WEST VIRGINIA DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
MATERIALS CONTROL, SOILS AND TESTING DIVISION

MATERIALS PROCEDURE

GUIDE TO DESIGNING HOT-MIX ASPHALT USING THE MARSHALL DESIGN METHOD

1. PURPOSE

1.1 To establish an approved Marshall design method, test procedures, and evaluation criteria for hot-mix asphalt (HMA). If reclaimed asphalt pavement (RAP) is used in the design, refer to Materials Procedure (MP) 401.02.24 for additional guidelines.

2. SCOPE

2.1 This procedure is applicable to design tests conducted for the purpose of establishing mixture proportions for HMA using the Marshall mix design method. Marshall designs that have already been approved under the previous version of this MP may still be used as long as the mix design verification and quality control requirements of MP 401.02.27 can be met using Tables 1, 2, and 3 of this MP as the reference design criteria. Note that Table 1 has slightly modified the air void design criteria for Base-I so verification and quality control for older designs will be based on the new value.

2.2 Any approved mix design that exhibits poor field performance may be rejected from further use by the Division.

3. REFERENCED DOCUMENTS

3.1 AASHTO Standards:

a) R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
b) T 30, Mechanical Analysis of Extracted Aggregate
c) T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA)
d) T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
e) T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
f) T 269, Percent Air Voids in Compacted Dense and Open Asphalt Mixtures
g) T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method

3.2 ASTM Standards:

a) D 5581, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus (6 inch-Diameter Specimen)

3.3 Asphalt Institute:

a) MS-2 Manual, Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types – This well written Asphalt Institute reference guide explains the entire Marshall Method design process in a logical order. The mix designer must still adhere to WVDOH design property requirements and procedures, and they must use the latest AASHTO and ASTM test methods.

3.4 Material Procedures:

a) MP 401.02.24, Guide to Designing Hot Mix Asphalt with Reclaimed Asphalt Pavement.
b) MP 401.02.27, Guide for Contractor Quality Control of Hot Mix Asphalt
c) MP 700.00.06, Aggregate Sampling Procedures
d) MP 700.00.54, Procedure for Evaluating Quality Control Sample Test Results with Verification Sample Test Results

4. TESTING REQUIREMENTS

4.1 The laboratory performing the design shall be a Division approved laboratory. To obtain Division approval, a laboratory must demonstrate that they are equipped, staffed and managed, for batching and testing HMA in accordance with this MP. This shall be accomplished by submitting a copy of their latest report of inspection by the AASHTO Materials Reference Laboratory (AMRL) to the District Materials Section. The laboratory must also submit a letter detailing the actions taken to correct any deficiencies noted in the test procedures listed below. The District will forward this information to Materials Control, Soils and Testing Division (MCS&T). It is also required that the laboratory request to be included on AMRL's routine schedule of inspections, which is usually every 18 to 24 months in order to maintain their approval status.

4.1.1 AASHTO Test Procedures

a) T 245, Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus
b) T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
c) T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
d) T 27**,** Sieve Analysis of Fine and Coarse Aggregates **(Note 1)**
e) T 11**,** Materials Finer Than 75 µm (No. 200) Sieve in Mineral Aggregates by Washing **(Note 1)**
f) T 84, Specific Gravity and Absorption of Fine Aggregate
g) T 85, Specific Gravity and Absorption of Coarse Aggregate

Note 1: T 30, Mechanical Analysis of Extracted Aggregate, may be substituted for T 27 and T 11 if the laboratory is using T 308, Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method or T 164, Quantitative Extraction of Asphalt Binder from Hot Mix Asphalt (HMA).

4.2 The laboratory is required to have a technician who has attended and successfully completed a Division approved Marshall mix design class. In addition to the class that is offered through the West Virginia University Asphalt Technology Program, hands-on Marshall mix design classes offered by the Asphalt Institute, National Center for Asphalt Technology (NCAT), National Asphalt Pavement Association (NAPA), Chicago Testing Laboratory, and various state DOTs have been approved. Proof of successful completion of all class requirements (including a written examination) must be provided. Approval of an older design class that did not require a written examination will be on a case-by-case basis including a review of the designer's experience. MCS&T will maintain a list of the approved design laboratories and design technicians.

