Full-Depth Reclamation with Asphalt Binders

Construction Guidelines

Materials and Tests Division

Soils and Aggregate Section

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Texas Department of Transportation

Contents

Introduction

Full-depth reclamation (FDR) has been used by TxDOT on numerous projects to strengthen the load carrying capability of an existing pavement, to rework the roadway to remove a variety of pavement distresses or to become a part of a roadway widening and strengthening process.

The use of recycled asphalt pavement (RAP), base, subbase and possibly subgrade materials in recycling operations will reduce costs; conserve energy; reduce emissions and hence greenhouse gases; and reduce the consumption of natural resources, including aggregates and asphalt binders, while reducing project completion time.

This document explains the steps of the FDR process and rationale behind the specifications to ensure successful projects for TxDOT and the residents of Texas. The target audiences for this document are TxDOT district staff and contractor field construction and quality control/quality assurance personnel.

The following appendices support this document's main text:

- A: Troubleshooting FDR with Asphalt Binders.
- B: FDR Field Support List.
- C: Example QC Data Sheet.
- D: Moisture Correction for Nuclear Density Gauge.

The FDR Process

The FDR process involves pulverization (typically 6 to 12 inches) of the asphalt-bound layers of the pavement and a portion of the underlying, base materials, with or without the addition of a stabilizer (Portland cement, lime, emulsified asphalt or foamed asphalt), followed by spreading and compaction operations. On some projects, additional base course material is added to increase the processed material depth or improve overall aggregate quality. When emulsified asphalts are used as stabilizers, hydrated lime or Portland cement may be used as an additive, typically not exceeding 1.0% by total weight of the recycled material. When foamed asphalt is used as the binder, Portland cement is often used as an additive with a content of about 1.0% by total weight of the recycled material.

Specifications

Special Specification 3089, “Full-Depth Reclamation Using Asphalt Emulsion (Road-Mixed)” (TxDOT 2024. *Texas Department of Transportation Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*. Item 290, “Emulsified Asphalt Treatment [Road-Mixed].”)

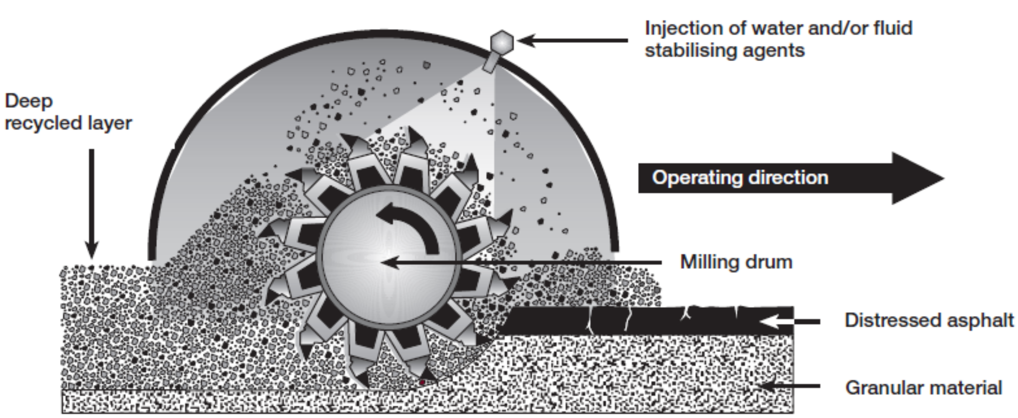
Special Specification 3088, “Full-Depth Reclamation Using Foamed Asphalt (Road-Mixed)” (TxDOT 2024. *Texas Department of Transportation Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*. Item 291, “Foamed Asphalt Treatment [Road-Mixed].”)

Additional Items from *Texas Department of Transportation Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* (TxDOT 2024) are cited in this document.

TxDOT Guidelines and Test Methods

These documents are used to construct FDR projects in Texas. Also, resource documents have been developed by TxDOT:

- TxDOT 2021. *Pavement Manual*. Maintenance Division, Austin, TX. https://onlinemanuals.txdot.gov/TxDOTOnlineManuals/TxDOTManuals/pdm/index.htm.
- TxDOT 2019. *Treatment Guidelines for Soils and Base in Pavement Structures*. Materials and Tests Division, Soils and Aggregates Section, Austin, TX. https://ftp.dot.state.tx.us/pub/txdot/mtd/treatment-guidelines.pdf.
- TxDOT 2005. *Guidelines for Modification and Stabilization of Soils and Base for Use in Pavement Structures*. Construction Division, Materials and Pavements Section, Geotechnical, Soils and Aggregates Branch, Austin, TX. https://ftp.dot.state.tx.us/pub/txdot-info/cmd/tech/stabilization.pdf.
- TxDOT 2005. *Guidelines for Treatment of Sulfate-Rich Soils and Bases in Pavement Structures*. Construction Division, Materials and Pavements Section, Geotechnical, Soils and Aggregates Branch, Austin, TX. https://ftp.dot.state.tx.us/pub/txdot-info/cmd/tech/sulfates.pdf.
- TxDOT 2018. *Guide Schedule of Sampling & Testing for Design Bid-Build (DBB) Projects (DBB Guide Schedule)*. Austin, TX. https://ftp.txdot.gov/pub/txdot/mtd/dbb-guide/guide_schedule.pdf.



Materials

Emulsified asphalt and asphalt cements suitable for foaming together with additives are specified. Asphalt emulsion/asphalt suppliers should provide pintle hitches on the rear bumper of the transports for mixing operations.

Asphalt Emulsion

For asphalt emulsion FDR, the emulsion used is CSS-1H or can be a high-yield emulsion that includes a rejuvenating agent. Application rates typically run from 3.0% to 5.0% emulsion, depending on the percentage of RAP in the material to be recycled. For high yield emulsion, typical rates are between 2.0% and 3.0% of the total weight of the recycled material.

Foamed Asphalt

For foamed FDR, the asphalt cement used is PG 64-22 delivered at an average temperature of 350 degrees Fahrenheit. To ensure that the asphalt cement has the adequate foaming properties, specifications are included for half-life and expansion ratio. Application rates typically run from 2.0% to 3.0% by total weight of recycled material.

