Guidelines for Evaluation, Mix Design and Field Acceptance of Cold Recycling of Asphalt Pavements using Solventless Emulsion

965.01 Scope
This document provides methods and requirements for investigation, design, construction-management, and acceptance of cold recycled, either in-place (CIR/CIPR) or central plant mixed (CCPR), asphalt pavement using solventless emulsion, and any corrective additives. It serves as a material design manual as well as guidance for UDOT personnel and consultants when managing a cold recycle project.

This series of procedures include the following:

- Procedures for materials evaluation to be used during project selection. Detailed pavement design project selection criteria and efforts are in the Pavement Design Manual of Instruction.

- Procedures for mix design of Cold Recycled asphalt mixes. This design process can be used for either Cold In-Place or Cold Central-Plant recycling operations.

- Procedures to be used for release to traffic and acceptance of Cold Recycled operations during construction.

REFERENCES:
The following AASHTO Standards are used in these procedures:

- R 67 Sampling Asphalt Mixtures After Compaction (Obtaining Cores)
- T 2 Sampling of Aggregates
- T 11 Materials Finer than 75-μm Sieve in Mineral Aggregate by Washing
- T 27 Sieve Analysis of Fine and Coarse Aggregates
- T 84 Specific Gravity and Absorption of Fine Aggregates
- T 85 Specific Gravity and Absorption of Coarse Aggregates
- T 209 Theoretical Maximum Specific Gravity ($G_{mm}$) and Density of Hot-Mix Paving Mixtures
- T 248 Reducing Samples of Aggregates to Testing Size
- T 255 Total Evaporable Moisture Content of Aggregate by Drying
T 283  Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture Induced Damage
T 305  Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures
T 312  Preparing and Determining the Density of Asphalt Mixtures Specimens by Means of the Superpave Gyratory Compactor

The following documents and manuals are referenced in these procedures:

Asphalt Institute MS-2, Current Version
UDOT Materials Manual of Instruction (MOI)
UDOT Standard Specifications
UDOT Special Provisions

965.02  Definitions

CR  =  Coarse RAP material passing the 1 ½ inch sieve and retained on the No. 16 sieve.
FR  =  Fine RAP material passing the No. 16 sieve.
$G_{Rm \text{ loose}}$ =  Theoretical Maximum specific gravity of the full gradation of RAP material in a loose state
$G_{Rb \text{ degF}}$ =  Bulk specific gravity of the full gradation of RAP material compacted at a given temperature in degrees F
$G_{b}$ =  Specific gravity of the asphalt binder
$G_{mb \text{ degF}}$ =  Bulk specific gravity of the processed mix compacted at a given temperature in degrees F
$G_{mm}$ =  Maximum Theoretical Specific Gravity of the processed mix
$h_{\text{degF}}$ =  Height (mm) of specimen compacted at a given temperature in degrees F at 30 gyrations
$Jc$ =  The critical SCB fracture energy of a semi-circular specimen
$M_{b}$ =  Mass of the Emulsion Residue (g)
$M_{CR}$ =  Mass of the CR (g) (4000 g)
$M_{Dry}$ =  Mass of the RAP with lime in a specimen (g)
$M_{FR}$ =  Mass of the fine RAP in a specimen (g)
$M_{MIX}$ =  Mass of the total mix with emulsion residue but with no water (g)
$M_{R \text{ degF}}$ =  Mass of the total RAP at a given temperature in degrees F (g)
$P_{b}$ =  Asphalt binder content after distillation of emulsion as percentage $M_{MIX}$ (percent residue of emulsion)
Proper selection of CIR projects is considered the most important factor in a successful project. For pavement design considerations, refer to the Pavement Design Manual of Instruction. In addition to the pavement design considerations, the following materials evaluation is necessary to determine both the ability of the in-situ material to be recycled, and to establish the limits of material to be recycled prior to final selection of the project as a candidate. The results of the following procedures can then be used in the final Pavement Design.

965.03.01 RAP Evaluation

The Department samples the project in accordance with Appendix A. The sample(s) is(are) then evaluated for expected field gradation and sensitivity to temperature, and field target densities are obtained.
A. Determine Target Gradation

For Crushed Cores Samples:

1. Remove layers to be recycled from cores by cutting. Crush layers to a maximum of 1.5 inches using laboratory crusher. Jaw crushers are preferred to better mimic field milling operations.

2. Construct samples conforming to gradation listed in Table 1 (do not wash sample).

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<thead>
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<th>Sieve Size</th>
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<tr>
<td>No. 200</td>
<td>0.3</td>
</tr>
</tbody>
</table>

For Field Milled Samples:

1. Reduce sample for gradation. AASHTO T 248.

2. Perform gradation using sieves listed in Table 1 (do not wash sample) AASHTO T 27
### B. **Determine RAP Temperature-Compaction Line**

It has been determined experimentally that RAP compacts to a smaller volume as temperatures rise between 80 and 120 degrees F. The relationship of rise in temperature to reduction in volume is linear. Historically, the slope of relationship is between 17 and 20 percent for all RAP sources. The slope of the relationship below 80 degrees F and above 120 degrees F has been shown to be relatively flat (little change in volume with temperature change). Testing on the coarse RAP has shown that this fraction behaves in the same manner as the total gradation. The slope and intercept of the temperature dependency curve is specific to each RAP source.

Compacting to 30 gyrations has been determined to represent the compactive effort available in the field. This is the number of gyrations used for mix designing.

1. **Create Superpave Gyratory Compacter (SGC) specimens.**
   a. Create two 4000 g samples of RAP at either the target gradation (crushed cores) or field gradation (milled sample).
   b. Using the SGC, compact one RAP sample at 80 ± 2 degrees F and another RAP sample at 120 ± 2 degrees F (AASHTO T 312, 30 gyrations) in accordance with Appendix B. Heat the RAP material to testing temperature before placing in the gyratory mold.
   c. Determine the height of the specimens at 30 gyrations from the SGC printout.

