



**INDIANA DEPARTMENT OF TRANSPORTATION
DIVISION OF MATERIALS AND TESTS**

**MIX DESIGN PROCEDURE FOR
FULL DEPTH RECLAMATION (FDR)
WITH ASPHALT EMULSION
ITM No. 594-20**

1.0 SCOPE

- 1.1 This method covers the procedure for mix design of Full Depth Reclamation of pavements with asphalt emulsion.
- 1.2 This ITM may involve hazardous materials, operations, and equipment and may not address all of the safety problems associated with the use of the test method. The user of the ITM is responsible for establishing appropriate safety and health practices and determining the applicability of regulatory limitations prior to use.

2.0 SIGNIFICANCE AND USE

- 2.1 This ITM is used to determine the appropriate mix design for an individual asphalt roadway by ensuring the sampled material with corresponding mix design meets specification requirements.
- 2.2 This ITM is used to perform mix design procedure for Full Depth Reclamation with asphalt emulsion.

3.0 REFERENCES.

3.1 AASHTO Standards

- T 11 Materials Finer Than 75- μ m (No. 200) Sieve in Mineral Aggregates by Washing
- T 27 Sieve Analysis of Fine and Coarse Aggregates
- T 49 Standard Test Method for Penetration of Bituminous Materials
- T 59 Testing Emulsified Asphalts
- T 180 Moisture-Density Relations of Soils Using a 4.54-kg (10-lb) Rammer and a 457-mm (18 in.) Drop, Method D
- T 166 Bulk Specific Gravity (G_{mb}) of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
- T 176 Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test, Method 2
- T 209 Theoretical Maximum Specific Gravity (G_{mm}) and Density of HMA
- T 269 Percent Air Voids in Compacted Dense and Open Asphalt Mixtures

T 283 Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage

T 312 Preparing and Determining the Density of Hot Mix Asphalt by Means of the Superpave Gyrotory Compactor

4.0 TERMINOLOGY. Definitions for terms and abbreviations shall be in accordance with the Department's Standard Specifications, Section 101.

4.1 FDR- Full Depth Reclamation

4.2 RAP- Reclaimed Asphalt Pavement

4.3 Constant mass- shall be defined as the mass at which further drying does not alter the mass by more than .05 percent in 2 hours.

4.4 Base Material- aggregate type material directly below a bituminous pavement

4.5 Mix Design Blend- The selected percentages, by weight, of RAP, aggregate base and/or other additional materials to be used throughout the mix design that accurately represents the chosen depth of treatment, material proportions and material type encountered during FDR construction.

5.0 APPARATUS.

5.1 Laboratory, capable of maintaining room temperature $77\pm 9^{\circ}\text{F}$ ($25\pm 5^{\circ}\text{C}$) and a relative humidity of less than 60%.

5.2 Mechanical Bucket Mixer with a bowl measuring 10-12 inches in diameter shall be used. The bowl should be capable of rotating on its axis at 50 to 75 revolutions per minute. The mixer shall use a paddle which makes contact with the bottom of the bowl and shall rotate on its axis at twice the bowl rotation rate, in the opposite direction of the bowl rotation.

5.3 Laboratory Crushing Machine, capable of crushing sampled material to pass the 1.5-inch sieve, if required by pavement sample type (field millings do not require further crushing).

5.4 Forced Draft Oven, of appropriate size, capable of maintaining temperatures of $104\pm 4^{\circ}\text{F}$ ($40\pm 2^{\circ}\text{C}$) and $230\pm 9^{\circ}\text{F}$ ($110\pm 5^{\circ}\text{C}$). Shall be equipped with racks containing slots or holes for circulation of air.

5.5 Scale, capable of showing a reading to the nearest 0.1 gram.

5.6 Miscellaneous lab equipment; scoops, pans, mixing bowls, containers

- 5.7 Vacuum system, capable of subjecting contents to partial vacuum of 25.0 to 30.0 mm of Hg.