Corrective Aggregate or Additional Materials

In addition to the materials in the existing pavement (asphalt-bound surfacing materials, flexible bases, subbase and possibly subgrade) that will be recycled, new flexible base (Item 247, "Flexible Base") and RAP from other sources can be used as shown on the plans, required by the mixture design or directed by the engineer. TxDOT specifications term this material "Additional Material."

Additives

Additives, including lime (DMS-6350), Portland cement (DMS-4600) and fly ash (DMS-4615), can be used when shown on the plans, required by mixture design or directed by the engineer. Although the specifications limit the additive to a maximum of 1.5% by weight of roadway materials being processed, it is recommended to not exceed 1.0% to maintain the flexibility of the resulting mixed materials and to keep the FDR layer from becoming brittle. The 2024 specifications limit cement to 1%. Because moisture must be controlled, cement slurry does not work well with this process and is normally used in dry form. If lime slurry is included in the design, it should be premixed and mellowed at least 24 hours before asphalt mixing. Fly ash has limited historical use as an additive for FDR with asphalt binders.

Mix Design Information

For mix design procedures, refer to Tex 122E and 134E for emulsion FDR and foam FDR, respectively. A copy of the mix design should be provided to the area engineer and the contractor before the preconstruction meeting. Ensure that the asphalt/asphalt emulsion used in the mix design is the same material provided in the field. TxDOT specifications allow mix design verification using actual project materials; this verification should occur whenever actual project materials or sources differ from those used in the mix design.

Field operations will need the following information from the mix design:

1. Optimum moisture content and maximum dry density on samples containing recycled pavement material and any corrective aggregate compacted by Test Method Tex-113-E. This information on untreated material is very useful, although mix design procedures require the materials to be treated to obtain optimum moisture density.
2. Asphalt Emulsion:
   a. Emulsion type and source.
   b. Design emulsion content (%).
3. Foamed Asphalt:
   a. Asphalt binder grade and source.
   b. Foam contents: design foamed asphalt content (%) and foaming water content (%).
   c. Half-life and temperature at which half-life is measured.
   d. Expansion ratio and temperature at which expansion ratio is measured.
4. Mixture components in percentages:
   a. Existing materials in the pavement that will be recycled (asphalt-bound, base and other material percentages).
   b. Additional material (flexible base and/or RAP); depth is usually shown on a typical section sheet in plans.
   c. Additives: type and percent (typically cement or lime).
5. Maximum dry density on recycled material (recycled pavement material, additional material, asphalt emulsion, or foamed asphalt and additive) at design-foamed asphalt or asphalt emulsion content and compacted by Test Method Tex-113-E. The maximum dry density will be used to calculate percent density in the field.

CONSTRUCTION

FDR involves pulverization of the entire thickness of the asphalt-bound materials and a predetermined depth of the underlying materials (base and/or subbase). It is recommended to not allow treatment depths into the subgrade because asphalt does not mix with plastic soils. The pulverized material is mixed with asphalt emulsion or foamed asphalt and is then used as a base course material. Portland cement or hydrated lime can also be used as an additive depending on the type of materials being recycled and the requirements of the mixture design.

FDR depths can approach 10 to 12 inches provided adequate pulverization, mixing and compaction can be achieved. Typical depths of FDR are 6 to 9 inches. The load carrying ability of pavements can be significantly improved with FDR operations.

Equipment

Various milling, pulverizing, mixing and compaction equipment is used on FDR projects. Key equipment typically on a project consists of the following:

- Self-propelled reclaimer.
- Tankers or bulk trucks for lime and/or cement.
- Asphalt emulsion or hot asphalt tanker with pintle hitches.
- Computerized asphalt emulsion or foamed asphalt injection systems on reclaimers.
- Motor grader.
- Water truck with spray bar.
- Compactors (pneumatic-tired, 20-ton minimum; vibratory pad foot, 18-ton minimum; and double-drum steel wheel rollers, 10-ton minimum).

Reclaimers

Reclaimers for emulsified asphalt FDR projects are typically capable of pulverizing and mixing in widths of 8 feet to depths greater than 12 inches in a single pass while pushing a loaded asphalt transport. Although TxDOT requires a minimum power capability of 400 horsepower, 500 horsepower is typical. The equipment must be capable of pushing the asphalt transport while mixing the existing roadbed materials with water; emulsified asphalt; additives; and additional materials, such as flexible base or RAP.

Reclaimers that use asphalt emulsion also use spray bars with a positive displacement pump interlocked to the machine speed such that the amount of emulsion added is automatically adjusted with changes in machine speed. The amount of emulsion is determined and metered for the depth of recycling, the width of recycling and the forward speed of the reclaimer. Typical forward speed is 30 feet per min.

The transports containing emulsified asphalt or hot asphalt are “pushed” by the reclaimer during the mixing process, so the supplier must provide a pintle hitch on the back of the transport trailers.

Compaction water can be added by sprinkling with a water truck before mixing asphalt or by a nurse truck depending on the capabilities of the reclaimer.

Reclaimers that mix foamed asphalt are equipped with spray bars that distribute the foamed asphalt. Some equipment manufacturers have machines that have two independent pumping and control systems interlocked to the forward speed of the equipment. One pump system injects the foamed asphalt into the mixing chamber while the other injects compaction water. With this setup, the asphalt transport is pushed ahead of the reclaimer while the water transport is pulled behind. The equipment contains an electric heating system to help prevent heat loss in the asphalt cement. The foamed asphalt is produced at the spray bar in individual expansion chambers into which hot asphalt cement, water and air are injected under pressure through individual small orifices that promote ionization of the asphalt cement. The minimum horsepower required for the reclaimer is 600.

While FDR equipment can pulverize and mix in one pass, some projects use an initial pass to pulverize (and sometimes add moisture) and then a second pass to mix and distribute the asphalt binder and processed materials. TxDOT specifications promote a one-pass operation, although the specific site conditions, and whether any significant profile corrections are required, may dictate a multiple pass sequence. If a pre-pulverization pass will be required, include this in the general notes.