2. **Calculate the slope of the compaction / temperature curve (S):**

   \[
   S = \frac{h_{120} - h_{80}}{120^\circ F - 80^\circ F}
   \]

   *(Equation 1)*

   Where:
   - \( S \) = the slope of the compaction/temperature curve
   - \( h_{80} \) = height (mm) of specimen compacted at 80°F
   - \( h_{120} \) = height (mm) of specimen compacted at 120°F

3. **Calculate the volume of the specimen compacted at 80 degrees F and the volume of the specimen compacted at 120 degrees F:**

   \[
   V_{deg^F} = \frac{\pi d^2 h_{deg^F}}{4 \times 1000}
   \]

   *(Equation 2)*
Where:

\[ V_{\text{degF}} = \text{Volume of the RAP specimen compacted at a given temperature in degrees F (cm}^3) \]

\[ d = \text{Measured diameter of the specimen in mm (149.90 to 150.00 according to AASHTO T 312)} \]

\[ h_{\text{degF}} = \text{Height (mm) of specimen compacted at 80 degrees F (at 30 gyrations from SGC printout)} \]

C. Determine Maximum Theoretical Specific Gravity of the loose RAP \( (G_{Rm \text{ loose}}) \)

**Note 1:** A RAP particle is considered a cemented aggregate particle for CIR (black rock). Although these particles change shape with temperature, their loose specific gravity remains constant.

1. Determine the *loose Theoretical Maximum Specific Gravity* \( (\text{loose } G_{Rm}) \). AASHTO T 209
   Follow procedure for drying entire sample. (report to three decimal places).

D. Determine the critical low \( (T_{CL}) \) and critical high \( (T_{CH}) \) temperatures of the RAP

1. Calculate the *bulk specific gravity* of the compacted RAP specimens at \( h_{80} \) and \( h_{120} \).

\[
G_{Rb \text{ degF}} = \frac{M_R}{V_{\text{degF}}} \tag{Equation 3}
\]

Where:

\[ M_R = \text{Mass of the compacted RAP specimen for the given temperature in degrees F (approx. 4000g)} \]

\[ V_{\text{degF}} = \text{Bulk Volume of the compacted RAP specimen at for the given temperature in degrees F (cm}^3) \]

\[ G_{Rb \text{ degF}} = \text{Compacted Bulk Specific Gravity of the RAP at a given temperature in degrees F} \]

2. Calculate and plot the percent compaction for the RAP specimens at \( T_{80} \) and \( T_{120} \).

\[
\% \text{Comp}_{Rb \text{ degF}} = \frac{G_{Rb \text{ degF}}}{G_{Rm \text{ - Loose}}} \times 100 \tag{Equation 4}
\]

Where:

\[ G_{Rm \text{ - Loose}} = \text{Bulk Specific Gravity of the loose RAP} \]
3. Calculate the critical temperatures for achieving 92% \( (T_{CL}) \) and 97% \( (T_{CH}) \) compaction.

\[
T_{CL} = 80 + 40 \times \left( \frac{92 - \%\text{Comp}_{Rb\ degF\ at\ 80}}{\%\text{Comp}_{Rb\ degF\ at\ 120} - \%\text{Comp}_{Rb\ degF\ at\ 80}} \right)
\]

(Equation 5)

And:

\[
T_{CH} = 120 + (-40) \times \left( \frac{\%\text{Comp}_{Rb\ degF\ at\ 120} - 97}{\%\text{Comp}_{Rb\ degF\ at\ 120} - \%\text{Comp}_{Rb\ degF\ at\ 80}} \right)
\]

(Equation 6)

Where:

\%\text{Comp}_{Rb\ degF} = \text{Percent Compaction of the RAP specimen at a given temperature in degrees F}

\( T_{CL} \) = Critical Temperature at which RAP compacts to 92%

\( T_{CH} \) = Critical Temperature at which RAP compacts to 97%

Note 2: If \%\text{Comp}_{Rb\ degF\ at\ 80} > 92 or \%\text{Comp}_{Rb\ degF\ at\ 120} < 97, use \( T_{CL} = 80 \) or \( T_{CH} = 120 \), respectively.

E. Determine need for corrective aggregate

1. If \( T_{CL} > 80^\circ\text{F} \), there is a need to evaluate the RAP gradation with fine corrective aggregate to fill the extra voids. 5% fine corrective aggregate is considered an appropriate starting point.
a. Construct new sample using 95% loose RAP and 5% fine corrective aggregate meeting the requirements of 02968S, by weight.

b. Repeat Steps B – D with the new blended sample. If \( T_{CL} \) is still greater than 80°F, report results as questionable for recycling. Additional fine corrective aggregate may be evaluated at the direction of the Pavement Management Engineer or Materials Engineer.

2. If \( T_{CH} < 120°F \), there is a need to evaluate the RAP gradation without any included sealcoats or with coarse corrective aggregate to fill the extra voids. 5% coarse corrective aggregate is considered an appropriate starting point.

   a. If seal coats are present, construct a new sample using RAP without the seal coats included.

   b. Repeat Steps B – D with the new sample. If \( T_{CH} \) is still less than 120°F or if no seal coats are present, incorporate coarse corrective aggregate. Construct a new sample using 95% loose RAP and 5% coarse corrective aggregate meeting the requirements of 02968S, by weight.

   c. Repeat Steps B – D with the new blended sample. If \( T_{CL} \) is still greater than 80°F, report results as questionable for recycling. Additional coarse corrective aggregate may be evaluated at the direction of the Pavement Management Engineer or Materials Engineer.

Report the following:

1. Pavement layers evaluated. Define by top and bottom depth of layer(s) in core.
2. Inclusion or exclusion of seal coats
3. Critical High and Low Temperatures for Density
   a. Note if fine or coarse corrective aggregate was necessary
4. List of mixes to be designed for project. Choose from:
   a. Base RAP with seal coat
   b. Base RAP without seal coat
   c. RAP with fine corrective aggregate
   d. RAP with coarse corrective aggregate

965.04 Emulsion Qualification

Determination of the proper emulsion grade is necessary for long-term performance of the Cold Recycle layer. The residual binder grade is determined based on the location of the project and the depth of the layer in the pavement.