6.0 SAMPLING.

- 6.1 A mix design shall be performed with the materials to be encountered during FDR construction, including in-place pavements, aggregate base, surface treatments, additional aggregate, additional RAP, asphalt emulsion and other additives. If construction materials change significantly between the time of sampling and construction, additional mix designs shall be performed to establish a representative mix for the project.
- 6.2 Samples of the existing pavement are collected as cores, test pits or milled RAP. Samples that represent the entire depth of treatment shall be collected, including any underlying materials and layers, which shall be kept separately.
- 6.3 The composition of in-place pavement should be examined. Location and placement of collected pavement samples shall accurately reflect minor variations in the pavement and form a representative sample of the entire project. Each mix design requires a minimum sample size of 350 lbs.
- 6.4 Samples from significantly different pavement sections shall be grouped separately, with separate mix designs performed for each section. Examples of these variations include large patches, significantly different asphalt mixes and significantly different pavement thicknesses.
- 6.5 One sample per lane mile shall be the minimum sampling frequency for mix design preparation.

7.0 PREPARATION OF TEST SPECIMENS.

7.1 Sample Preparation Procedure

- 7.1.1 Pavement samples shall be cut, if necessary, to a depth that accurately represents the FDR treatment to take place, also accounting for pre-milling that may take place in the field.
- 7.1.2 Sampled pavement shall be crushed using a laboratory crusher or other methods to pass the 1.5-inch sieve, although care should be taken to avoid fracturing the aggregate. Heat shall not be applied to the sampled pavement during the crushing process.
- 7.1.3 Ensure materials, including RAP, aggregate base and/or other additional materials are stored and prepared separately. Prior to batching specimens ensure these materials are dried to constant mass in a forced draft oven and thoroughly mixed.

- 7.1.4** Materials containing bituminous material shall be dried to constant mass at $104\pm 4^{\circ}\text{F}$ ($40\pm 2^{\circ}\text{C}$) in a forced draft oven. Materials without bituminous material may be dried at temperatures up to $230\pm 9^{\circ}\text{F}$ ($110\pm 5^{\circ}\text{C}$) in a forced draft oven.

7.2 Selecting Material Proportions for Mix Design

- 7.2.1** Select the percentages, or mix design blend, by dry weight, of RAP, aggregate base and/or other additional materials to be used throughout the mix design. A project may require an additional mix design using a different mix design blend or material type if there is a significant change in pavement structure, material or treatment depth.

7.3 Asphalt Emulsion Content Selection

- 7.3.1** Mix designs shall be performed using an asphalt emulsion that meets all requirements detailed in Table 1.

Table 1. FDR Asphalt Emulsion Material Specification

Test	Procedure	Minimum	Maximum
Viscosity, Saybolt Furol, at 77°F (25°C), SFS	AASHTO T 59	20	100
Sieve Test, No. 20 ($850\ \mu\text{m}$), retained on sieve, %	AASHTO T 59		0.10
Storage Stability Test, 24 hr, %	AASHTO T 59		1
Distillation Test, Residue by distillation, % (See Note 1)	AASHTO T 59	64.0	
Oil Distillate by volume, %	AASHTO T 59		1
Penetration, 77°F (25°C), 100 g, 5 s, dmm	AASHTO T 49	50	200

Note 1—Modified AASHTO T 59 procedure – distillation temperature of $350\pm 9^{\circ}\text{F}$ ($177\pm 5^{\circ}\text{C}$) with a 20 minute hold.

- 7.3.2** Select at least three asphalt emulsion contents in increments of 0.5 to 1.0 percent within a suggested range of 1.0 to 4.0 percent by dry weight of material.

7.4 Design Moisture Content Selection/Calculation

- 7.4.1** Design Moisture Content shall be the amount of water added to the mixture during coating procedure. The Design Moisture Content chosen for each selected asphalt emulsion content represents the in-situ moisture and additional water combined during FDR construction. The Design Moisture Content does not include water in the asphalt emulsion.
- 7.4.2** Determine and Record the Optimum Moisture Content for the Mix Design Blend in accordance with AASHTO T 180 Method D.

- 7.4.3** The selected Design Moisture Content shall be between 40 and 65 percent of the Optimum Moisture Content.
- 7.4.4** If the Mix Design Blend contains less than 4 percent passing the No. 200 sieve or if no peak develops with the Optimum Moisture Content curve, the Design Moisture Content shall be between 2 and 3 percent by dry weight of material.
- 7.4.5** Record the Design Moisture Content selected for each selected asphalt emulsion content.

7.5 Batching Procedure

- 7.5.1** Batch the Mix Design Blend, by weight of RAP, aggregate base and/or other additional materials for each specimen. Ensure a representative sample is obtained from all incorporated materials when batching specimens. The following table identifies the gradation limits for the Mix Design Blend.

