METHODS OF SAMPLING AND TESTING
MT 306-04
MARSHALL METHOD FOR BITUMINOUS MIX DESIGN

GENERAL

1 Scope:

1.1 The Marshall method may be employed for specifying, obtaining and maintaining the best possible physical or structural properties of the paving mixture. To achieve these objectives, the test is applied in the following ways:

2 Application:

2.1 Determine the limits for specifications, with reference to gradation and aggregate source proposed for use, to produce the most satisfactory physical properties.

2.2 Design the paving mixture from the materials proposed for use in order that the requirements will be determined before plant production starts.

3 Maximum Size Aggregate:

3.1 The Marshall method as presented here is applicable only to hot-mix asphalt paving mixtures using penetration grades of asphalt cement and containing aggregates with maximum size of one inch or less.

4 Preliminary Requirements:

4.1 The procedure for the Marshall method starts with the preparation of test specimens. Preliminary to this operation it is, of course, required that:

4.2 The material proposed for use must meet the requirements of the project specifications.

PREPARATION OF TEST SPECIMENS

5 General:

5.1 In determining the optimum asphalt cement for a particular gradation of aggregates by the Marshall method, a series of test specimens is prepared for a range of different asphalt contents so that the test data curves show a well-defined "optimum" value. Tests should be scheduled on the basis of one-half of one percent increments of asphalt contents, with at least one asphalt content above "optimum" and at least one asphalt content below "optimum."

6 Number of Specimens:

6.1 To provide adequate data, three test specimens are prepared for each asphalt content used. Thus, a hot-mix design study using five different asphalt contents, based on ½% increments with two on each side of the optimum asphalt content, will normally require fifteen test specimens. Each test specimen will usually require approximately 1100 to 1150 grams of aggregate

7 Equipment:

7.1 Pans, metal, round, approximately 4-quart capacity for mixing.

7.2 Oven and hot plate, electric, for heating aggregates, asphalt and equipment required.

7 Equipment: (continued)

7.3 Scoop, for batching aggregates.

7.4 *Containers* - gill-type, tins, beakers, pouring pots, for heating asphalt.

7.5 *Thermometer* - armored glass, or dial type with metal stem, +50ºF to +450ºF for determining temperature of aggregates, asphalt and aggregate mixtures.

7.6 *Balance* - 5 kg capacity, sensitive to 1 g, for weighing aggregates and asphalt. Balance, minimum 2 kg capacity, sensitive to 0.1 g, for weighing compacted specimens.

7.7 Mixing spoon or trowel.

7.8 Spatulas, large, stiff.

7.9 Boiling water-bath, consisting of hot plate and bucket for water, for heating compaction hammer and mold.

7.10 *Compaction pedestal* - consisting of an 8 inch x 8 inch x 18 inch wooden post capped by a 12 inch x 12 inch x 1 inch steel plate. The post should be placed on a 24 inch x 24 inch x 4 inch concrete block so it is plumb, the top is level, and the entire assembly is free from movement during use.

7.11 *Compaction mold* - consisting of a base plate, forming mold, and collar extension. The forming mold has an inside diameter of 4∀.005 inches and a height of approximately three inches; the base plate and collar are designed to be interchangeable with either end of the forming mold.

7.12 *Compaction hammer* - consisting of a flat, circular, tamping face 3-7/8 inches in diameter and equipped with a ten pound weight constructed to obtain a specified 18-inch height of drop.

7.13 *Mold holder* - consisting of a spring tension device designed to hold compaction mold in place on compaction pedestal.

7.14 *Extrusion jack, or arbor press* - for extruding compacted specimens from the mold.

7.15 Welders gloves for handling hot equipment and rubber gloves for removing specimens from water bath.

7.16 Marking crayons for identifying test specimens.

7.17 *Set of standard sieves* - 10 mesh (2.00 mm) to 1" (25.0 mm)

Note 1 - All laboratories are equipped with the Marshall Mechanical Compactor. These should be used in preference to hand compaction. It is essential that the mechanical compactor be placed on a foundation or base as described in paragraph 7.K. Double or triple hammer compactors will require an appropriately larger base than the one described.