Weather Limitations

The FDR process works best during the drier and warmer seasons, which allows better control of moisture and faster curing times. If the roadway ditches contain standing water, it is best to allow time for the roadway to dry before attempting to mix.

The TxDOT specifications for the use of emulsified asphalt and foamed asphalt in FDR operations contain weather restrictions that are the similar for both stabilizers. The contractor is directed to suspend additive and asphalt stabilizer mixing operations when any of the following conditions exist:

- Pavement surface temperature is below 50 degrees F for emulsion and foam, although the warmer the surface the better for this process.
- Weather forecast calls for freezing temperatures within 3 days after incorporation of the asphalt stabilizer
- Moisture content of the roadway is unsuitable
- Engineer determines weather conditions are not suitable

Pre-Pulverization

This step is sometimes used on projects to help correct the pavement cross-slope and to blend corrective aggregates. It is the first pass of the reclaimer, before mixing emulsion or asphalt, and governs the size of the recycled materials. Some projects may require this preliminary step, but it is best during the warm, dry months because a rain event between the pulverization step and emulsion or asphalt mixing step could cause delays.

Pre-pulverization should be conducted with a reclaimer and should be at a slow speed (20 to 30 feet per minute) to allow for pulverization through the asphalt pavement into the underlying materials. The first pass accelerates tooth wear and may cause bouncing of the equipment; therefore, the depth of cut can vary. Pulverizing thick asphalt-bound layers is more prone to reclaimer bouncing than pulverizing pavements with thin asphalt-bound layers. Cutting depths of at least 1 to 2 inches into unstabilized materials is recommended to help cool the cutting teeth and to help prevent excessive tooth wear.

The pulverized material occupies a larger volume than the volume of the same materials in the pavement section, which causes the rear wheel of the reclaimer to “ride up” on the pulverized materials. This can cause vertical control of depth of cut to vary, so depth of cut should be checked frequently.

The Asphalt Recycling and Reclaiming Association (ARRA) recommends that the depth of cut for pre-pulverization be about 1 to 2 inches less than the final depth of the FDR layer. This will allow for more uniform mixing of the stabilizer into the recycled materials on subsequent passes. Before mixing with the emulsified asphalt or foamed asphalt, the pulverized material should be reshaped and lightly compacted to provide a working platform for the construction equipment and allow for a more uniform depth of the layer and more uniform mixing speed for the equipment.

Mixing and Placement

Recycled material is typically not at the correct moisture content for mixing or compaction, so moisture may need to be added during the pulverization pass or during the mixing process. Performing FDR during dry periods will allow greater control of moisture levels. In some cases, the recycled materials will need to be aerated to reduce the moisture content before mixing or compaction. Recycled materials are typically bladed to speed aeration; however, if additional moisture is needed, water trucks are used to supply the water to the pulverizer (mixer) or to the material on grade.

Always perform a moisture check before mixing emulsion or foamed asphalt. Do not begin mixing of the recycled materials with emulsified asphalt if the moisture content is greater than 70% of the optimum moisture content determined during mixture design. Research has shown that a moisture content of 60% to 70% of optimum, before mixing emulsion, is the correct moisture range. For foamed-asphalt-stabilized FDR projects, the asphalt and recycled materials should be mixed at or near the optimum moisture content. The optimum moisture content is determined during the mixture design phase of the project and for materials with emulsified asphalt or foamed asphalt and additives.

Cut or Mixing Plan

Recycling widths and reclaimer widths often do not match, requiring some nozzles to be turned off to achieve the desired mixing width. An effective cut plan showing mixing sequence with widths, overlaps and traffic is critical. Overlap between adjacent passes at least 6 inches as required. Avoid overlap locations in future traffic wheel paths. The overlap section should be treated with asphalt. Depth of cut should be controlled automatically by an onboard sensing system. Depth can be controlled on both sides of the cut.

Gradation or Level of Pulverization

Gradation of the pulverized pavement materials is controlled by one or more of the following:

- Front and/or rear door opening on the pulverizing/mixing chamber.
- Breaker bar setting on the pulverizing/mixing chamber.
- Rotation speed of the cutting drum.
- Condition of the cutting teeth.
- Forward speed of the reclaimer.
- Condition of the existing roadway, including:
  - Hardness of the asphalt-bound materials (partially controlled by temperatures).
  - Depth of various layers relative to depth of cut.
  - Type of pavement distress (alligator or fatigue cracking causes oversized particles).
- Gradation of underlying unstabilized materials.

Reducing forward speed, increasing rotating drum speed, closing the rear door and adjusting the breaker bar to a small distance to the cutting drum will reduce the particle size of the pulverized material. Slow rotating speeds are used when pulverizing thick sections of asphalt-bound materials, and faster rotating speeds are used when pulverizing thin sections of asphalt-bound materials. Greater production is obtained when recycling pavements with thin sections of asphalt-bound materials.

Smaller particle sizes are typically produced during pre-pulverization when the asphalt-bound materials are at a lower temperature and the forward speeds are slower. Typically, the most efficient ambient temperatures (in terms of particle size) for pulverization are between 50 and 90 degrees F.

Raising the drum height will help prevent "slabbing" of the asphalt-bound mixtures and therefore reduce particle maximum sizes. However, more than one pass of the equipment may be needed for pulverization.

Reclaimers are not crushers, so oversized particles can be expected. The intent is to ensure that the reclaimer pulverizes the asphalt-bound layers adequately.

Additional Materials or Corrective Aggregate

Additional material may be needed to correct gradation, increase thickness or provide materials to meet mix design requirements. Flexible base, RAP and/or crushed concrete meeting Item 247, "Flexible Base" can be used for this purpose.

Additional materials can be spread with a mechanical spreader or placed in a windrow with bottom dump trucks, or dumped on grade with rear dump trucks and spread to uniform thickness with a motor grader. Additional materials can be placed during pre-pulverization (if pre-pulverization is required) or while mixing the stabilizing agent.