4.3 The required mix design properties are:

4.3.1 Stability and Flow: AASHTO T 245 or ASTM D 5581 as applicable.

4.3.2 Air Voids: AASHTO T 269

4.3.3 Voids in Mineral Aggregate (VMA): Asphalt Institute MS-2 Manual

4.3.4 Voids Filled with Asphalt (VFA): Asphalt Institute MS-2 Manual

4.3.5 Fines to asphalt (FA) ratio: Asphalt Institute MS-2 Manual

4.4 The design PG Binder shall normally be selected in accordance with Section 401.2 of the Standard Specifications. However, the laboratory's mix designer should refer to the contract documents to determine if a nonstandard binder has been specified for the project.

4.5 A series of test specimens shall be prepared for a range of different asphalt contents so that the test data curves show a well-defined "optimum" value. Samples shall be fabricated to include a range of asphalt contents of at least 2 percent at intervals not to exceed 0.5 percent.

4.6 Test specimens shall be fabricated from materials of the same sources and types as proposed in the job mix formula (JMF). The gradation of the combined aggregates used in the test samples shall be the same as that proposed in the plant mix formula and shall meet the requirements of Table 401.4.2A of the Standard Specifications. The percent passing each sieve contained in Table 401.4.2A, from one sieve larger than the nominal maximum size down to the 75 μm (No. 200) sieve, shall be included in all gradation calculations.

4.7 The gradation of each aggregate size from each source used in the mix design shall be determined from an average of at least three individual gradations of each material from the stockpile at the plant or from material supplied by the aggregate producer. The aggregates shall be sampled in accordance with MP 700.00.06.

4.8 If a mix contains reclaimed asphalt pavement (RAP), the asphalt must be removed from the RAP for gradation analysis by the ignition oven method (T 308) or a solvent extraction process (T 164). If the T 164 solvent extraction test method is used, a non-chlorinated solvent may be substituted for the standard specified solvent, and the test method may be modified as per the recommendations of the solvent supplier. The solvent must be a product that has been tested for use in extracting asphalt from HMA. The RAP used for designing a mix must come from the plant stockpile from which it will be produced.

4.9 A minimum of three compacted test specimens for each combination of aggregates and asphalt content are required.

4.10 The maximum specific gravity shall be based on the average of two samples prepared at the estimated optimum asphalt content.

4.11 Immediately after mixing each of the Marshall bulk specific gravity samples and the maximum specific gravity samples, age the samples for 2 hours ± 5 minutes in accordance with AASHTO R30 before further testing.

4.12 Mixtures shall be designed in accordance with the criteria set forth in Table 1, 2, and 3 unless otherwise indicated in a special provision or as a note in the contract documents.

TABLE 1—Marshall Method Mix Design Criteria

Design Criteria	Medium Traffic Design (Note 2 and 3)	Heavy Traffic Design	Base-I Design (Note 4)
Compaction, number of blows each end of specimen	50	75	112
Stability (Newtons) (minimum)	5,300	8,000	13,300
Flow (0.25 mm) (Note 5)	8 to16	8 to 14	12 to 21
Percent Air Voids	4.0	4.0	4.0
Percent Voids Filled with Asphalt (Note 6)	65 to 80	65 to 78	64 to 73
Fines-to-Asphalt Ratio	0.6 to 1.2		

Note 2: If the traffic type is not provided in the contract documents, contact the District to obtain this information before developing the mix designs.

Note 3: All Wearing-III mixes shall be designed as a 50-blow mix regardless of traffic type.

Note 4: All Base-I mixes will be designed and tested using 112 blows with six-inch diameter specimens in accordance with ASTM D 5581.

Note 5: When using a recording chart to determine the flow value, the flow is normally read at the point of maximum stability just before it begins to decrease. This approach works fine when the stability plot is a reasonably smooth rounded curve. Some mixes comprised of very angular aggregates may exhibit aggregate interlocking which causes the plot to produce a flat line at the peak stability before it begins to drop. This type of plot is often difficult to interpret, and sometimes the stability will even start increasing again after the initial flat line peak.

When such a stability plot occurs, the stability and flow value shall be read at the initial point of peak stability.