8 Preparation of Test Specimens:

8.1 Number of specimens - Prepare at least three specimens for each combination of aggregates and asphalt.

8.2 Preparation of aggregates - Dry aggregates to constant weight at 230 ± 9ºF (110 ± 5ºC) and separate the aggregates by dry sieving into the desired size fractions.

8 Preparation of Test Specimens: (continued)

8.3 Mixing Temperature - Select the mixing temperature for asphalt required to produce a viscosity of 170 ± 20 C_{st} as obtained by using the temperature-viscosity charts in MT-308.

8.4 Compaction Temperature - Select the compaction temperature so that the viscosity of asphalt is 280 ± 30 C_{st} as obtained by using the temperature-viscosity charts in MT-308.

8.5 Preparation of mold and hammer - Thoroughly clean the specimen mold assembly and the face of the compaction hammer. Heat them in a boiling water bath or on the hot plate to a temperature between 200 and 300 F. Place a filter paper, cut to size, in the bottom of the mold before the mixture is placed in the mold.

8.6 Preparation of mixture - Weigh the quantity of each size of aggregate to produce a 63.5 ± 1.27 mm (2.5 ± 0.05 inches) high finished briquet. The total weight of aggregate is usually 1150 grams. Progressively combine these fractions into a single pan. (Note 2) Place the pan in an oven or on a hot plate and heat to a temperature approximately 28°C (50°F) above the mixing temperature specified in 8.3. Prevent local overheating. Dry mix the aggregate thoroughly, form a crater in the center and weigh the required asphalt cement into the crater. At this point, the temperature of the aggregate and asphalt shall be within the limits of the mixing temperature established in paragraph 8.3. Mix the asphalt and aggregate with a trowel or stiff spatula as quickly and thoroughly as possible to yield a mixture having a uniform distribution of asphalt throughout. (Note 3)

Note 2 - A mixture of aggregate shall be prepared without the minus 200 mesh and washed to determine the percentage of minus 200 mesh coating the coarser fractions. An adjustment shall be made for minus 200 mesh coating the coarser fractions when batching the other specimens.

Note 3 - In place of hand mixing, a mechanical mixer may be used, if it is available and provides thorough mixing without fracturing the aggregate.

9 Compaction of Specimens:

9.1 Place a piece of filter paper or paper toweling cut to size in the bottom of the mold before the mixture is introduced. Place a sufficient amount of the mixture, at the temperature prescribed in paragraph 8.4, in the mold to produce a compacted briquet approximately 63.5 ± 1.27 mm (2.5 ± 0.05 inches) high. Spade the mixture vigorously with a heated spatula or trowel 15 times around the perimeter and 10 times through the interior. Care should be taken so that an excess of coarse aggregate is not segregated to the surface or the face of the specimen will be rough and have higher voids than the interior of the specimen.

9.2 Remove the collar and smooth the surface to a slightly rounded shape.

9.3 Replace the collar and place a filter paper on top of the mixture prior to compaction.

9.4 Place the mold assembly on the compaction pedestal in the mold holder and, unless otherwise specified, apply 50 or 75 blows with the compaction hammer, using a free fall of 18 inches. (Hold the axis of the compaction hammer perpendicular to the base of the mold assembly during compaction.)

9.5 Remove the base plate and collar, reverse and reassemble the mold.

9.6 Apply the same number of blows to the face of the reversed specimen.

9.7 After compaction is completed, air cool the specimen by the use of fans for 30 minutes.

9 Compaction of Specimens: (continued)

9.8 Remove the specimen from the mold by means of an extrusion jack or other compression device, and place on a smooth, level surface until ready for testing.

9.9 Form a second specimen, as rapidly as possible, in the same manner as described in paragraph 9.1 through 8.

TEST PROCEDURE

10 General:

10.1 In the Marshall method each compacted test specimen is subjected to the following tests and analysis in the order listed:

Bulk Specific Gravity Determination
Stability and Flow Test
Density and Voids Analysis

11 Equipment:

11.1 Water Bath - At least six inches deep and thermostatically controlled to 60 ± 1°C (140 ± 2ºF). The tank should have a perforated false bottom or be equipped with a shelf for suspending specimens at least two inches above the bottom of the bath.