Addition of Stabilizing Agent

Asphalt emulsions and foamed asphalt are added into the pulverizing/mixing chamber of the reclaimer. The amount of stabilizer is controlled by the forward speed of the reclaimer with input into the control system for width and depth (volume and weight) of material recycled. The stabilizer mixing rate is provided in the mix design. Suppliers must provide pintle hitches on the rear bumper of the transports for the reclaimer to connect.

Addition of Additives

Lime or Portland cement is normally used with asphalt emulsion and foamed asphalt operations. These additives help control the break and setting of the asphalt emulsion, improve the moisture susceptibility and help provide early strength in both stabilized systems to allow traffic on the reclaimed materials a few hours after mixing. TxDOT also allows fly ash as an additive, although it is rarely used.

TxDOT allows the additives to be added dry or as slurries. Slurries of either lime or Portland cement can be used to reduce dusting problems during construction. Although older specifications allowed up to 1.5% cement or lime, the 2024 specifications limit them to 1%. When lime is used, it is typically mixed in slurry form at least 1 day before asphalt mixing to allow the roadway materials to dry below optimum moisture. Portland cement is normally spread dry just ahead of emulsion/asphalt mixing operation.

Mixing

Mixing is performed by the reclaimer, which is connected to the asphalt emulsion or hot asphalt transport with a push bar and a suction hose. Typically, one pass of the reclaimer is used to mix the various ingredients in the FDR process at 20 to 30 feet per minute. If pre-pulverization has not occurred, 20 feet per minute is recommended. In some cases, more than one pass is required to thoroughly mix water, corrective aggregate, stabilizing agent and additive. Before mixing the stabilizer, the moisture content of the roadway materials should be checked.

TxDOT requires that mixing and compaction of the emulsified asphalt and foamed asphalt be completed the same day on which the asphalt products are applied to the recycled material. Overlap each adjacent pass by 6 inches. Multiple passes are required if the process control requirements are not met.

TxDOT does not allow the start of mixing if the insitu moisture content is greater than 70% of optimum moisture content as defined in the mixture design when asphalt emulsion is used, or greater than optimum moisture if foam is used.

Compaction

Proper compaction is critical to the performance of FDR projects. If the recycled materials are poorly compacted, the desired strength of the materials will not be achieved. Poor compaction can cause rutting, fatigue cracking and potholes, and other forms of distress.

A motor grader may be needed between the reclaimer and the padfoot roller if the reclaimer leaves a large hump between its wheelpaths. The intent is to have the padfoot compact the entire width.

Immediately following the mixing operation, a minimum 18-ton padfoot roller should follow the reclaimer in vibratory mode set at high amplitude and low frequency. This roller performs the bulk of the compaction and should perform enough passes until it "walks out" of the material. "Walking out" for the heavy vibratory tamping roller is defined as light being evident between all the pads and the material-heavy tamping roller drum interface. Alternate passes of the roller should be offset with the roller operating between 2 and 6 mph.

During compaction, moisture content control is critical for asphalt emulsion and foamed asphalt projects. TxDOT requires that the moisture content be held within 2 percentage points below to 0.5 percentage point above the optimum moisture content when using emulsified asphalt and foamed asphalt as the stabilizing agent in FDR projects.

Typically, one or more compactors are used to achieve density. The size, type and operational sequence of the compactors are somewhat project-specific.

The following rollers are used in the compaction sequence:

- Initial or breakdown rolling: vibratory padfoot (sheepsfoot), 18-ton minimum.
- Intermediate rolling: heavy pneumatic-tired (20-ton minimum) during blading (spreading) operations.
- Final or finish rolling: double-drum steel wheel roller (10-ton minimum) in static mode.

Spreading

A motor grader is commonly used to spread the pulverized and mixed materials to the specified thickness, width, longitudinal grade and cross-slope. Grade control and finish are important on the FDR layer if surface treatments or thin layers of hot-mix asphalt are to be used as the only surface course. In some cases, a cold-milling machine is used to achieve the desired grade and elevation control to ensure ride quality on the finished surface of the roadway.

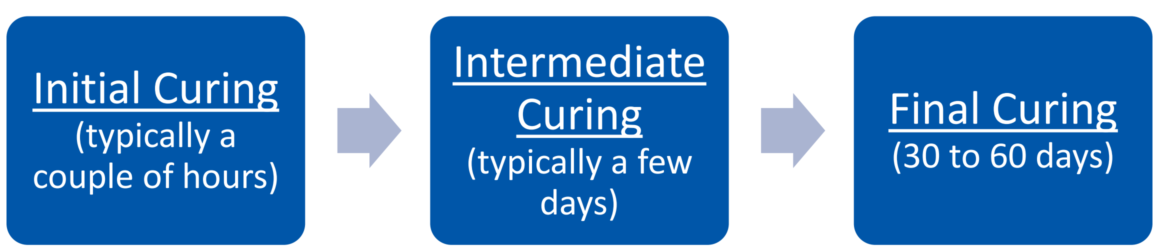
Normally, the motor grader begins working after an adjacent reclaimer pass because of the motor grader's width requirements. After tamping rolling, the motor grader should cut into the material to a depth slightly below the tamping roller marks. A pneumatic roller should be used during blading operations. Ensure that the bladed materials are maintained at the proper moisture content, and blade until the proper lines and grades are achieved as shown on the plans. When additional moisture is needed, use light applications; do not overwater.

Clip, skin or tight-blade the surface to remove any accumulated fines. It is recommended not to use fines to fill tamping marks. When blade work is completed, finish with smooth drum roller in static mode. Do not finish-roll in vibratory mode. If necessary, use a light spray of water to aid in final compaction to achieve the designated density and appearance. Perform final shaping on the same day on which the asphalt emulsion or foamed asphalt is mixed with the processed materials. **Blading this material again the following day is not advised**.

Rework material that fails to meet or loses the required density and stability of surface finish. The reworking should be completed within 24 hours of initial compaction. Reworking includes loosening with reclaimer; adding material or removing unacceptable material; and, if necessary, remixing, compacting and finishing. After blading and compaction operations, do not water the surface.