Note 6: A Wearing-I heavy traffic design shall have a VFA range of 73–78 percent. A Wearing-III mix shall have a VFA range of 75–81 percent.

TABLE 2—Percent Voids in Mineral Aggregate (Note 7)

Mix Type	Nominal Size Sieve	Percent Voids in Mineral Aggregate (VMA) (minimum)
Wearing-III & Scratch-III	4.75 mm (No. 4)	17
Wearing-I & Scratch-I	9.5 mm (⅜ in.)	15
Base-II, P&L & Wearing-IV	19 mm (¾ in.)	13
Base-I	37.5 mm (1 ½ in.)	11

Note 7: Mixtures designed with the VMA exceeding the minimum value by more than two percent may be susceptible to flushing and rutting problems, especially when used on pavements subjected to slow moving traffic conditions. They may also be difficult to compact as they often have a tendency to shove under the roller.

TABLE 3—Design Aggregate Gradation Requirements for Marshall Mixtures (Note 8)

TYPE OF MIX	**Base-I**	**Base-II (Patch & Level)**	**Wearing-IV (Note 9)**	**Wearing-I (Scratch-I)**	**Wearing-III (Scratch-III)**
SIEVE SIZE	**Nominal Maximum Size**				
	1 ½ in (37.5 mm)	**¾ in** (19 mm)	**¾ in** (19 mm)	**3/8 in** (9.5 mm)	**No. 4** (4.75 mm)
2 in (50 mm)	100				
1 ½ in (37.5mm)	90 - 100				
1 in (25 mm)	90 max	100	100		
¾ in (19 mm)	-	90 – 100	90 – 100		
½ in (12.5 mm)	-	90 max	90 max	100	
3/8 in (9.5 mm)	-	-	-	85 - 100	100
No. 4 (4.75 mm)	-	-	47 min	80 max	90 - 100
No. 8 (2.36 mm)	15 – 36	20 – 50	20 – 50	30 – 55	90 max
No. 16 (1.18 mm)	-	-	-	-	40 - 65
No. 30 (600 µm)	-	-	-	-	-
No. 50 (300 µm)	-	-	-	-	-
No. 200 (75 µm)	1.0 – 6.0	2.0 – 8.0	2.0 – 8.0	2.0 – 9.0	3.0 – 11.0

Note 8: For quality control of the mixture the allowable tolerances for each JMF shall be the specified design control points shown in Table-3 with the exception that a Wearing-III mix shall have a tolerance limit of the JMF ± 5% on the 1.18 mm (No. 16) sieve, and all other mix types shall have a tolerance limit of the JMF ± 6% on the 2.36 mm (No.8) sieve. These tolerances shall also be applied to the mix design and shall be documented on the T-400 Form. The tolerances shall not fall outside of the specified control points of Table-3.

Note 9: In addition, a Wearing-IV mix shall have a tolerance limit of the JMF ± 5% on the 4.75 mm (No. 4) sieve, but not below the minimum requirement.

5. DETERMINING THE OPTIMUM ASPHALT CONTENT

5.1 Prepare a graphical plot of the following relationships:

a) Asphalt Content vs. Percent Air Voids.
b) Asphalt Content vs. Stability
c) Asphalt Content vs. Flow
d) Asphalt Content vs. VMA
e) Asphalt Content vs. VFA

5.2 From the plot of asphalt content vs. percent air voids, pick the asphalt content that corresponds to the 4.0 percent air voids.

5.3 If the corresponding stability, flow, VMA, and VFA values are within the specified design criteria at the asphalt content determined in Section 5.2, then this asphalt content shall be considered the optimum asphalt content for the mix.

5.4 If the design property values determined as per Section 5.3 do not meet the specified criteria at the percent asphalt content determined in Section 5.2, then new mix proportions must be determined, and new test data developed.