A. Refer to the materials section of the project specifications for qualified emulsion systems.

B. Determine Emulsion Residual Binder Grade
1. Use LTPPBind to determine the appropriate PG binder grade for the emulsion based on the following:
   - Use the closest weather station at an elevation within 100 feet of the project elevation
   - Use a depth of 1” below pavement surface
   - Use 98% reliability
   - Identify both High and Low temperatures for Residual PG Grade
   - Note: Some projects may have multiple grades due to large changes in elevation.
965.05 Mix Design

The Mix Design for Cold Recycling is performed after the project is awarded and specific materials are identified, including the Cold Recycle Emulsion, and the fine and coarse corrective aggregates. Based on RAP characteristics and anticipated mat temperature during construction, multiple mix designs (with/without seal coats, with/without corrective aggregate) may be necessary. The mix design(s) should be completed prior to the preconstruction meeting.

A. Field Sampling (required if milling not used in RAP temperature/density evaluation)

1. Take samples from the project in accordance with Appendix A and the requirements of the contract. The samples are then evaluated for expected field gradation, used to determine emulsion content, and determine field target densities. Take care to take samples from the specific layers identified during the project selection materials evaluation.

2. Determine Target Gradation
   a. Reduce the sample for gradation. AASHTO T 248.
   b. Perform and report gradation using sieves listed in Table 1 (do not wash sample). AASHTO T 27
   c. If corrective aggregate is anticipated, repeat a and b with appropriate RAP/Corrective aggregate blend.

B. Determine Optimum Emulsion and Moisture

1. Using Target Gradation(s), determine the initial percent binder \( P_b \) according to effective film thickness equations contained in Asphalt Institute MS-2 based on an effective film thickness of 6.0 microns.

2. Using the initial \( P_b \), calculate the initial percent emulsion \( P_e \).

\[
P_e = \frac{P_b}{%B_{Em}} \times 100
\]

\( (Equation \ 7) \)

Where:

\( % B_{Em} \) = Percent Residual Binder in the approved project emulsion

3. Determine the optimum moisture content for each mix in accordance with Appendix C.

4. [This step for information only and is not required] Determine the critical SCB fracture energy \( (Jc) \) for each mix according to Appendix D.
a. Prepare the test specimens:
   i. At the initial $P_e$, initial $P_e +0.5\%$ and initial $P_e -0.5\%$
   ii. Add sufficient moisture to bring total liquid content (emulsion+water) to optimum.
   iii. Use 1% lime
   iv. Bring the mix to $77 \pm 2$ degrees F before placing in the gyratory mold
   v. Compact the specimen(s), AASHTO T 312 (30 gyrations)
   vi. Cure the test specimen(s) for $24 \pm 1$ hour at $140 \pm 2$ degrees F ($60 \pm 1$ degrees C)

b. Bring specimen(s) to $77 \pm 2$ degrees F ($25 \pm 1$ degrees C) and perform the SCB procedure.

c. The target for $J_c$ is -0.60

d. Determine the $P_e$ associated with $J_c = -0.60$. This emulsion content is the optimum emulsion content (optimum $P_e$).

*Report the following:*
- Optimum Moisture Content (%$w_m$)
- Optimum Emulsion Content ($P_e$)

C. Determine Target Densities and Critical Temperatures for each mix ($T_{CL}, T_{CH}$)

1. Use procedures outlined in 965.03.01 RAP Evaluation.

2. Determine the *Theoretical Maximum Specific Gravity* of the mix ($G_{mm}$). AASHTO T 209
   Follow procedures for drying entire sample. *(report to three decimal places)*

3. Build and compact two 4000 g samples using RAP, the optimum emulsion content, 1% lime and additional moisture to bring the total liquid (emulsion and water) to optimum moisture content.
   a. Compact one sample at $T_{CL}$ and one sample at $T_{CH}$

4. Determine *bulk densities, specific gravities and percent compaction* of the samples. If the respective densities are not $92\pm1\%$ and $97\pm1\%$, adjust $T_{CL}$ and $T_{CH}$.

*Report the following:*
- Theoretical Maximum Density ($G_{mm}$)
- Minimum Field target density (92% of $G_{mm}$)
- Maximum Field target density (97% of $G_{mm}$)
- $T_{CL}$ and $T_{CH}$ (limits at which corrective aggregate is expected to be necessary to achieve density and/or stability in the field)

D. **Perform Performance Testing of Mix**

1. Use procedures outlined in Appendix E.
2. Create specimens at optimum emulsion, optimum moisture and 1% lime.
4. Determine the Tensile Strength Ratio (TSR) of the mix.
5. If Cold Recycle design is for Central Plant operation, determine draindown characteristics of the uncompacted mix. AASHTO T 305. Draindown must be less than 0.2 percent of the total mix.
6. If any performance tests are not met, target gradation, emulsion content or use of corrective aggregate must be revised and mix design repeated. If performance test requirements cannot be met, material may not be suitable for recycling operations.

Report the following:
- Marshall Stability of mix
- TSR of mix
- Draindown of mix (if required)

**965.06.05 Mix Design Report**

A. Provide a final report that lists the following mix design information. All weights and percentages are to be as a percent of dry RAP.

1. Emulsion properties
   a. Emulsion supplier
   b. Emulsion designation
   c. Emulsion residue content
   d. Emulsion weight per gallon
   e. $G^*$ value of emulsion residue
   f. “M” and “S” value of emulsion residue
2. Field table for calculating emulsion content based on field gradation.
3. RAP gradation
4. Type and Percentage of Corrective Aggregate, if any
5. Lime slurry target content as a percentage of dry RAP (P_{L, RAP})
6. Optimum moisture content target as a percentage of dry RAP (%w_{m})
7. Optimum emulsion content target as a percentage of dry RAP (P_{e}) in the form of a target ± 0.2 percent and associated film thickness
8. Theoretical Maximum Density (Rice)
9. Minimum and Maximum Density Targets
10. T_{CL} and T_{CH} (limits at which corrective aggregate is expected to be necessary to achieve density and/or stability in the field)
11. SCB Jc/emulsion content curve [Currently Optional]
12. Marshall Stability at optimum P_{e} and %w_{m}
13. Retained Marshall Stability (TSR/Lottman) at optimum P_{e} and %w_{m}
14. Temperature sensitivity compaction curve as a % slope
965.07 Project Construction Management
Inspection, Sampling and Testing for Quality Control and Assurance

A. The following should be performed to properly control the project.

1. Station the project
   • Place a stake or pavement mark to the side of the project each 528 feet (10 divisions between mile markers) for location references.