Table 2. FDR Mix Design Blend Gradation Criteria

Sieve Size		Percent Passing
2 in.	50 mm	100%
No. 4	4.75 mm	≥ 35%
No. 200	75 μm	≤ 20%

- 7.5.2** Batch the following specimens for each incorporated base material separately. Ensure a representative sample is collected from the available material, including all fine particles.
- a.** Prepare 2 washed gradation specimens for each base material, with a minimum weight requirement of 2500g per specimen. Tested according to Washed Gradation Sieve Analysis Procedure in 8.1
 - b.** Prepare material to perform a Sand Equivalent Test. Using only material passing the No. 4 (4.75mm) sieve, 2000g per sample is typical. Three specimens shall be obtained from this sample. Tested according to Sand Equivalent Testing in 8.2
- 7.5.3** Batch the following specimens, using each incorporated RAP and corrective material, separately. Ensure a representative sample is collected from the available material, including all fine particles.
- a.** Prepare 2 washed gradation specimens for each incorporated RAP and corrective material, with a minimum weight requirement of

2500g per specimen. Tested according to Washed Gradation Sieve Analysis Procedure in 8.1

- 7.5.4** Batch the following specimens, using the selected mix design blend. Ensure a representative sample is collected from the available material, including all fine particles.
- a.** Prepare 2 washed gradation specimens at the selected mix design proportion, with a minimum weight requirement of 2500g per specimen. Tested according to Washed Gradation Sieve Analysis Procedure in 8.1
 - b.** Prepare 4 Theoretical Maximum Specific Gravity Specimens. Two specimens each shall be tested at the highest selected asphalt emulsion content and the lowest selected asphalt emulsion content. Minimum weight requirement for specimens is 2500 g per specimen, using only material passing the 1" sieve. Prepared according to Theoretical Maximum Specific Gravity Specimen Preparation in 8.3
 - c.** Prepare 4 specimens per selected asphalt emulsion content for Indirect Tensile Strength Testing in 8.4. Using only material passing the 1" sieve, 2500 g or more per specimen is typical. The total specimen weight shall be such that it will produce a 70 to 80 mm tall specimen using a 150 mm diameter gyratory mold, using 30 gyrations.
 - d.** Prepare material to perform a Sand Equivalent Test. Using only material passing the No. 4 (4.75mm) sieve, 2000g per sample is typical. Three specimens shall be obtained from this sample. Tested according to Sand Equivalent Testing in 8.2

7.6 Mixing Procedure.

- 7.6.1** Mixing occurs at room temperature. One specimen shall be mixed at a time. Design Moisture Content, selected in 7.4, shall be the amount of water added to the mixture during mixing. Any other additives are combined in a manner and order similar to field production.
- 7.6.2** Using a mechanical bucket mixer, begin mixing batched material at 50-75 revolutions/minute.
- 7.6.3** Add Design Moisture Content to batched material.
- 7.6.4** Mix for no less than 60 seconds.

7.6.5 Add asphalt emulsion to mixer.

7.6.6 Mixing time with asphalt emulsion shall be 55 ± 5 seconds.

7.7 Theoretical Maximum Specific Gravity Specimen Preparation.

7.7.1 After Mixing Procedure detailed in 7.6, transfer and spread each specimen to individual shallow containers.

7.7.2 Cure in a $104 \pm 4^\circ\text{F}$ ($40 \pm 2^\circ\text{C}$) forced draft oven, for at least 16 hours but no more than 48 hours. Care should be taken not to over-dry the specimens.

7.7.3 Remove specimens from oven once reaching constant mass.

7.7.4 After curing, gently break up clusters that have formed in the specimen. Care should be taken to avoid fracturing aggregate.

7.7.5 Let cool to room temperature before continuing to Theoretical Maximum Specific Gravity Test procedure detailed in 8.3.

7.8 Indirect Tensile Strength Pill Preparation.

7.8.1 Superpave Gyratory Compactor shall be prepared in accordance with AASHTO T 312, preparation of apparatus. Use the following machine settings: 1.16° internal angle, 87 psi (600 kPa) ram pressure, 30 gyrations. Only final specimen height is to be monitored.