12 Bulk Specific Gravity of a Compacted Bituminous Test Specimen:

12.1 The bulk specific gravity of a compacted specimen may be obtained by computing the ratio of its weight in air to its bulk volume (including both permeable and impermeable voids normal to the material). Weighing the specimen in water then weighing the saturated surface-dry specimen in air, and calculating the difference may ordinarily determine the bulk volume. The equipment necessary to conduct this test is as follows:

12.1.1 *Balance* - A balance having a minimum capacity of 2 kg and sensitive to 0.1 g or less

12.1.2 *Wire basket* - A wire basket constructed to hold the test specimen while it is being weighed immersed in water.

12.1.3 *Container with overflow device* - For immersing the wire basket in water and maintaining a constant water level.

12.1.4 *Suspension apparatus* - For suspending the wire basket from the center of a scale pan of the balance.

12.1.5 *Cloth towel* - For blotting the excess water from the specimen after weighing in water.

12.2 Weigh the specimen in air on the balance to the nearest 0.1 g and record this weight as "A". Weigh the specimen suspended in the basket and immersed for three to five minutes in a water bath at 77ºF (25ºC). Weigh to the nearest 0.1 g and designate this weight as "C". Remove the specimen from the water, surface dry by blotting with a damp towel, weigh the surface-dry specimen in air to the nearest 0.1 g and designate this weight as "B".

12.3 Calculate the bulk specific gravity of the test specimen as follows:

$$\text{Bulk Specific Gravity} = \frac{A}{B-C}$$

12 Bulk Specific Gravity of a Compacted Bituminous Test Specimen: (continued)

where:

A = weight of specimen in air,

B = weight of saturated surface dry specimen in air and

C = weight of specimen in water

Note 4 - This method is applicable for relatively smooth, densely graded, non-absorptive compacted mixtures; with less than 2% absorption only. This method conforms to AASHTO T-166, Method A.

13 Stability and Flow Tests:

13.1 After the bulk specific gravity of the test specimens has been determined, the stability and flow tests are performed as follows:

13.1.1 Place an old briquet in the 140ºF water bath for five minutes. Place it in the breaking head and center breaking head in the loading device. Warm the Marshall Proving Ring by flexing it three times from 0.100 to 0.200 inches (approximately two complete revolutions of the dial).

Note 5 - Not all Marshall machines have proving rings.

13.1.2 The flowmeter gage shall be adjusted to zero when placed in position on the breaking head when each individual test specimen is inserted between the breaking head segments. Graduations of the flowmeter gage shall be in 0.01 in. (0.25 mm) divisions.

13.1.3 Immerse specimen in water bath at 140 ± 1.8ºF for 30 to 40 minutes.

13.1.4 Thoroughly clean inside surfaces of testing head. Lubricate guide rods with a thin film of oil so that the upper test head will slide freely.

13.1.5 With testing apparatus in readiness, remove test specimen from water bath and carefully dry surface. Place specimen in lower testing head and center, then fit the upper testing head into position and center complete assembly in the loading device. Place flowmeter over guide rod.

13.1.6 Apply testing load to specimen at constant rate of deformation of 2 inches per minute, until failure occurs. The point of failure is defined as the maximum load obtained. The total number of pounds required to produce failure of the specimen at 140ºF shall be recorded as the Marshall stability value.

13.1.7 While stability test is in progress, hold the flowmeter firmly in position over the guide rod and remove as soon as the load begins to decrease; take the reading and record. This reading is the flow value of the specimen, expressed in units of 1/100 inch. For example, if the specimen deformed 0.15 inches, the flow value is 15.

13.1.8 The entire procedure, both stability and flow tests, starting with the removal of the specimen from the water bath, shall be completed within a period of thirty seconds.

14 Density and Voids Analysis:

14.1 After the completion of the stability and flow tests, density and voids analysis is made for each series of test specimens as follows:

14 Density and Voids Analysis: (continued)

14.1.1 Average the bulk specific gravity values for all test specimens of a given asphalt content. Values obviously in error shall not be included in the average.

