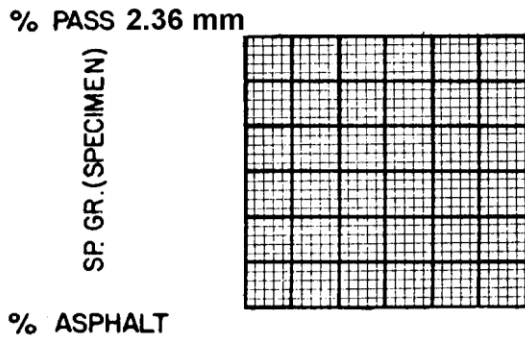
# MARSHALL DESIGN SUMMARY

OPTIMUM PERCENT ASPHALT AND PERCENT PASS 2.36 mm

DATE \_\_\_\_\_ SPEC \_\_\_\_\_ AGG \_\_\_\_\_

BIT. CONC. PRODUCER \_\_\_\_\_ LOCATION \_\_\_\_\_

DISTRICT \_\_\_\_\_ COUNTY \_\_\_\_\_ SR \_\_\_\_\_ SEC \_\_\_\_\_



# MARSHALL DESIGN SUMMARY

OPTIMUM PERCENT ASPHALT AND PERCENT PASS No. 8

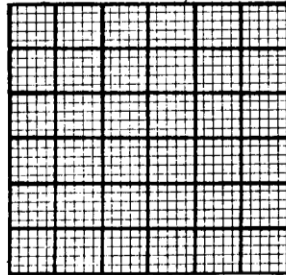
DATE \_\_\_\_\_ SPEC \_\_\_\_\_ AGG \_\_\_\_\_

BIT. CONC. PRODUCER \_\_\_\_\_ LOCATION \_\_\_\_\_

DISTRICT \_\_\_\_\_ COUNTY \_\_\_\_\_ LR \_\_\_\_\_ SEC \_\_\_\_\_

% PASS NO 8

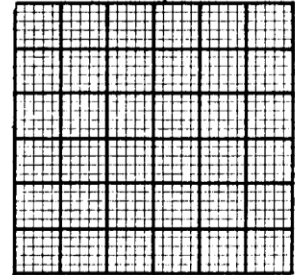
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% ASPHALT

% PASS NO 8

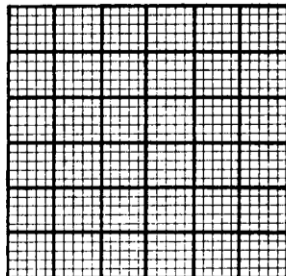
% VMA



% ASPHALT

% PASS NO 8

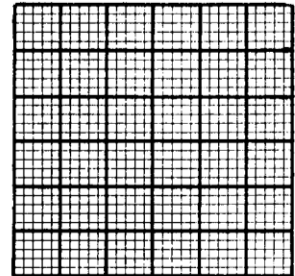
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% ASPHALT

% PASS NO 8

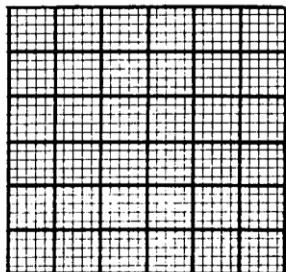
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% ASPHALT