Curing

Three phases of curing for asphalt-bound FDR projects are identified below and briefly discussed.



Initial Curing

Initial curing is typically a 30-minute to 2-hour period, which provides an opportunity for the surface of the FDR layer to gain sufficient strength and cohesion to resist the abrasive action of traffic. Foamed asphalt projects can require less time after mixing and compaction than the emulsified-asphalt-stabilized projects. TxDOT requires an initial cure period of at least 2 hours before opening to traffic on foamed asphalt projects. Proof-rolling can help determine return-to-traffic timing.

If traffic will be placed on asphalt-treated FDR projects, some contractors will use a light fog seal of diluted asphalt emulsion to help resist the abrasive effects of traffic, especially on foamed asphalt projects. Initial curing periods usually depend on the type and amount of asphalt binder used, as well as the environmental conditions and the moisture content of the FDR layer after compaction. A prime coat is not recommended since the solvent can soften the asphalt in the completed FDR layer as well as delaying the curing process.

Intermediate Curing

Intermediate curing is used to gain strength in the asphalt-treated reclaimed material. During this period, moisture needed for mixing and compaction is allowed to escape from the recycled material, and strength gain occurs. This moisture must escape from emulsified asphalt and foamed asphalt projects before any surfacing materials are placed.

Typical periods for intermediate curing are a few days to 2 weeks. The roadway is normally required to carry traffic during this curing period.

TxDOT indicates that intermediate curing should continue until the moisture content is at least 2% below the optimum moisture content for an asphalt emulsion FDR project before applying the next successive paving course.

Final Curing

Final curing is the period for the FDR material to reach its ultimate strength. This will normally take months, depending on several factors. The loss of mixing and compaction moisture is key to strength gain. Wetting of the layer while it is in service can cause loss of strength during this period. FWD data pertaining to emulsified-asphalt- and foamed-asphalt-stabilized FDR projects indicate that substantial strength gain typically occurs within 30 to 60 days.

Surfacing Materials

Typical surfacing materials used on FDR asphalt-stabilized projects include surface treatments, seal coats and hot-mix asphalt layers. **It is recommended to not use prime coats with solvents because of potential softening of the asphalt.** These layers should be placed on the surface of the FDR materials as soon as practical but not before the required degree of intermediate curing has occurred. Bonding of the surfacing material to the FDR layer is critical to the success of the project. A light application of emulsified asphalt tack coat should be applied between the FDR layer and the surface layers.

If a seal coat is used directly on the FDR surface, a light shot of water followed by thorough brooming just before application of the seal will aid adhesion. Asphalt emulsion typically works best for the seal because of fine aggregate on the surface of the FDR layer.

QC/QA

Staffing Requirements

Before beginning the FDR project, the contractor must provide on-site staff with at least 2 years of experience in supervising TxDOT FDR recycling projects using either asphalt emulsion or foamed asphalt, depending on which type of binder is used on the project. This person should be identified at the preconstruction meeting. Also, a field specialist certified by TxDOT's approved Soils and Base Certification Program is required to perform all sampling and testing on the project.

Preconstruction Meeting

A preconstruction meeting of TxDOT and contractor personnel is not required by the specifications but is highly recommended to discuss safety, construction operations and QC/QA at minimum. This meeting should be scheduled before the control section is placed.

Control Section

The control section is required to demonstrate the contractor's capability to meet the project specifications with equipment and materials that will be used on the project. The control section will be one lane width and at least 300 feet long to the depth required on the plans. Sampling and testing will be performed by the contractor and witnessed by the engineer. Use one asphalt transport for this section.

The nuclear gauge used for the project should be calibrated for in-place density and moisture content measurements (Test Method Tex-115-E, Part 1). Moisture content will be determined in samples from the control section using Test Method Tex-103-E (oven method) and Tex-115-E, Part I (nuclear gauge). This moisture testing of the control section will provide a correction factor for the nuclear gauge moisture content (Appendix D) because the nuclear gauge will detect the asphalt binder as moisture.

Material Sampling and Testing

Table 1 shows the **minimum** TxDOT QA testing and contractor QC testing requirements. Additional testing can be helpful.

Table 1: Minimum TxDOT QA Testing and Contractor QC Testing Requirements.

Measurement		Engineer's QA Testing Frequency	Contractor's QC Testing Frequency[1]
Description	Test Method		
Gradation	Tex-101-E, Part III	One per 3,000 cubic yards or one per lift	One per day of production
Density	Tex-115-E or Ordinary Compaction	One per 3,000 cubic yards or one per lift[2]	–
Moisture content	Tex-115-E	One per 3,000 cubic yards or one per lift[2]	–
	Tex-103-E	–	Three per day of production[3]
Depth	Tex-140-E	One per 3,000 cubic yards or one per lift	One per day of production
Asphalt emulsion or foamed asphalt content	Meter readings or truck weight tickets	–	One per day of production
Water for foamed asphalt	Meter reading	–	One per day of production

[1] Identified as process control testing in specifications.
[2] After mixing and compaction.
[3] Before mixing.

Asphalt Emulsion and Asphalt Cement

The asphalt emulsion or the asphalt cement used in the FDR process will be sampled and tested by TxDOT at least once per project. The asphalt binders must be provided by an asphalt producer that participates in TxDOT's Asphalt Binder Quality Program. TxDOT is required to sample the asphalt binder at least once daily during project construction. These samples will be held for future testing as needed.

Additives

TxDOT will sample and test additives used in FDR projects at least once per project and/or use TxDOT Quality Monitoring (WM) Programs. Additives include lime, Portland cement and fly ash. Specifications for these products are contained in Departmental Material Specification requirements.

Gradation

If the gradation fails to meet the specification, construction operations will be modified until the engineer's test result meet specifications. The intent is to ensure that the reclaimer pulverizes the asphalt-bound layers adequately.