14.2 Obtain the maximum specific gravity of each mixture. For the purpose of these calculations, the maximum mixture specific gravity (Gcm) may be determined by:

14.2.1 MT-321, the Rice Method, which is an actual measurement of the maximum mixture specific gravity,

14.2.2 The following alternate method which provides a theoretical value for maximum mixture specific gravity [aggregate bulk saturated-surface-dry (SSD) specific gravity basis]. The value obtained by the bulk specific SSD gravity method will usually be lower than the actual measurement obtained with the Rice Method, possibly as much as two percent. This should be taken into account when considering using this method for calculation of maximum mixture specific gravity.

$$G_{cm} = \frac{p_1 + p_2 + p_3 + p_4}{\frac{p_1}{g_1} + \frac{p_2}{g_2} + \frac{p_3}{g_3} + \frac{p_4}{g_4}}$$

where:

G_{cm} = maximum theoretical specific gravity of mixture (void less, aggregate bulk SSD specific gravity basis).

p_1, p_2, p_3, and p_4 = percent by weight of coarse aggregate, fine aggregate, mineral filler and bituminous material, respectively. These percentages are based on total weight of mix and their sum should equal 100%.

g_1 and g_2 = bulk SSD specific gravity of coarse and fine aggregate.

g_3 = bulk or apparent specific gravity of mineral filler or chemical additive.

g_4 = specific gravity of bituminous material.

example: p_1 = 43.9, p_2 = 48.6, p_3 = 1.5, p_4 = 6.0

g_1 = 2.683, g_2 = 2.635, g_3 = 2.404, g_4 = 1.028

$$G_{cm} = \frac{43.9 + 48.6 + 1.5 + 6.0}{\frac{43.9}{2.683} + \frac{48.6}{2.635} + \frac{1.5}{2.404} + \frac{6.0}{1.028}}$$

$$G_{cm} = \frac{100}{16.36 + 18.44 + 0.62 + 5.84} = \frac{100}{41.26} = 2.424$$

14.3 The percentage of air voids by volume is calculated for each specimen and is determined by use of the following equation:

$$Vv = \frac{G_{cm} - G_{mb}}{G_{cm}} x100$$

where:

14 Density and Voids Analysis: (continued)

V_v = volume of air voids as percent of the bulk volume of specimen.

G_{cm} = calculated maximum theoretical specific gravity of mixture or measured (Rice) maximum mixture specific gravity.

G_{mb} = measured bulk specific gravity of compacted mixture.

INTERPRETATION OF TEST DATA

15 Preparation of Data:

15.1 The stability, flow values, and air void data are prepared as follows:

15.1.1 Measured stability values for specimens that depart from the standard 2.5 □.05 inch value are corrected by means of a Correlation Ratio. Correlation Ratios used to convert the measured stability values are set forth in Table **I**.

TABLE I - STABILITY CORRELATION RATIOS

Specimen Vol., cc.	Approx. Specimen Thickness in inches	Corre- lation Ratio	Specimen Vol., cc.	Approx. Specimen Thickness In inches	Corre- lation Ratio
200-213 . . .	1 . .	5.56 . .	406-420 . .	2 . .	1.47
214-225 . . .	1-1/16 . .	5.00 . .	421-431 . .	2-1/16 . .	1.39
226-237 . . .	1-1/8 . .	4.55 . .	432-443 . .	2-1/8 . .	1.32
238-250 . . .	1-3/16 . .	4.17 . .	444-456 . .	2-3/16 . .	1.25
251-264 . . .	1-1/4 . .	3.85 . .	457-470 . .	2-1/4 . .	1.19
265-276 . . .	1-5/16 . .	3.57 . .	471-482 . .	2-5/16 . .	1.14
277-289 . . .	1-3/8 . .	3.33 . .	483-495 . .	2-3/8 . .	1.09
290-301 . . .	1-7/16 . .	3.03 . .	496-508 . .	2-7/16 . .	1.04
302-316 . . .	1-1/2 . .	2.78 . .	509-522 . .	2-1/2 . .	1.00
317-328 . . .	1-9/16 . .	2.50 . .	523-535 . .	2-9/16 . .	0.96
329-340 . . .	1-5/8 . .	2.27 . .	536-546 . .	2-5/8 . .	0.93
341-353 . . .	1-11/16. .	2.08 . .	547-559 . .	2-11/16. .	0.89
354-367 . . .	1-3/4 . .	1.92 . .	560-573 . .	2-3/4 . .	0.86
368-379 . . .	1-13/16. .	1.79 . .	574-585 . .	2-13/16. .	0.83
380-392 . . .	1-7/8 . .	1.67 . .	586-598 . .	2-7/8 . .	0.81
393-405 . . .	1-15/16. .	1.56 . .	599-610 . .	2-15/16. .	0.78
611-625 . .		3 . .			0.76