% PASS NO 8

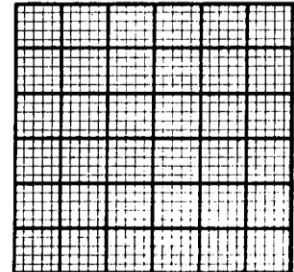
FLOW - UNITS



% ASPHALT

% PASS NO 8

% AIR VOIDS



% ASPHALT

## 6. Mix Design Method for Cold Recycled Base Course, In-Place or Central Plant Mix Recycling.

6.1 The following procedures shall be followed when cold recycling is to be done by the Contractor or Department forces:

1. Obtain representative samples of the RAP material by one of the following methods:
  - a. From Stockpile: If the material to be recycled is stockpiled, obtain five 2.2 kg (twenty pound) bags of the milled material or RAP from different locations on the stockpile. Remove at least six inches of the material from the stockpile surface before obtaining the sample. Scalp off the material over a (2-inch sieve).
  - b. By Milling: If cold recycling is to be done in place without stockpiling the RAP, obtain five 2.2 kg (twenty pound) bags of RAP by milling a representative portion of the project. Use a milling machine similar to the one intended for use on that project.
  - c. Cores: Although milled material or RAP is preferred for designing the cold recycled mixture, cores from the existing pavement are acceptable as an alternate. Obtain fifteen 152 mm (6-inch) diameter cores from a representative portion of the project. If the project has areas with different pavement layers and/or thickness, obtain fifteen cores from each area.

Screen RAP on a one inch sieve. Reduce any material retained on the one inch sieve to 100% passing. If cores are used, crush the cores and sieve over a 25.0 mm (one inch) sieve. Determine the asphalt content based on an average of four samples using either the extraction method or ignition furnace. The correction factor for mass loss in the ignition oven shall be 0.5.

2. Run a minimum of three gradations on the RAP material. Determine if virgin aggregate is needed by reviewing the sieves listed below and ensuring that the RAP material meets the required range for % passing on these sieves. If the RAP does not meet the % passing requirements below, virgin aggregate is needed.

Sieve Size	% Passing
19 mm (3/4")	52 – 100
9.5 mm (3/8")	36 – 70
4.75 mm (#4)	24 – 50

3. Prepare one thousand (1000) gram samples of RAP material passing the 25.0 mm (1") sieve and retained on the 12.5 mm (1/2") sieve, material passing the 12.5 mm (1/2") sieve and retained on the 4.75 mm (#4) sieve, and material passing the 4.75 mm (#4) sieve and retained in the pan.
4. Keep the moisture content of the prepared RAP samples constant at three percent.
5. Select the grade of emulsion to be used from the following list:  
MS-2 (E-4), CMS-2 (E-5), SS-1 (E-6A), CSS-1 (E-6C), SS-1h (E-8A),  
CSS-1h (E-8C), HFMS-2h (E-11-60), HFMS-2 (E-11-90), HFMS-2S (E-11-150)

Any of these emulsions may be polymer modified. Evaluate the emulsion by a coating test. The ability of the emulsion to coat the aggregate is critical. Typically, compatible emulsions will achieve 80 percent or greater coating with little or no wads. (Non-dispersed asphalt and fines).

6. Prepare three mixtures at four different emulsion contents using a three percent moisture content. For mixing purposes, the RAP should be at ambient temperature and the emulsion at 60 C (140°F). Normally, use 2.0%, 2.5%, 3.0% and 3.5% emulsion content. If the RAP is rich in asphalt, start with 1.5% emulsion content and vary by 0.5% increments. If RAP is blended with virgin aggregate, start at 3.0% emulsion.
7. Cure the mixtures in an oven at 40C (105°F) for one hour. Remix for 30 seconds and allow to cool to room temperature.
8. Compact the mixtures using a Marshall hammer with 75 blows on each side. Extrude the compacted specimens the following day.
9. Prior to testing, cure the specimens to constant weight in an oven at 40C (105°F). Lay samples on their side to maximize surface exposure during the curing process. For this test method, constant weight is defined as a sample with a mass loss of less than 0.5 grams when weighed at 15 minute intervals.
10. Record the specimen thickness and weight.
11. Determine the Bulk Specific Gravity for each specimen (five minutes in water bath).
12. On the SSD conditioned specimens, determine the Marshall Stability at 25°C (77°F) and at a flow of 10.
13. Determine the optimum emulsion content based on the averages for maximum stability and specimen density.