Density and Moisture

The moisture content determined by the nuclear gauge on the recycled material (recycled pavement materials, corrective additive, stabilizer and additive) is not the same moisture content as measured by the contractor on the pavement materials and corrective aggregate before the addition of the stabilizer and additive.

The reference density is that established during mixture design for samples that are mixtures of recycled pavement materials, additional materials, stabilizer and additives at the design stabilizer content and compacted with Test Method Tex-113-E. Although not required by the specifications, some contractors sample and compact the recycled material after mixing and compact with Test Method Tex-113-E to establish a target density that can more accurately represent field conditions. Field processing often causes various gradations of materials that are being recycling, and project variability along a project causes changes in the density from the laboratory mixture design density. This issue should be addressed during the preconstruction meeting.

Asphalt Binder Content

Check periodically to ensure that a transport covers the calculated distance required. When using foamed asphalt, the water content needed for foaming is also determined by meter readings. If changes are needed in asphalt binder content, this must be approved by the engineer.

Foaming Qualities

QA/QC (process control) for foam FDR projects should also include field checks on half-life and expansion ratio to ensure effective mixing characteristics. Half-life describes the stability of the foam and is the time required for the foam to reduce to half its maximum volume. Expansion ratio describes the dispersion properties of the foam and is the ratio of the maximum foam volume to the original asphalt volume.

Summary

FDR projects process existing roadbed materials that may be variable. Establishing mixture designs and maintaining quality in the field for materials that vary is difficult. Therefore, having attention on the things we can control is of utmost importance.

The mixture design process provides information for field QC and QA programs. Additional mix designs may be provided to account for material variability in the field. Optimum moisture content, treatment rate and dry density are important parameters from the laboratory mixture design process that should be provided to field personnel.

FDR field tests of high importance during construction QC include asphalt binder quantity, moisture content and density of recycled material. Nuclear gauge moisture and density reading should be compared to laboratory compacted density obtained from field-processed materials using Test Method Tex-113-E. Proof-rolling also provides valuable information.

The contractor “process control” testing will not be used for acceptance. The contractor sampling and testing will be used for controlling the construction process.

Volumes and weights of materials processed and asphalt binder contents should be determined regularly. Asphalt binder temperature for emulsified asphalt and the asphalt cement in foamed asphalt operations should be checked frequently. Foaming of the asphalt binder depends on the asphalt binder temperature, among other factors.

Weather conditions and forecasts should be checked frequently. Surface temperatures should be recorded to ensure compliance with specifications.

FDR with Asphalt Binders can be challenging even for the experienced practitioner but with proper care and attention to detail savings in both time and money can be realized for the Department and the traveling public.

APPENDIX A

TROUBLESHOOTING FDR WITH ASPHALT BINDERS

Considerations:

1. Design Process
    a. Is the job a good candidate? (Too many fines, inadequate base material/depth, PI >10)
    b. Sampling for design: Check depth of base, appearance of subgrade in at least 2 "typical" locations. Identify potential variability of materials across project limits. See TxDOT treatment guidelines for recommended sampling plans.
    c. Determine QC process (outside lab or visual approach).
    d. Treatment depth: Keep depth 1" to 2" above subgrade.
    e. Mix design should provide pretreatment target moisture and asphalt binder (asphalt emulsion or foamed asphalt) treatment rate.
    f. Will any of the existing pavement be removed and replaced before mixing? Mix designs should be run on the actual anticipated materials that will be mixed.
2. Construction
    a. Moisture considerations: Prior to mixing check moisture content per TxDOT and calibrated hand squeeze technique. Post mixing: Remember that nuclear density gauge will read asphalt as moisture. Calculate correction factor by comparing nuclear results to TxDOT moisture (Tex-103-E).
    b. Reclaimer must meet specification horsepower requirements and include injection system for emulsions or foam as applicable to the project.
    c. Watch mat behind reclaimer to check for streaking to indicate nozzle issues. For emulsion projects, nozzles should have water run through them at the end of each day and be "solvent-soaked" at the end of the week.
    d. Injection systems for foamed asphalt should include an automatic nozzle cleanout feature. The injection system filter should be checked and cleaned daily.
    e. Watch material behind reclaimer for signs of subgrade/clay soils. If subgrade/clay is visible in the mix, the mixing depth is too deep.
    f. Density: Start heavy vibratory padfoot roller immediately after reclaimer and make sure it "walks out" of material in vibratory mode.
3. Misc.
    a. Additive (cement, lime, fly ash) may be needed per mix design. If the design does not call for an additive and rutting is observed in treated section the next day, consider adding additive to the process.
    b. Check project drainage before project and make recommendations for any needed corrections. FDR will not fix saturated subgrades/base courses.

Corrective Measures:

Problem: Mix became stiff quickly (+50% RAP)

- The width of reclaimer is 8 feet wide and the grader blade 14 feet wide. Therefore, after mixing the first pass, set back and mix the adjacent pass so that grader can start to work.
- Mix could become too stiff to work with the blade if waiting too long to start finishing operations.
- Split the road into thirds and cover the entire road so the blading operation can start earlier.

Problem: The material is too wet before mixing

- Aerate material before mixing.
- If 100% gravel, loosen material with the motor grader.
- If chip seal/HMA on top of gravel, use reclaimer or motor grader to loosen and aerate the materials.
- Recheck moisture. Continue aeration until moisture reaches required level before mixing.

Problem: Soft areas due to moisture before mixing

- It needs to be aerated or subgrade moisture is pumping up into base.
- Open the localized area either with the reclaimer or the motor grader and allow to aerate.
- Recheck moisture.
- Import material as last option.

Problem: Soft areas due to poor base or subgrade before mixing

- Should have been addressed during selection process.
- Additional materials could help reduce the impact of poor bases.
- Addition of an additive (cement/lime) could help improve stability.
- If clay is encountered and subbase is too yielding, undercutting and replacing with additional material may be an option, or lime-treat before mixing.

Problem: The material is too dry before mixing

- Add water — SPARINGLY! Use light shots of water.
- Some reclaimers have water injection capabilities.
- Water truck with a spreading bar.
- Reclaim a small section and recheck the moisture.