Note 6 - The measured stability of a specimen multiplied by the Correlation Ratio, corresponding to the volume of the specimen and found in Table I, equals the corrected stability for a standard 2.5 ∀ .05 inch specimen. The volume of the specimen used to find the Correlation Ratio is equal to (B-C) as in paragraph 12.C.

Note 7 - Volume-thickness relationship is based on a specimen diameter of 4 inches.

15 Preparation of Data: (continued)

15.2 Average the flow values, the converted stability values, the bulk specific gravity values and the percent air voids for all specimens of a given asphalt content. Prepare a graphical plot for the following values as illustrated in Fig. 1. (In each graphical plot, connect the plotted values with a smooth curve that obtains the "best fit" for all values.)

15.2.1 Stability vs. Asphalt Content

15.2.2 Flow vs. Asphalt Content

15.2.3 Percent Air Voids vs. Asphalt Content

15.2.4 Bulk Specific Gravity vs. Asphalt Content

16 Trends and Relations of Test Data:

16.1 The test property curves, as plotted in Figure 1, have been found to follow a reasonably consistent pattern for dense-graded asphalt paving mixtures. Trends generally noted are outlined as follows:

16.1.1 The stability increases with increasing asphalt content up to a maximum after which the stability decreases.

16.1.2 The flow value increases with increasing asphalt content. It generally increases quite rapidly after the point where the maximum stability has been reached.

16.1.3 The percentage of air voids in the compacted mixture decreases to a minimum value with increasing asphalt contents. The minimum aggregate value, for the most part, represents the air voids within the mineral aggregate particles. When this minimum value is attained, the air voids between the particles are essentially filled and further increases in asphalt content tend to decrease the stability and increase the flow to a marked degree. The bulk specific gravity also decreases after this point, since the specimen is being increased in volume with the lower specific gravity asphaltic constituent.

17 Determination of Optimum Asphalt:

17.1 The optimum asphalt content of the asphalt paving mix is determined from data obtained as outlined above. Consideration is given to the four test properties illustrated in Figure 1:

17.1.1 Stability

17.1.2 Bulk Specific Gravity

17.1.3 Limit for Air Voids (limits shown in Table II)

17.1.4 Flow

17.2 The optimum asphalt content of the mix is the median of the limits for air voids unless the other values are unacceptable at this percent of air voids. This should result in a satisfactory paving mix with relatively non- absorptive, well-graded, angular aggregates. Where unusual aggregates must be used, their unusual properties must be recognized, and adjustments made in the application of the criteria to obtain the best possible paving mixture. A discussion on possibilities follows:

17.2.1 Highly absorptive aggregates will produce mixtures with high air void contents. It may not even be possible to come within the air void range without violating satisfactory stability or flow requirements. (Note 8)

17 Determination of Optimum Asphalt: (continued)

Note 8 - Using bulk specific gravities of absorptive aggregates in voids determinations assumes that there is no asphalt absorption and all voids are between the aggregate pieces. By using apparent specific gravities, the assumption is made that the aggregate absorbs all the asphalt it is capable of absorbing and all interior voids are filled. Neither assumption is correct for absorptive aggregates as the actual absorption is dependent upon asphalt viscosity, size of interior pores, surface tension, temperature and time. It is recommended that air voids always be determined by use of the maximum (Rice) mixture specific gravity when absorptive aggregates are involved.

17.2.2 Some good quality, well graded and very angular aggregates will develop stabilities which are greatly in excess of requirements for a satisfactory pavement. If the stability is 2500 pounds or over, there is no advantage in gaining more stability if an adjustment in the asphalt content will benefit the other criteria. An abnormally high stability mixture may have an abnormally low flow value, which would indicate a brittle mixture. In this instance, the better paving mixture would be obtained by increasing the flow (above 8), and perhaps losing some stability. This would be accomplished by increasing the asphalt content.