**6.2 Field Adjustments.** Because RAP gradation and composition may vary, field adjustments to the moisture content or emulsion content may be necessary. If the coating of the surface dry mix is not satisfactory (less than 75%), adjust the moisture content first. Cure the mixture if necessary before compaction. Adjust the emulsion content based on mix behavior during and after compaction. Optimum compaction should be achieved using nuclear gauge control strip techniques.

## **7. Full Depth Reclamation (Using Bituminous Stabilization Process)**

### **7.1 General.**

Full depth reclamation (FDR) is a method by which asphalt layers and underlying base, and subbase layers may be treated to produce a stabilized base course. FDR is suitable for pavements where inadequate asphalt pavement depth precludes the use of cold recycling. Unlike cold recycling, FDR may incorporate suitable subgrade soil, making it ideal for lower type roads, including roads with poor base conditions, ‘pie-crust’



roads consisting of multiple thin layers and surface treatments, or even unpaved roads. See subsection 7.4 for specifications.

Different types of additives may be used to treat reclaimed materials. This section provides mix design guidelines for FDR with asphalt emulsion stabilizers. *Guidelines for FDR using Portland cement, lime, and liquid calcium chloride are provided in Strike-off-letter 420-00-19 dated April 26, 2000. Non-bituminous methods should be considered if preliminary analysis of in-situ materials determines asphalt emulsions are unsuitable for this process (See the following Guidelines for Selecting Asphalt Emulsions for FDR).*

## **7.2 Guidelines for Selecting Asphalt Emulsions as Stabilizers for Full Depth Reclamation (FDR)**

**Before** using asphalt emulsion as a stabilizer for full depth reclamation, the reclaimed pavement material **must** meet the following characteristics:

- The material should consist of 100% RAP or a blend of RAP and underlying granular base or non-plastic or low plasticity soils.
- The maximum percent passing the 75 µm (No. 200) sieve should be less than 25%. (AASHTO T11)
- The plasticity index (AASHTO T 90) should be less than six or the sand equivalent (AASHTO T 176) 30 or greater, or the product of multiplying the P.I. and the percent passing the 75 µm (No. 200) sieve being less than 72.

Additionally, small amounts of hydrated lime or cement, typically 1.5 and 1.0 percent respectively by weight, can be added with asphalt emulsion to produce reclaimed mixtures with higher early strength and greater resistance to water damage.

If an asphalt emulsion is used for full depth reclamation, use the design procedure outlined below in Section 7.3.

## **7.3 Design Process for Full Depth Reclamation (FDR) Using Emulsified Asphalts**

1. Obtain representative samples of the material (full depth) to be reclaimed. Either loose samples from milling or cores can be utilized. Screen millings on the 25 mm (one inch) sieve. Reduce in size any material retained on the 25 mm (one inch) sieve to 100% passing. If cores are used, crush the cores and sieve over a 25 mm (one inch) sieve. Determine the asphalt content and gradation based on an average of four samples using either the extraction method or ignition furnace. The correction factor for mass loss in the ignition oven shall be 0.5.
2. Run a minimum of three gradations on the reclaimed material. Determine if virgin aggregate is needed.
3. Prepare one thousand (1000) gram samples of material passing the 25 mm (one inch) sieve and retained on the 12.5 mm (1/2 inch) sieve, material passing the

12.5 mm (1/2 inch) sieve and retained on the 4.75 mm (#4) sieve, and material passing the 4.75 mm (#4) sieve and retained in the pan.

4. Keep the moisture content constant at three percent.
5. Select the grade of emulsion to be used from the following list:  
MS-2 (E-4), CMS-2 (E-5), SS-1 (E-6A), CSS-1 (E-6C), SS-1h (E-8A),  
CSS-1h (E-8C), HFMS-2h (E-11-60), HFMS-2 (E-11-90), HFMS-2S (E-11-150)

Any of these emulsions may be polymer modified. Evaluate the emulsion by a **coating test**. The ability of the emulsion to coat the aggregate is critical. Typically, compatible emulsions will achieve 80 percent or greater coating with little or no wads. (Non-dispersed asphalt and fines).