5.5 Full mix design testing will not be required when a mix design is developed using the sources, exact aggregate types, and compaction level as a prior Division approved design, along with a different neat binder grade. The designer may instead select to make a set of bulk specific gravity test specimens and a maximum specific gravity test specimen with the approved aggregate structure and the new binder grade at the optimum asphalt content of the approved design. Since these samples are laboratory produced design specimens, they must be oven aged for 2 hours ± 5 minutes before testing in accordance with R 30. Mix and compaction temperature will be based on the requirements of the new binder grade. The percent air voids must be 4.0 ± 0.3 percent. The voids-in-mineral aggregate must be within ± 0.5 percent of the original approved job mix formula design target (but not outside of the design limits of this MP). All other mix design criteria must be within the design limits specified in this MP (including stability and flow). If the mix design meets all of these requirements then this test data may be submitted along with a new T400 form for approval as a new mix design. A copy of the approved T400 on which this new design is based should also be included. If the mix design fails to meet all of the requirements then a new mix design must be developed.

6. REPORT

6.1 The T-400 JMF form shall include the design property information required in Section 401.4 of the Standard Specifications. The JMF package shall include the following:

6.1.1 A summary sheet (Marshall Mix Design Package Attachment #1, Optimum Asphalt Content Determination) showing the proposed asphalt content determination plus the design properties compared to the design criteria of Table 1. This attachment shall be signed and dated by the mix design technician.

6.1.2 The chart showing the plots described in Section 5.1 used to determine the optimum asphalt content (Attachment #2).

6.1.3 A Summary of Marshall Mix Design Data worksheet (Attachment #3).

6.1.4 Worksheet for calculating the effective gravity of the blended aggregates (Attachment #4 or #4A).

6.1.5 Worksheets showing calculations for maximum specific gravities of the mix at different asphalt contents (Attachment #5). For any mix design that contains any single coarse aggregate component with the water absorption of 1.5 percent or greater, follow the supplemental procedure of T 209 to determine if a dry-back is necessary. Because the dry-back procedure is addressing an aggregate coating issue, this same supplemental procedure shall be used on quality control and verification samples of mixes containing these high absorptive aggregates to determine if the dry-back procedure is necessary.

6.1.6 Worksheet for calculating the bulk and apparent specific gravities of the total aggregate, and the percent VMA in the compacted mixture (Attachment #6 or #6A).

6.1.7 Worksheet for determining the maximum specific gravity of the mixture, including the dry-back procedure when required (Attachment #7).

6.1.8 Worksheets showing calculation for bulk and apparent specific gravities and absorption of the coarse and fine aggregates used in the mix design (Attachments #8 and #8A).

6.1.9 The 0.45 power gradation chart (Attachment #9) developed for each mix design. This chart shall include the maximum density line, aggregate control points, and a gradation plot showing each screen used in the design.

6.1.10 A worksheet showing the calculations for the combined aggregate of the mix design (Attachment #10).

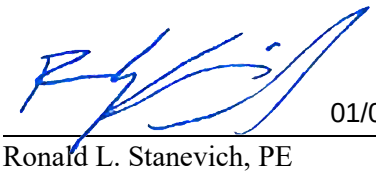
6.1.11 Worksheets showing the washed sieve analysis results for each aggregate used in the mix design (Attachment #11).

6.1.12 The temperature-viscosity chart for the asphalt used in the mix design. An asphalt supplier issued chart or document containing the mix and compaction temperature recommended for the specific grade of asphalt will be acceptable.

6.2 The entire printed JMF package shall be submitted to the local District Materials Section in which the HMA plant is located. After reviewing, the District shall attach a memo to the JMF package requesting approval of the design and submit it to the MCS&T Asphalt Section.

6.2.1 The JMF package can also be submitted electronically by scanning it into an Adobe Acrobat Reader file and e-mailing the file to the appropriate District Materials Section and the MCS&T Asphalt Section. After reviewing the JMF package, the District will send an e-mail to the MCS&T Asphalt Section verifying that the JMF package has been reviewed. The District will also note any problems that they find with the JMF. The MCS&T Asphalt Section will conduct a final review on the design package and assign a laboratory number to each approved mix design. MCS&T will contact the mix designer if there are any problems or concerns with the JMF package that will delay final approval. An electronic copy of the approved T400 form shall be e-mailed to the District and Producer for distribution.

6.3 All applicable mix design worksheets can be found on the MCS&T's Webpage[1] under the "Toolbox."



01/04/2023

Ronald L. Stanevich, PE
Director
Materials Control, Soils & Testing Division

MP 401.02.22 Steward – Asphalt Section
RLS:J

[1] https://transportation.wv.gov/highways/mcst/Pages/default.aspx