2. Monitor Mat Temperature
   • Record the mat temperature and sunshine, i.e. sunny (S), partly cloudy (PC), and cloudy (C), at each test location on C 965-01. Sunshine is a significant factor in the mat temperature.

3. Monitor Gradation
   • Provide a mobile lab within 5 minutes transit of the project. Use wireless communication or other instantaneous means to transmit data.
   • Provide Results of control testing (Forms Located in Appendix I) to the processing equipment manager, through the Engineer’s designated channels in less than 30 minutes after sample is obtained.

4. RAP Gradation Process Control
   Gradation, moisture, and emulsion adjustments
   • Ensure the contractor obtains samples of the RAP and delivers to the lab within 5 minutes. AASHTO T 2, belt discharge.
   • Determine percentage of fines in the milled RAP ($P_{FR}$) and moisture content (M), Appendix H, E.
   • Compare measured $P_{FR}$ to the target
   • Cease production if measured $P_{FR}$ is outside the action limit (02968S)
   • Adjust the moisture and emulsion contents, if necessary, when the $P_{FR}$ is within the action limit.
   • Record all calculations and measurements on C 965-02.

5. Monitor Milling and Paving Operation
   • Monitor mill speed. Ensure the contractor obtains gradation tests as required.
• Verify the joint between the two recycled passes is clean and free of loose material.

• Have areas where the processing machine leaks lime slurry or emulsion removed and replaced.

• Verify the pickup machine is:
  - Picking up the windrow to within 1 inch of the milled surface.
  - Keeping up with the processing equipment.

• Monitor the paver.
  i. Is the mat segregating?
  ii. Is it showing drag marks from the screed?
  iii. Is the mat thickness correct?

  1. Observe the outer edge of the mat.

6. Monitor compaction, verify:

• The mat is reaching the design target temperature.

• The mat is reaching the daily target temperature.

• The knock down roller is getting on the mat as water begins to bleed from the pavement and off the mat when the surface begins to get tacky.

• The pneumatic roller isn’t causing the surface to bleed clear water.

• The finish roller is holding off until the surface dries.

• Density targets are being met.

• The roller operator is paying attention to the longitudinal joints.

7. Monitor Release to Traffic

• Perform the Shear Vane and Marshall Field Hammer tests as required (Appendices F and G).

• Release to traffic when targets are met.

8. Assure tack coat has been applied before covering the mat with asphalt paving.

9. Ensure the contractor provides an emulsion sample each day of processing.
Appendix A

Field Sampling for Cold Recycle Designs

A.01 Scope

Field Sampling of the pavement for Cold Recycle mixes is performed in a manner that allows for an understanding of 1) the susceptibility of the existing RAP to deform throughout a range of temperatures and 2) the anticipated gradation of the material and how it may affect achievement of density.

A.02 Determine method of sampling

1. Determine whether the RAP evaluation will be performed on material obtained by milling the existing RAP or on material cut from cores and milled to gradation.
2. If cores will be used, the core size and quantity should be checked to ensure enough material is cored to perform RAP evaluation tests. A 6” core of a 3” layer of HMA will provide approximately 7 lb. of material. The sampling should provide a minimum of 300 lbs. of material to provide enough material at each screen size after crushing and sieving.
3. If the RAP evaluation is performed on milled material, the cores to verify asphalt depth and condition can be smaller diameter (down to 2”). Milling must be performed using a mill large enough to provide RAP samples similar to the mills used in the Cold Recycle process. Milling should provide a minimum 600 lbs. of material as this material will be used for RAP evaluation and mix design.

A.03 Coring for Pavement Design and RAP Evaluation

1. Core to the full asphalt depth along the length of the project in 1000’ increments.
2. Take at least 1 core from the shoulder and 1 core from the travel lane for each direction totaling 4 cores across the roadway for a two lane roadway.
3. Take shoulder cores from within 1’ of the edge of asphalt. If the asphalt depth is less than the minimum depth for processing (CIR layer plus 2”), take additional cores towards the travel lane to determine where the asphalt meets minimum depth required for processing.
4. Vary the travel lane locations laterally to provide a representation of the full width of travel lane.
5. Measure total depth and depth of each lift. Evaluate cores for stripping problems or other characteristics detrimental to the cold recycling process.
6. If using the core material for RAP evaluation:
a. Cut the top and bottom of the cores down to the layer to be processed. For the RAP evaluation, samples with and without any existing seal coats may be required.

b. Crush enough cores down to sizes adequate to make 2-4000 g coarse gradation samples. Crush additional pucks, either with or without the seal coat as required, during the RAP evaluation.

**A.04 Milling for Mix Design**

1. The sample must be representative of the CIR milling and crushing process.
2. Sample the project in at least 4 locations.
3. Mill the top one inch of each sample location and collect separately from the balance of the sample.
4. Mill the sample to the specified depth using a mill of the same size as the mill used for the project.
5. Mill with an up-cut direction at a rate of 30 ft per minute.
   a. Gradations from the initial set of the mill in the pavement are not representative of the regular milling. During sampling, the mill should be set in to the proper depth and then lifted out. Discard the millings. The mill can then be reset and moved forward.
   b. Typical areas for proper sample size are approximately 2 ft by 4 ft for a 3 inch deep layer.
6. Keep the sample from each location separate so that the materials can be evaluated independently.
7. Combine seal coat with millings with lower layer proportionately as required in the RAP evaluation process.
Appendix B

Cold Recycle Mix Bulk Density (30 Gyration)

B.01 Scope
This test determines the achievable mix density at the design or project temperature using the compactive energy provided by 30 gyrations in the Superpave gyratory compactor (SGC). This procedure can be used on either the full gradation of RAP or the processed mix.