Problem: Rain while you are reclaiming

- Light/short rain shower: Do nothing.

- Intense/long rain shower: Stop the reclaiming process. Try to give minimum compaction with the steel roller to any loose material.
- Recheck moisture.

Problem: Rutting evident following treatment

- If caused by rainfall during treatment, allow to dry then remix just below rut depth with small amount of asphalt.
- If caused by subgrade moisture wicking up, remix with cement and small amount of asphalt just below rut depth.
- If caused by instability, verify the moisture content and density.

Problem: Too shallow/too deep

- Monitor the thickness of the cut: Reclaimer will have depth indicator.
- Use a measuring tape to double-check the mixing depth.
- Check at the beginning of every day and then randomly throughout the day.

Problem: Time allowance for initial compaction and grading

- Weather-dependent: Hotter and drier will result in less working time.
- Work in defined sections (about 1/8 mile — full-width sections) to remove padfoot marks within 30 minutes to 1 hour.
- Finish grading within 3 hours (or less).
- Intermediate compaction with rubber tire pneumatic.
- Finish compaction using steel wheel.
- Complete all compaction and finishing operations the same day as mixing.

Problem: Too much/too little asphalt

- Ensure asphalt/emulsion is ±1% from target (mix design).
- Measure asphalt content by how far the first truck covered.
- Double-check asphalt content (yield check).
- Double-check depth.
- Too rich/free asphalt: Reduce asphalt content with engineer’s approval.
- Poor dispersion and coating: Increase RPM of milling head and/or reduce the speed of the reclaimer. If this is not enough, increase the asphalt % with engineer’s approval.
- For foamed asphalt, check asphalt temperature, expansion ratio and half—life.

Problem: Potential swelling and haul-off

- Dependent on existing bituminous thickness (the greater the bituminous, the greater the swelling).
- As much as 1/8 inch per inch in 100% bituminous.
- As little as no swelling in 100% granular.
- To maintain curb height: pre-mill, crown adjustment, post-mill.

Problem: Significant slope/grade change is needed

- Should be completed before mixing asphalt.
- Adjust high and low spots; restore crown and cross-slopes.
- Check that the layer to be recycled is consistent between the center and edge of pavement. Must be consistent with the mix design.

Problem: Big chunks of RAP/top size too large

- Reduce speed of reclaimer.
- Increase the RPM of milling head if possible.
- Close the front and back gates of the mixing chamber.
- If the existing pavement has extensive cracking, might consider pre-pulverization or milling.

Problem: Wait too long to compact or blade

- Do not wait more than 30 minutes to start compaction with the vibratory padfoot roller, in most cases as quickly as 1 minute after mixing begins.
- Use the control strip to set a compaction rolling pattern.
- Start blading as soon the pad foot “walks out” of the section and there is enough room for the blade to operate efficiently.

APPENDIX B

FDR FIELD SUPPORT LIST

Pre-Letting
Must-Do's:

- ❑ Visit road to determine whether it is an actual candidate. Take pictures. Follow TxDOT treatment guidelines.
- ❑ Obtain representative materials and run preliminary tests (gradation, % passing #200, Atterberg limits).
- ❑ Evaluate supply source, base stock and asphalt binder availability. (Where to ship asphalt from? What is the base AC?)
- ❑ Evaluate available contractor capabilities (level of experience) and equipment.
- ❑ Develop pavement strategy, gather roadway samples and perform mix design.

Good to Do:

- ❑ Obtain records of pavement: original construction and maintenance.
- ❑ Obtain soil information if geotechnical work is/was performed.

Preconstruction
Must-Do's:

- ❑ Some of the pre-letting items and construction items above may apply here.
- ❑ Visit jobsite: Assess any potential problems; take pictures before startup.
- ❑ Obtain samples (cores and/or base materials and/or additional materials): Ensure that the materials are gathered according to sampling guidelines.
- ❑ Determine whether geotechnical work should be performed.
- ❑ Confirm supply sources. (Verify where the asphalt binder is coming from.)
- ❑ Determine whether material will be added to thin areas (or may need to be determined from mix design).
- ❑ Perform mix design(s) using the actual materials proportioned for site conditions.
- ❑ Attend preconstruction meeting during which the mix design should be reviewed and discussed as well as mixing operations plan (cut plan).
- ❑ Confirm asphalt equipment systems (reclaimer, support trailers) have been flushed and fitted with appropriate connections before starting project.
- ❑ **Make sure support trailers and asphalt transports have appropriate pintle hitches.**

Construction
These should be reinforced at the preconstruction meeting and monitored during construction.
Must-Do's:

- ❑ Production:
  - Asphalt binder temperature, compatibility issues, storage and handling.

- Asphalt binder for the project meets the material requirements as defined within the specification.
- If emulsion is stored in a contractor’s tank, make sure flushing issues are discussed!

❑ Reclaimer/train:

- Confirm pump and meter can handle the asphalt binder content and the depth being processed. Make sure the reclaimer has automatic control of flow rates according to depth, machine speed and material density.
- Confirm water meter is working (train) for water trucks, one pass = about 1% increase.
- The minimum required power for the reclaimer is 400 horsepower for emulsion and 600 horsepower for foam.
- Ensure uniform distribution of asphalt binder across width and that nozzles are not plugged.

❑ Process control on the project: Review specification and/or bid document to determine responsibility for process control testing:

- Pull sample to check maximum aggregate size.
- Verify moisture content before mixing asphalt binder: Pull sample (two) and perform moisture content in accordance with Tex-103-E.
- Verify correct asphalt binder content is being used. Verify at the start of each day truck weight tickets vs. length, width and depth treated.
- Asphalt binder temperature is within parameters:
  - Asphalt emulsion: 120 degrees F or less.
  - Foamed asphalt: generally 330 to 360 degrees F in transport, no less than 320 degrees F when injected through reclaimer.
- Verify cutting depth (inside and outside cut).
- Although not required by the specification, field proctor preparation is a very helpful practice. Prepare field Proctor samples on the project site to obtain dry density values. At least two samples during first day of mixing asphalt binders.
- A significant discrepancy between field proctor density and lab-reported (Tex 113-E) max density should trigger a lab (Tex 113-E) verification of the moisture-density properties of the material.
- Record data on appropriate data sheets.