7.8.2 Immediately after Mixing Procedure detailed in 7.6, transfer material into an individual container measuring 4 to 7 inches (100 to 175 mm) in height and 6 inches (150 mm) in diameter.

7.8.3 Place container in a $104 \pm 4^\circ\text{F}$ ($40 \pm 2^\circ\text{C}$) forced draft oven for 30 ± 3 minutes.

7.8.4 Upon removal from oven, immediately compact material using Superpave gyratory compactor with 150mm diameter, room temperature mold.

7.8.5 Extrude pill from mold immediately after compaction is completed.

7.8.6 Cure compacted pills in a $104 \pm 4^\circ\text{F}$ ($40 \pm 2^\circ\text{C}$) oven, at least 24 hours but no more than 72 hours.

7.8.7 Remove pills from oven once reaching constant mass.

- 7.8.8** Let cool to room temperature before continuing. Continue to Indirect Tensile Strength Testing Preparation, 8.4.

8.0 PROCEDURE.

8.1 Washed Gradation Sieve Analysis.

- 8.1.1** Perform Sieve Analysis on all washed gradation specimens in accordance with AASHTO T 11 and T 27, except as noted for drying procedure.
- 8.1.2** Washed gradations shall be dried, according to the temperatures in Material Preparation Procedure, 7.1.4, in a forced draft oven.
- 8.1.3** Remove specimens from oven once constant mass is reached.
- 8.1.4** Record gradation results for the following sieves: 2.0", 1-1/2", 1-1/4", 1", 3/4", 1/2", 3/8", #4, #8, #16, #30, #50, #100, #200. If the gradation specimen is a mix design blend, ensure sample gradation is within recommended gradation limits.
- 8.1.5** Calculate Total % of Material Passing for the recorded sieves per AASHTO T 27.

8.2 Sand Equivalent Testing

- 8.2.1** Perform Sand Equivalent Test on Sand Equivalent Specimens, according to AASHTO T 176, Method 2.
- 8.2.2** Record results.

8.3 Theoretical Maximum Specific Gravity Test Procedure.

- 8.3.1** Theoretical Maximum Specific Gravity Specimens shall be prepared according to Mixing Procedure, 7.6 and Theoretical Maximum Specific Gravity Specimen Preparation, 7.7.
- 8.3.2** Determine and record Theoretical Maximum Specific Gravity of each specimen in accordance with AASHTO T 209.
- 8.3.3** Calculate and Record the Average Theoretical Maximum Specific Gravity for each asphalt emulsion content measured.
- 8.3.4** Calculate Average Theoretical Maximum Specific Gravities for remaining asphalt emulsion contents using interpolation of the measured Theoretical Maximum Specific Gravities.

8.4 Indirect Tensile Strength Testing Preparation and Procedure.

- 8.4.1** Measure and record pill heights to be used for Indirect Tensile Strength Test calculation.
- 8.4.2** Determine and Record Bulk Specific Gravity (G_{mb}) of each pill in accordance with AASHTO T 166.
- 8.4.3** Calculate and Record % Air Voids of each pill in accordance with AASHTO T 269.
- 8.4.4** Dry and Moisture Conditioned Indirect Tensile Strength Pills are to be conditioned and tested concurrently. Moisture Conditioned pills shall be conditioned using Vacuum Saturation.

8.4.5 Moisture Conditioned Pill Procedure

- a. Using the vacuum system in accordance with AASHTO T 209, place pill in vacuum container using a spacer to support pill 1 in. (25mm) above bottom of container.
- b. Fill container with water to a level at least 1 in. (25 mm) above top of pill.
- c. Apply vacuum for a short time (typically 5 to 15 seconds).
- d. Release vacuum.
- e. Remove pill from water.
- f. Damp dry the pill by blotting it with a damp towel and record saturated surface dry (SSD) mass.
- g. Calculate the volume of air voids, V_a , as follows:

$$V_a = \frac{Pa \times E}{100}$$

Where:

V_a = volume of air voids, cm^3

Pa = percent air voids as determined in 8.4.3

E = volume of the pill, cm^3

- h. Calculate degree of saturation of the pill as follows:

$$S' = \frac{100(B'-A)}{V_a}$$

Where:

S' = degree of saturation, %.