B.02 Sample Preparation.
1. Obtain a 20kg minimum sample from the windrow. AASHTO T 2.
2. Minimize evaporation throughout the sampling, splitting and compaction process by working efficiently and keeping the sample in a sealed container as much as possible.
3. Reduce the sample to 4000 g. AASHTO T 248.
4. Bring the sample to the test temperature (design, compaction) using an oven, heat lamps or solar radiation.
5. Weigh the sample to the nearest one gram.
6. Compact in the SGC to 30 gyrations. Record height.
7. Eject the sample and remove the top and bottom plates. Use care not to chip the sample.
8. Clean excess moisture out of the gyratory compactor each time samples are made. The lime water that can come out of the pucks can have detrimental effects on equipment.

Note B1: For laboratory samples, construct a 4000 g sample using centerline process and appropriate gradation.

B.03 Determine \( G_{mb} \) or \( G_{Rb} \)
1. Pat the sample with a moist towel.
2. Weigh the sample. This is the saturated weight. Designate \( S \)
3. Determine Specific Gravity of the puck. \( (G_{mb} \text{ or } G_{Rb}) \)
   a. Use Method B and C in AASHTO T 166 as modified here
b. Fill the volumeter with 77 degree F water placing the lid allowing water to escape the capillary hole. Dry the outside of the volumeter. Weigh the volumeter plus water. Designate $D$

c. Place the sample in the volumeter and fill with 77 degree F water.

d. Allow to saturate for 4 minutes. Remove any air bubbles from the water surface.

e. Place the lid on the volumeter allowing water to escape through the capillary hole. Dry the outside of the volumeter

f. Weigh the volumeter, water and sample to the nearest one gram. Designate $F$

g. Remove the lid and drain the water being careful not to decant any particles.

h. Remove the sample to a pan. Include all particles lost into the volumeter.

i. Break the sample into particles no larger than those which cannot be further reduced under finger pressure.

j. Dry the sample using an oven, heat lamp or solar radiation until the dark color leaves the fine particles and the sample no longer clumps.

k. Weigh the sample. Designate this weight $A$

l. Calculate the water in the sample $SW = S - A$

m. Calculate the mass of the volumeter filled with specimen and water minus the water in the specimen. Designate $E = F - SW$

n. Calculate Bulk Specific Gravity

\[
G_{mb} \text{ or } G_{RB} = \frac{A}{(A+D-E)}
\]

(Equation B.1)

Where

$A$ = the dry weight of the specimen after break down

$D$ = the weight of the volumeter plus water

$E$ = the weight of the volumeter plus water plus sample minus the water inside the sample
Appendix C

Determining Optimum Moisture of a CIR Mix

This procedure is used to determine the moisture content required in the mix to prevent emulsion break by determining moisture content of fine RAP (FR) at point of liquefaction. Liquefaction is a condition of the FR where moisture is driven to the surface by vibration. It is characterized by the surface developing a sheen and a smooth, shiny texture. Lime slurry moisture content should be included in this moisture content.

1. Prepare a 100 g sample of fine RAP with the following gradation.

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<th>Sieve Size</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
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<td>No. 16</td>
<td>100</td>
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<tr>
<td>No. 200</td>
<td>5</td>
</tr>
</tbody>
</table>

2. Add 5 g of lime (Lime content is assumed at 1 percent of the mass of the RAP and that 20 percent of the RAP is FR)

3. Add 25.2 g water (24 percent of the RAP and lime)

4. Vibrate the sample at 50 Hz for 15 seconds. A VIBCO SCR-50 bin vibrator, or similar, mounted on a table is an acceptable apparatus.

5. Observe the surface of the sample for the appearance of liquefaction.

6. Add water in 2.1 g (2 percent of RAP and lime) increments and repeat vibration and observation.

7. Repeat Steps 4 through 6 until liquefaction is achieved. Record total amount of water added.
8. Determine water content percentage at liquefaction ($%w_{FR}$):

$$
%w_{FR} = \frac{\text{Mass of water}}{\text{FR} + L} \times 100
$$

(Equation C.1)

Where:

- $%w_{FR}$ = percent water in the FR at liquefaction
- FR = fine RAP sample mass (100 g)
- L = lime (5 g)

This is the required moisture content to prevent emulsion break.

Calculate the optimum moisture content of the total mix ($%w_m$) based on the percent FR in the mix ($P_{FR}$) and the percent water in the FR at point of liquefaction.

$$
P_{FR} = \frac{V_{FR}}{\frac{G_{FRb}}{V_{des}} - G_{mm - RAP}} \times 100
$$

(Equation C.2)

Where:

- $P_{FR}$ = amount of fine RAP expressed as a percentage of total RAP
- $V_{FR}$ = Volume of fine fraction of the RAP in a specimen (cm$^3$)
- $V_{des}$ = Estimated volume of specimen compacted at $T_{des}$ (cm$^3$)

And

$$
%w_m = \frac{%w_{FR}}{P_{FR}}
$$

(Equation C.3)

Where:

- $%w_m$ = Amount of water in the mix at optimum as a percent of RAP
- $%w_{FR}$ = percent water in the CF at liquefaction

Report:
Percent water in the fines at liquefaction ($w_{FR}$)

Percent water in the mix at optimum ($w_m$)
Appendix D

Note B1: This method is used by permission of its author, Dr. Louay Mohammad at Louisiana State University. This method references AASHTO T 67, a discontinued method of test. Please refer to ASTM E 4 for equivalent standard.

Method of Test for Evaluation of Asphalt Mixture Crack Propagation Using the Semi-Circular Bend Test (SCB)

1. SCOPE

1.1. This test method covers procedures for the preparation, testing, and measurement of fracture failure of semi-circular asphalt mixtures of specimens loaded monotonically.