TABLE II
DESIRABLE RANGES OF TEST PROPERTIES
FOR MARSHALL DESIGN CRITERIA (Note 10)

Test Property	Grade A		Grade B		Grade C		Grade D		Base	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max
Stability, lbs.	1500	---	1500	---	1000	---	1500	---	750	---
Flow	8	16	8	16	8	18	8	16	8	16
Air Voids in Compacted Mix	4	7	3	5	3	6	3	5	3	8

Note 9 - For a project under the rutting specification, the Marshall design criteria shall be as follows: sufficient stability in the laboratory so that 1500 pounds of stability can be obtained in the field within a void range of 2 to 5 percent.

18 Determination of Optimum Gradation:

18.1 The contractor makes a determination of the grading he will use based on his stockpile gradations and the most efficient utilization of aggregate. Normally when applicable specification requirements are met by the aggregate, the contractor uses the average gradation of the stockpile. If not, he sets the target gradations within specifications to best match his stockpile quantities and gradations. In some cases the contractor may have to reject fines, etc. In any case the contractor tries to obtain the most efficient and economical utilization of the materials available.

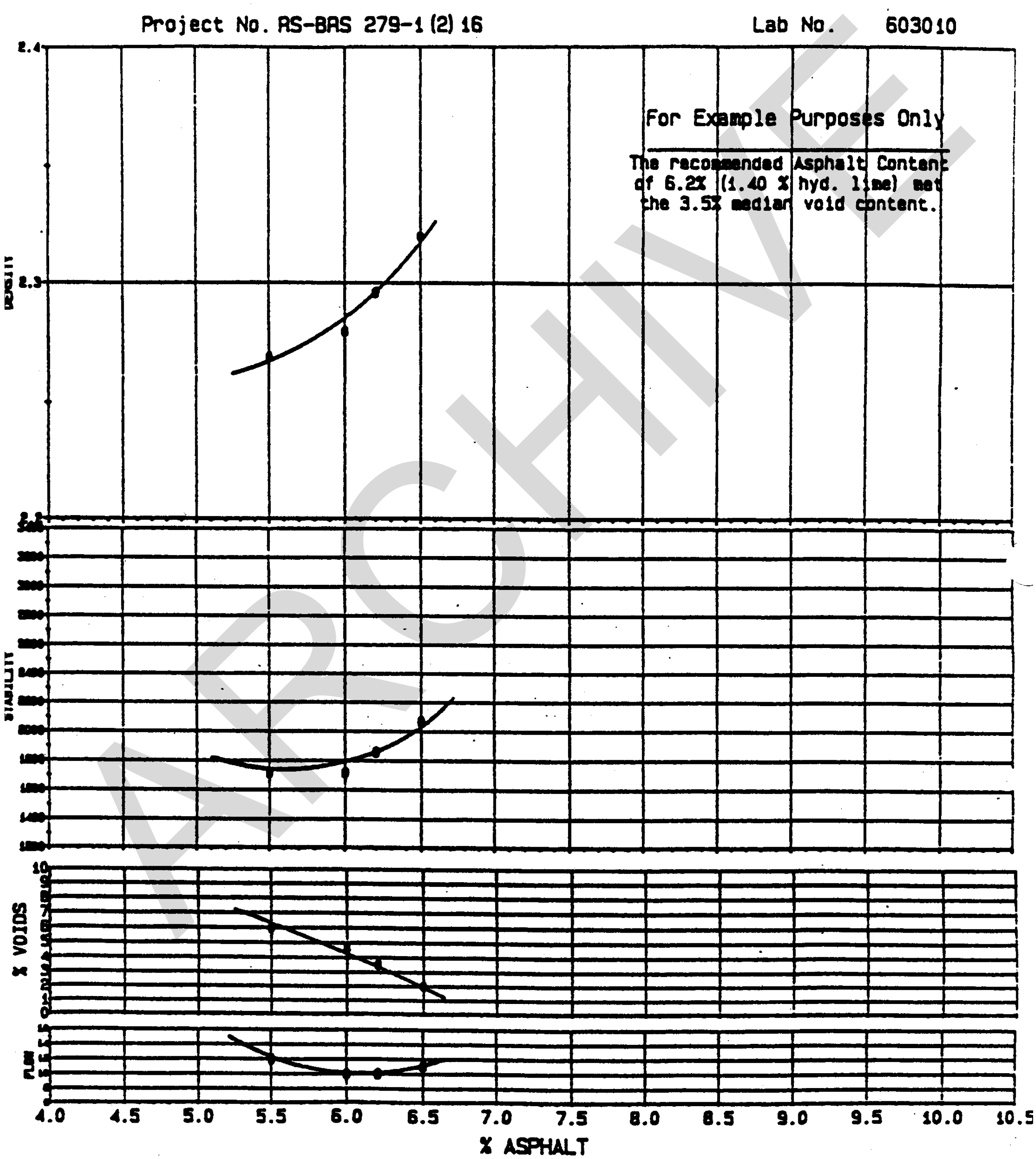
18.2 The target gradings or job mix formula, as determined in 18.1, are used when testing for the optimum asphalt content.