B' = mass of the SSD pill after partial vacuum, g

A = mass of the dry pill in air, g

V_a = Volume of air voids, cm³

If degree of saturation is below 55%, repeat previous steps to reach appropriate degree of saturation. If saturation is above 75%, sample is damaged and must be discarded.

If saturation is between 55 and 75 percent, proceed to the following step.

- i. Immediately submerge correctly saturated pills in a 77 ±2°F (25 ±1°C) water bath for 24 hours.
- j. See step 8.4.7 for testing of conditioned pills.

8.4.6 Dry Pill Procedure.

- a. Ensure dry pills are at constant mass prior to conditioning.
- b. Dry pills shall condition at 77 ±2°F (25 ±1°C) for at least 2 hours prior to Indirect Tensile Strength Testing.

8.4.7 Indirect Tensile Strength Testing. Follow procedure for testing Indirect Tensile Strength in accordance with AASHTO T 283, except as previously noted for specimen preparation, compaction and conditioning.

9.0 CALCULATIONS.

9.1 Indirect Tensile Strength Testing Calculations

- 9.1.1 Using the previously measured height of each pill, calculate tensile strength of each pill according to AASHTO T 283.
- 9.1.2 Calculate and Record average tensile strength at each asphalt emulsion content for moisture conditioned and dry pills separately.

9.1.3 Calculate and Record Tensile Strength Ratio (%) for each asphalt emulsion content according to AASHTO T 283, using the average tensile strengths calculated in 9.1.2.

9.2 Selecting a Final Design Asphalt Emulsion Content.

9.2.1 Select and report one asphalt emulsion content that meets or exceeds all mix design requirements detailed in Table 3.

Table 3. FDR with Asphalt Emulsion Mix Design Requirements

FDR Test	Passing Criteria
Indirect Tensile Strength, AASHTO T 283, psi (kPa)	40 (276) minimum
Conditioned Tensile Strength, AASHTO T 283, psi (kPa)	25 (172) minimum
Additional Additive(s) (See Note 2) Cement, %	1.0% maximum
Emulsified Asphalt ¹ Emulsion to Cement Content Ratio	3:1 minimum

Note 2—Report shall include type/gradation and producer/supplier.

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10.0 REPORT. All mix design test results shall be reported to the Department per Table 4. All additional additives and bituminous material shall be reported to the Department.

Table 4. Reported Results

FDR with Emulsified Asphalt- Mix Design Requirements and Reported Results		
Initial Selected Criteria	Test Purpose	Reported Results
Tested Asphalt Emulsion Contents (%)	Establish a complete dataset	Each Content selected
Design Moisture Contents (%)	Dispersion of Asphalt Emulsion	Each Content Selected
Test Method	Test Purpose	Reported Results
Washed Gradation, AASHTO T 11, T 27	Simulate field gradation	Average for each specimen tested
Sand Equivalent, AASHTO T 176	Characterize Material	Average for each material tested
Modified Proctor, AASHTO T 180, Method D	Optimum Moisture Content	Per Mix Design
Design Moisture Contents, %	Dispersion of Asphalt Emulsion	Per Asphalt Emulsion Content
Superpave Gyratory Compaction, 1.25° external angle, 87 psi (600 kPa), AASHTO T 312	Standardize Lab Compaction Effort	Report Compliance for all compacted specimens
Rice (Maximum Theoretical) Specific Gravity, AASHTO T 209	Laboratory Density Indicator	Average at each Asphalt Emulsion Content Tested
Bulk Specific Gravity (Density), AASHTO T 166		
Air Voids, AASHTO T 269, %		
Indirect Tensile Strength, AASHTO T 283, psi (kPa)		
Conditioned Tensile Strength, AASHTO T 283, psi (kPa)	Moisture Damage Resistance	
Additional Additive(s) (See Note 3) Course Aggregate Fine Aggregate RAP Cement, %		Report Quantities
Emulsified Asphalt (See Note 3) Distillation Residue, % (See Note 4) Residue Penetration, dmm Optimum Emulsion Content, % Emulsion to Cement Content Ratio		Report Results
Final Selected Recommendations	Test Purpose	Reported Results
Final Design Asphalt Emulsion Content (%)	Select Highest Performing Asphalt Emulsion Content	Content per Mix Design

Note 3—Report shall include type/gradation and producer/supplier

Note 4—Modified AASHTO T 59 procedure – distillation temperature of 350±9°F (177±5°C) with a 20-minute hold.