1.2. This standard may involve hazardous material, operations, and equipment. This standard does not purport to address all safety problems associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

2. REFERENCED DOCUMENTS

2.1. AASHTO STANDARDS

- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- T 67, Load Verification of Testing Machines
- T 166, Bulk Specific Gravity of Compacted Hot Mix Asphalt Using Saturated Surface-Dry Specimens
- T 168, Sampling Bituminous Paving Mixtures
- T 209, Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
- T 269, Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
3. SUMMARY OF TEST METHOD

Semi-Circular Bend Test UT T-1 EMCRF

3.1. A semi-circular specimen is loaded monotonically until fracture failure. The load and deformation are continuously recorded and the critical strain energy rate, $J_c$, is determined.

4. SIGNIFICANCE AND USE

4.1. The critical strain energy rate is used to compare the fracture properties of asphalt mixtures with different binder types.

4.2. This fundamental engineering property can be used as a performance indicator of fracture resistance based on fracture mechanics, the critical strain energy release rate, also known as $J_c$ value.

5. APPARATUS

5.1. Load Test System- A load test system consisting of a testing machine, environmental chamber, and data acquisition system. The test system shall meet the minimum requirements specified below.

5.2. Testing Machine- The testing machine should be a closed loop system capable of applying a 4.5kN load monotonically under a constant cross-head deformation rate of 0.5 mm/min in a three point bend load configuration.

5.3. Environmental Chamber- A chamber for controlling the test specimen at the desired temperature is required. The environmental chamber shall be capable of controlling the temperature of the specimen at 25°C to an accuracy of +/- 1°C.

5.4. Measurement System- The system shall include a data acquisition system comprising analog to digital conversion and/or digital input for storage and analysis on a computer.

   The system shall be capable of measuring and recording the time history of the applied load for the time duration required by this test method. The system shall be capable of measuring the load and resulting deformations with a resolution of 0.5 percent.

5.4.1. Load- The load shall be measured with an electronic load cell having adequate capacity for the anticipated load requirements. The load cell shall be calibrated in accordance with AASHTO T 67.

5.4.2. Axial Deformations- Axial deformations shall be measured with linear variable differential transformers (LVDT).
5.4.3. Temperature - Temperature shall be measured with Resistance Temperature Detectors (RTD) accurate to within +/- 1ºC

5.5. Gyratory Compactor - A gyratory compactor and associated equipment for preparing laboratory specimens in accordance with AASHTO T 312 shall be used.

5.6. Saw - The saw shall be capable of producing three different notch sizes ranging from 0 – 50 mm. The width of the saw blade shall be 3.0mm.

5.7. Loading Frame - The loading frame shall consist of a loading rod and two sample support rods. The schematic of the test apparatus is shown in Figure x (need permission from ATM). The diameters of the loading and supports rods shall be 25.4 mm and the anvil span shall be 127.0 mm.

6. TEST SPECIMENS

6.1. Semi-circular bend testing may be performed on field cores or laboratory prepared test specimens.

6.2. Specimen Size - The test specimen shall be 150 mm diameter and 57 mm thick.

6.2.1. The semi-circular shaped specimens are prepared by slicing the 150 mm by 57 mm specimen along its central axis into two equal semi-circular samples.

6.2.2. Field cores can also be used if pavement is at least 57 mm.

6.3. Notching - A vertical notch is introduced along the symmetrical axis of each semicircular specimen. The three nominal notch sizes are 25.4 mm, 31.8 mm, and 38.1 mm. The notch depth tolerance is ± 1.0 mm. The width of the notch shall be 3.0 ± 0.5mm

6.4. Prepare four test specimens at the target air void content ±0.5%.

6.5. Aging - Laboratory-prepared mixtures shall be temperature-conditioned in accordance with the oven conditioning procedure outlined in AASHTO PP2. Field mixtures need not be aged prior to testing.

6.6. Air Void Content - Prepare four test specimens at the target air void content ±0.5%.

6.7. Replicates - Four specimen should be tested at each at each notch depth (25.4-, 31.8-, and 38.1-mm).

7. PROCEDURE

7.1. Place the specimen on the bottom support, ensuring the support is centered and level (as shown in Figure 1), in the environmental chamber and allow it to stabilize to 25ºC. A
dummy specimen with a temperature sensor mounted to its center can be monitored to
determine when the specimen reaches 25ºC. In the absence of a dummy specimen, a
minimum of 0.5 hours from room temperature is the required temperature equilibrium
time.

7.2. After temperature equilibrium is reached, apply a preload of 10 lb to specimen to ensure
the sample is seated properly. After ensuring the sample is level, release the load.

7.3. Begin to apply load to specimen in displacement control at a rate of 0.5 mm/min ensuring
that time, force, and displacement are being collected and recorded. During the test have
the load versus displacement plot visible, paying close attention to the peak load. Test may
be terminated 120 seconds after peak load is reached.

8. CALCULATIONS

\[ J_c = - \left( \frac{1}{b} \right) \frac{dU}{da} \]  

(Equation D.1)

where:

\( J_c \) = Critical fracture energy
\( b \) = sample thickness
\( a \) = notch depth
\( U \) = strain energy to failure.

8.1.1. Strain energy to failure, \( U \) is the area under the loading portion of the load vs. deflection
curves, up to the maximum load measured for each notch depth (shown in Figure 2).

8.2. The specimens are randomly clustered into 4 groups of three (one specimen at each notch
depth within the grouping) before testing. Each cluster of three notch depths may be
analyzed individually. The three values of \( U \) (one at each notch depth) are plotted versus
their respective notch depths. The data is then modeled with a linear regression line (shown
in Figure 3). The slope of the linear regression line represents the strain energy release rate.