19 Reporting Results:

19.1 Figure 1 is an example of processing data by means of graphical plots referred to in paragraph 15.2.

19.2 Figure 2 is an example of a completed report form on which test results are recorded.

MT-306



Revised 08/99

______ ADT ______
______ ADT ______
ESALS ______

MONTANA
DEPARTMENT OF TRANSPORTATION
Materials Bureau

PLANT MIX SURFACING, GRADE D

Lab. No. 775599 Sample No. 1 Project No. HWY- #305706-RR
Termini East Glacier - West
Date Sampled 8-25-99 Date Received 8-30-99
Sampled by D. Wollan Title MTC Supt. Address Shelby, Mt.
Submitted by James Blossom Title DMS Address
Area Source Represented by Lab. No. 658357-375 Sample taken at
Owner Roy Doore Jr. Address Browning, Mt.

TEST RESULTS ON AGGREGATE

	% Passing As Tested
1-½"	
1"	
¾"	100
½"	82
⅜"	68
4M	48
10M	32
40M	15
200M	6.5

LL NP
PL NP
PI NP
SE 38
Wear 19

Fracture 1 face 88
2 face 79
Dust
Asphalt Ratio 1.16

Volume Swell
NO 3.0 % Hard
HL 2.3 % Hard
CF 2.7 % Hard
NF %

Absorption CS 1.107 Fine 2.585 Blend 1.337

Bulk Dry Sp. Gr. of Agg. Fine 2.565 CS 2.616

NOTE: VMA of this Mix Design 14.2 VFA 78.2

MARSHALL TESTS

%	Type	% Asphalt	Rice Gravity	Unit Weight Lbs./Ft.³	% Voids	Lb. Stability	Flow (in.)	Appearance
1.4	HL	4.5	2.484	144.6	6.7	3232	13	Normal
1.4	HL	5.0	2.463	145.8	5.2	3064	13	Normal
1.4	HL	5.5	2.443	147.1	3.5	2910	14	Sltly Rich
1.4	HL	6.0	2.422	147.7	2.3	2614	15	Sltly Rich
1.4	HL	6.5	2.402	147.9	1.3	2434	17	Rich
1.4	HL	5.6	2.439	147.3	3.1	2820	14	Interplted

MODIFIED LOTTMAN

Mineral Filler		Percent Asphalt	Breaks (PSI)		Retained Strength	Adhesion
%	Type		Dry	Wet		
----	None	5.9			%	80%
1.4	Hyd.Lime	5.7			%	85%

1 Admin. Maintenance Div.
District Admin./Eng. Great Falls
1 District Const. Eng. Great Falls
1 Project Manager Great Falls
1 Dist. Mat. Supr. Great Falls
Area Lab
1 Chief Const. Bureau
1 Chief Materials Bureau
Bit. Mix Design Sect.
FHWA
1 Materials Bureau File
1 BIAHNZK CONST.

Recommended: 5.6 % Pg 64-22 A/C 1.4 % Hyd. Lime

Asphalt Supplier MRC

REMARKS: Discussed with RDT RRB

9/2/99 [signature]
Date Name

April 1, 2000

13 of 13