6. Prepare three mixtures each with four different emulsion contents using a three percent moisture content. For mixing purposes, the reclaimed material should be at ambient temperature and the emulsion at 60°C (140°F). Normally, use 3.0%, 3.5%, 4.0% and 4.5% emulsion content with reclaimed material containing from 75% to 100% RAP by weight. If RAP is rich in asphalt, start with 1.5% emulsion. For reclaimed materials with lesser quantities of RAP, some increase in the emulsion content will probably be necessary, particularly when fine graded soil material is present or virgin aggregate has been added.
7. Cure the mixtures in an oven at 40°C (105°F) for one hour. Remix for 30 seconds and allow to cool to room temperature.
8. Using a Marshall apparatus, compact the mixtures with 75 blows on each side. Extrude the compacted specimens the following day.
9. Prior to testing, cure the specimens to constant weight in an oven at 40°C (105°F). Lay specimens on their side to maximize surface exposure during the curing process. For this test method, constant weight is defined as a specimen with a mass loss of less than 0.5 grams when weighed at 15 minute intervals.
10. Record the specimen thickness and weight.
11. Determine the Bulk Specific Gravity for each specimen (five minutes in water bath).
12. On the SSD conditioned specimens, determine the Marshall Stability at 25°C (77°F) and at a flow of 10.
13. Determine the optimum emulsion content based on the averages for maximum stability and specimen density.

## 7.4 Bituminous Stabilization Interim Specifications

### SECTION 345 – BITUMINOUS STABILIZED SUBBASE

**345.1 DESCRIPTION** – This work is the construction of a bituminous stabilized subbase by use of in-place equipment capable of pulverizing, blending, and mixing existing materials with emulsified asphalt and aggregate as needed.

Do not place bituminous stabilized subbase from September 1 to April 30 in districts 1-0, 2-0, 3-0, 4-0, 9-0, and 10-0; and from October 1 to April 30 in all other districts. This provision may be waived as local conditions permit only with the written approval of the Engineer. Construct the bituminous stabilized subbase only when temperature remains above freezing for 24 hours prior to paving and the ambient temperature on the project is 7°C (45F) and rising.

#### **345.2 MATERIAL** –

(a) **Reclaimed Material.** 95% of the material is required to pass through a 50 mm (2-inch) sieve. Reduce oversize material as required. Incorporate all reclaimed material into the stabilized subbase.

1. **Reclaimed Aggregate Material (RAM).** In situ aggregate material which is incorporated in the stabilization.

2. **Reclaimed Asphalt Pavement (RAP).** Processed paving material containing asphalt cement and aggregates.

(b) **Bituminous Material.** Add to the mix the type and quantity of bituminous material as determined by the approved mix design. Use bituminous material conforming to the applicable requirements of Bulletin 25. Use one of the following:

- Emulsified Asphalt – MS-2(E-4), CMS-2(E-5), SS-1(E6A) CSS-1(E6-C), SS-1h(E-8A), CSS-1h(E-8C), HFMS-2h(E-11-60), HFMS-2(E-11-90), HFMS-2s(E-11-150). Polymer modified versions of the above materials can be used as necessary, conforming to the requirements in Publication 242, Chapter 5.

(c) **Aggregate.** Section 703.2 (Type A), No. 8, 10, 57, and 67. Add the gradation and quantity to the mix as required.

(d) **Mix Design.** Remove samples of RAP and RAM to the specified depth and perform the appropriate testing to establish the mix design. Design in accordance with the requirements of this Bulletin and submit to the DMM/DME for review at least three weeks prior to commencement of work on the project.