8.3. The critical value of J-integral \( (J_c) \) then computed by dividing the slope of the linear
regression line \( (dU/da) \) by the specimen thickness, \( b \).
Figure D-1: Schematic of the loading apparatus
Figure D-2: Loading Position
Figure D-3:

Figure D-4: Deformation versus Load
9. REPORT

9.1. The report shall include the following parameters:

9.1.1 Asphalt Mixture Type;

9.1.2 Test Temperature, °C;

9.1.3 Specimen Air Voids, %;

9.1.4 $J_c$ per Notch Depth, kJ/m$^2$;

9.1.5 Coefficient of Determination, $R^2$;

9.1.6 Mean $J_c$ Value, kJ/m$^2$;

9.1.7 Standard Deviation of $J_c$;

9.1.8 Coefficient of Variation, %.
Appendix E

Modified Laboratory Performance Tests for Cold Recycling Asphalt

E.01

Maximum Theoretical Specific Gravity RICE

E.01.1 Scope  Rice testing assumes that the binder becomes stable through cooling. In using the test with emulsions, the binder becomes stable through emulsion break and curing. When using asphalt recycling emulsions, it is important to dry the sample completely to stabilize the emulsion and prevent re-emulsification.

E.01.2 Sample preparation.
   1. Obtain a 1800 g sample of the mix either by sampling the windrow or by lab mixing. If sampling a windrow, reduce a 20kg sample to testing size with a splitter.
   2. Spread the sample on a surface so that the particles do not stack.
   3. Dry the sample until the particles do not clump and the dark color leaves the fines.

E.01.3 Determine the Gmm. AASHTO T 209

E.02

Moisture Content

E.02.1 Scope. Moisture content is an important part of compaction in Cold Asphalt Recycling. Speed in obtaining results is critical to project control. A close result is much more valuable than a late result.

E.02.2 Sample Preparation.
   1. Obtain a representative 500 g sample from the mat behind the paver.
   2. Place it in an air tight bag.
   3. Tare the pan.
   4. Weigh the sample wet. Designate A
   5. Place the sample on a surface so that the particles do not stack.
   6. Dry the sample using an oven, heat lamp or solar radiation until the particles do not clump and the dark color leaves the fines.
7. Weigh the Sample. Designate B

8. Determine moisture content. Mc% = B/(A-B)

E.03

Marshall Stability

E.03.1 Scope. Marshall Stability is an important part of understanding the short-term curing and stability of the Cold Recycle material. Unstable mixes will not permit early opening to traffic.

1. Determine the Marshall Stability of the mix at optimum Pe and %wm. AASHTO T 245
   a. Prepare three samples of mix such that when compacted according to T 312 each 6 inch specimen is compacted to 80 ± 1 mm and percent air voids (%V_{a}) is 94 ± 0.5 percent of G_{mm}.
   b. Cure the mix for 24 ± 1 hours at 77 ± 2 degrees F (25 ± 1 degrees C)
   c. Compact the specimen(s)
   d. Perform the Marshall Stability Test procedure at 77 ± 2 degrees F (25 ± 1 degrees C)

E.04

Tensile Strength Ratio (TSR)

E.02.1 Scope. Tensile Strength Ratio is an important part of the long-term performance of Cold Recycle materials. Material incompatibility can result in pavement failure.

1. Determine the Tensile Strength Ratio (TSR) of the mix at optimum Pe and %wm. AASHTO T 283
   a. Bring the mix to 77 ± 2 degrees F before placing in the gyratory mold. Do not cure the material before compaction.
   b. Compact the specimen(s). AASHTO T 312
   c. Cure the test specimens for 24 hours ± 4 at 140 ± 2 degrees F (60 ± 1 degrees C)
   d. Perform a single freeze thaw cycle
Appendix F

Cold In-Place Recycled Asphalt Field Shear Vane Test

F.01 Scope

This procedure provides a method for performing Shear Vane testing on Cold In-Place Recycled (CIR) asphalt to determine the progress of curing after compaction.

F.02 Apparatus

- Sledge hammer, 5 lb minimum
- Torque wrench capable of reading to 150 ft/lb
- Shear vane (Figure F-1, F-2)
- 15/16 inch socket

Figure F-1. Photo of Shear Vane with socket attached
The Shear Vane is constructed by welding 1/8 inch steel plates to a 5/8 inch bolt and a 3/16 inch washer from the edges of the washer to the center.

**F.03 Procedure**

1. Select a test location according to project specifications and at least 1 ft. from the edge of the CIR pass and other test sites.

2. Using the hammer, drive the Shear Vane into the CIR, keeping the Shear Vane vertical, until the washer sits flush on the surface.

   **Note D1:** The socket must be on the bolt head before striking with the hammer so that the Shear Vane is not damaged. Care must be taken to keep the device as vertical as possible to minimize damage to the CIR before testing.

3. Place the torque wrench onto the head of the Shear Vane bolt. Apply slight downward pressure to ensure that the Shear Vane does not lift during the test.

4. Evenly apply pressure to the torque wrench (90 degrees in 10 seconds) while watching the dial closely. Apply increasing pressure until the CIR material is broken loose by the Shear Vane.

5. Record the highest torque value reached during test.
6. Determine and record pavement temperature at 2 inches below surface.

7. The test will leave a hole in the mat, repair by pressing loose material into the hole and coating the site with emulsion.

**F.04 Record the following on Form 965-03:**

- Time and date of the test
- Location
- Maximum torque value achieved in ft/lbs
- Pavement temperature at a depth of 2 inches
Appendix G

Determining In-place Flow of Cold In-place Recycled (CIR) Asphalt using the Marshall Hammer

Use this procedure for quick evaluation of flow characteristics of CIR mat to determine appropriate hold time for CIR mixes before finish compactive efforts and release to traffic.

G.01 Apparatus


G.02 Field Procedure

1. Perform test on the initially compacted mat.

2. Place the Marshall hammer with its head flat on the mat. Do not move the hammer or rock the head.

3. Pick up the sliding weight until it reaches the upper stop. Drop the weight. Repeat 50 times.

4. All measurements are from the level of the undisturbed mat.
   a. Measure the depth of the depression made by the hammer in mm.
   b. Measure the height of the lateral deformation, if any, in mm.

5. Determine the moisture condition of the mat. (Water bleeding from the mat or is it dry?)

6. Determine temperature of the mat to the nearest 1 degree F.

G.03 Report on Form 965-03

- Test location
- Mat temperature
- Depth of depression, mm
- Height of lateral deformation (Ht LD), if any, mm
- Moisture condition
G.04 Determination of CIR Sample Cure Time

The mat is not ready for final rolling and opening to traffic if the depression is greater than 10 mm, the height of the lateral deformation is greater than 5 mm or if the mat is bleeding.
Appendix H

Standard Method to Rapidly Obtain the Gradation of RAP Millings

Use this method to rapidly determine the gradation of RAP. These results are used to determine and control the percent emulsion in the CIR mix.

All testing equipment and supplies are required to be within 5 minutes of the CIR processing unit so that results may be provided to the processor operator within 45 minutes.

H.01 Sample

1. Have the contractor obtain a sample of milled RAP from below the scalping sieve but above the pugmill on the recycling train. The sample must be:
   
   a. A complete cross section of the flow from the mill and from the crusher. If the flow separates into two streams, sample each flow for an equal time. Contact the belt with the sampling tool to assure inclusion of fine particles.
   
   b. 10 kg minimum

2. Reduce the sample using a riffle splitter. AASHTO T 248

3. Obtain a 1.4 kg sample for testing.

4. Determine and record wet mass (W) of the sample to the nearest 1 g.

5. Spread the sample out on a surface so that the large particles are not stacked.

6. Dry the sample at 110 degrees F or less until particles separate easily in an air stream moving 5 ft. per second or less. When the dark coloration on the fine particles disappears, the sample is considered to be dry.

7. Sieve the dry sample on the following sieve sizes: 1”, ¾”, ½”, 3/8” #4, #8, #16, #50, #100, #200.

H.02 Adjust the gradation for fines retained on large aggregates

Once per day, perform a washed gradation AASHTO T 11. Decant over the #50, #100 and #200 sieves. After drying and re-shaking, determine the quantity of material moving down the sieve nest.

Use the percentage change to recalculate the percent passing each sieve for the other samples during the day.

H.03 Report the following on Form 965-02:
Return results to the Engineer’s designated representative within 45 minutes after the sample is obtained.

- Wet mass of the sample \((W)\)

- Dry Mass retained on each screen\% retained on each screen\% Total dry mass of sample \((D)\)

- \% passing each screen

- Moisture content of the whole sample to 0.1\% \(((W-D)/D) \times 100\)

- Percent passing each sieve adjusted for washing
Appendix I

Construction Forms
# C 965-01 Daily Worksheet

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<th>Time</th>
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<th>% Lime</th>
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**Remarks:**

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C 965-02 Gradation and Moisture Content

Gradation and Moisture Content Results and Action

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<td>2 Dry weight CR</td>
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<td>3 Dry weight FR</td>
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<td>4 Total Dry weight</td>
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<td>a Measure wet weight from sealed sample</td>
<td>80</td>
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<tr>
<td>b Dry to surface dry</td>
<td>90</td>
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<tr>
<td>c Sieve over 1/2&quot;, 3/8&quot;, #4 and #16 screens</td>
<td>100</td>
</tr>
<tr>
<td>d Combine all + # 16 (CR) material</td>
<td>110</td>
</tr>
<tr>
<td>e Microwave CR material to dry &amp; weigh</td>
<td>120</td>
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<tr>
<td>f Microwave FR material to dry &amp; weigh</td>
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Field Mix Temperature _______ degrees F

Predicted Compaction Temperature _______

Percent Passing # 16 (P_{Fr}) _______ Percent

P_{Fr} from Design _______

Report Time _______

P_{e RAP} from Design _______

Deviation from Gradation Target _______

Contractor Initial _______

New Target P_{e RAP} _______

Technician Initial _______

Change Implement Station (M-1+000) _______

C 965-03 Release to Traffic
### UDOT CIR Release to Traffic Daily Worksheet

**Location**

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# C 965-04 In-place Density Report

## CIR DENSITY DAILY REPORT

**PROJECT**

**CIR CONTRACTOR**

**PAVING CONTRACTOR**

**WEATHER**

**CIR EMULSION**

**CONTRACTOR'S EQUIPMENT**

**TECHNICIAN NAME**

**CONTRACTOR'S EQUIPMENT**

**TTQP QUAL. NUMBER**

**TEMPERATURE TARGET / DAY**

**ACTUAL TEMPERATURE / DAY**

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**TIME BEGIN**

**TIME FINISH**

**HOURS**

**MILEAGE**

**REMARKS / LOCATION MAP**
Appendix J

Time Charges

For Information Only

Designers: Include the following in Section 02221S of the Special Provisions

Time Charges

A. Divide the time charges into four categories: Sampling Plan, Sampling, Pre-construction and Construction time.

B. A maximum of 5 days Sampling Plan Charges are provided to the Contractor.

C. A maximum of 5 days of Sampling Charges are provided to the Contractor.

D. A maximum of 10 days Pre-construction Charges are provided to the Contractor.

E. Sampling Plan Time charges begin at the Notice to Proceed (NTP) and continue until the contractor submits the Sampling Plan required in the specification. Penalties for time begin if the contractor submittal exceeds 5 working days after NTP.

F. Time charges are suspended while the Department reviews the Sampling Plan.

G. Sampling Time Charges start when the Sampling Plan is approved in writing by the Engineer and continue until the Contractor submits the required samples. Penalties for time begin if the contractor’s sample submittal exceeds 5 working days after approval of the Sampling Plan.

H. Time charges are suspended while the Department prepares the Mix Design.

I. The Mix Design will be provided to the Contractor a minimum of 10 days before the pre-construction conference.

J. Preconstruction time charges begin when the Department delivers the mix design to the Contractor. Penalties for time begin if the contractor fails to hold the pre-construction conference within 10 working days after the Department provides the mix design.

K. Construction time charges begin the day of the pre-construction conference.