(e) **Mixture.** Combine the reclaimed material, aggregates (if necessary), and bitumen, in such proportions that the total aggregate and bitumen in the reclaimed mix conform to the requirements and composition specified in the mix design with the recommended optimum moisture and emulsion content. When composition varies sufficiently, make field adjustments as recommended in the design to obtain completed bituminous stabilized subbase, with satisfactory particle coating and optimum compaction.

### 345.3 CONSTRUCTION –

(a) **Equipment.** Use equipment that will produce the completed bituminous stabilized subbase as follows:

1. Use equipment capable of automatically metering liquids with a variation of not more than  $\pm 2\%$  by mass (weight) of liquids.
2. Maintain all equipment in a satisfactory operating condition as specified in Section 108.05(c).

(b) **Mixing.** Maintain adequate total liquids to ensure total mixing of the reclaimed material and aggregate (if required) with the bituminous material. Add water to the surface by a calibrated meter as necessary to aid in mixing and compaction.

Measure the milling depth at the time of pulverization. Make at least one measurement for each 2500 square meters (3000 square yards) of work done and record the measurements to ensure that the specified milling depth is met. Correct or satisfactorily replace any section deficient 13 mm (1/2-inch) or more from the specified depth at no expense to the Department.

(c) **Compaction.** Shape, grade, and compact to the lines, grades, and depth shown on the plans and cross sections after the material has been processed. Roll with rollers meeting the requirements of Section 108.05(c). Allow the mixture to cure as necessary prior to rolling. Commence rolling at the low side of the course. Leave 80 to 150 mm (3 to 6 inches) from any unsupported edge(s) unrolled initially to prevent distortion.

Determine in-place density requirements by the construction of at least one control strip under the guidance of a nuclear gauge operator. After each pass of the compaction equipment, take a nuclear density reading in accordance with PTM No. 402. Continue compaction with each piece of equipment until no appreciable increase in density is obtained by additional passes. Upon completion of compaction, make a minimum of ten tests at random locations to determine the average in-place density of the control strip.

Compact the bituminous stabilized subbase to a target density of at least 96% of the average in-place density of the control strip. Determine the in-place density in accordance with PTM No. 402 for each 2500 square meters (3000 square yards) area. When less than 96% of the average in-place density of the control strip is determined for any area and additional compaction cannot produce acceptable results, rescarify and adjust moisture content to achieve optimum compaction conditions and recompact. If the minimum density still is not achieved but the completed bituminous stabilized subbase is uniform in texture, stable and acceptable in all other respects, define as a new control strip making a minimum of ten tests at random locations to determine a new target in-place density. However, if the completed bituminous stabilized subbase is unacceptable for any reason, do not continue construction until the cause of the deficiency(ies) is determined.

(d) **Finishing.** Complete all portions of the bituminous stabilized subbase during daylight hours, unless otherwise permitted.

(e) **Protection.** Protect any finished portion of the bituminous stabilized subbase upon which any construction equipment is required to travel to prevent marring, distortion or damage of any kind. Immediately and satisfactorily correct any such damage.

**(f) Surface Tolerance.** When directed by the Engineer, test the completed bituminous stabilized subbase for smoothness and accuracy of grade, both transversely and longitudinally using suitable templates and straightedges. Satisfactorily correct any 2500 square meter (3000 square yard) area where the average surface irregularity exceeds 25 mm (1 inch) under a template or straightedge, based on a minimum of at least three measurements.

**(g) Maintenance and Traffic.** Maintain the completed bituminous stabilized subbase and control traffic as specified in Section 401.3.

**(h) Curing.** Allow the bituminous stabilized subbase to cure for at least one week after final compaction has been completed. Protect the surface from drying. Apply a bituminous seal coat if excessive raveling is present.

#### **345.4 MEASUREMENT AND PAYMENT –**

**(a) Bituminous Stabilized Subbase.** Square Meter (Square Yard).

**(b) Aggregate.** Tonne (Ton).

**(c) Bituminous Material.** Liter (Gallon).