❑ Spreading/compaction:

- Initial compaction is provided by an 18-ton (minimum) vibratory padfoot roller, applying high-amplitude and low-frequency vibration. The vibratory padfoot should work an area until it “walks out” before moving forward and should be no more than 500 feet behind the reclaimer.
- Confirm material is being spread by motor grader within 15 minutes of being placed in windrow (for train operation).

- After the completion of the initial compaction, remove any remaining padfoot roller marks using a motor grader cutting just below the depth of the padfoot marks. Do not use fines to fill in padfoot marks.
- A 20-ton pneumatic roller should be rolling the material behind the motor grader for intermediate compaction, and a 10-ton double-drum vibratory steel roller in static mode is used for final compaction. Water spray system working is preferred for both rollers.
- Do not finish-roll in vibratory mode.
- Water truck will be available for addition of light moisture if necessary.
- Monitor rolling occasionally to check that rollers are working correctly (no sticking, and water systems working) and the correct number of passes is being applied by each roller (determined from nuclear density or other testing).

❑ Other:

- Take pictures/video/notes during the construction.
- Always compare process control results to the specification requirements.

Post-Construction

❑ Before placing any surfacing, the reclaimed base must be allowed to cure:

- For asphalt emulsion, until the moisture content in the materials is 2.0% below OMC.
- For foamed asphalt, a minimum of 2 hours.

APPENDIX C

EXAMPLE QC DATA SHEET
(USE ONE OR MORE DATA SHEETS PER DAY)

Information

Date:	Project/location:
QC personnel:	Phone:
Temperature at start of day:	Temperature at end of day:
Climate conditions:	
Other notes:	

Results of mix design

Optimum moisture content (OMC) from Modified Proctor	
Density at OMC	
Recommended field moisture range	Recommended emulsion content

Add rock or dry additive

Station/location						
Type and source						
Length, ft						
Width, ft						
Weight, lb						
Rate, lb/SY						

Nuclear density testing

Location	Station	Wet density, pcf	Moisture, %	Dry density, pcf	Notes
Proctor density					
Operator	Gauge model	Gauge serial #			
Final roller pattern:					

❑ Density measurements not required. Final roller pattern:

Material tests

Station/location						
Size (Sec. 3.3) — 1.75"						
Size (Sec. 3.3) — 0.75"						
Moisture content, % (Section 3.4)						
Emulsion content, % (Section 3.5)						

Other Comments:

Reported by:____________________________

APPENDIX D

MOISTURE CORRECTION FOR NUCLEAR DENSITY GAUGE

Moisture and Density Determination on Cold-In-Place Asphalt Cement Concrete Recycling with Asphalt Emulsion

Apparatus:

- Laboratory Sampling Flat Scoop
- Freezer Plastic Bags
- Balance
- Round Pans
- Microwave Oven or Single-burner Field Stove
- Nuclear Gauge
- Ruler
- Marker

Procedure:

A. Pavement Sampling for in-place moisture

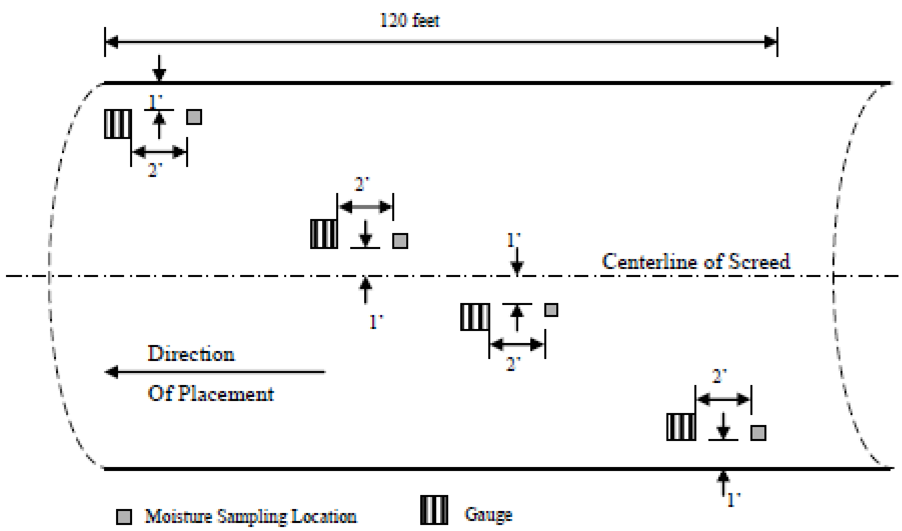
1. Samples shall always be taken behind the laydown machine before the material receives any compaction. Sampling shall be distributed over a length of approximately 120 feet.

2. The samples shall be obtained using a flat scoop by straight it down through the entire depth of the mat being laid. The materials shall be placed in a tied plastic bag. The plastic bag shall be marked.

3. Samples shall be taken to represent a cross section of the mat as follows:

   A minimum of four samples for in-place moisture shall be taken. On approximately 1 foot (0.30 meters) in from the left edge of the mat, one approximately 1 foot left of the center of the screed, one approximately 1 foot right of the center of the screed, and one approximately 1 foot in from the right edge of the mat. The gauge reading shall be taken 2 feet in front of every location of the sampling for in-place moisture.

<u>SAMPLING DIAGRAM</u>



B. Roadway Testing Procedure:

1. Sample approximately 600 grams of recycled ACC at each test location to determine the in-place moisture content. The moisture content on the sample in the field is determined by drying the entire sample to a constant dry mass in a small oven no to exceed 135°C (275 F) or a single-burner field stove.

   Moisture determination will be calculated using the following formula:

   $$\% \text{ MOISTURE} = \frac{(\text{WET MASS SAMPLE} - \text{DRY MASS SAMPLE})(100)}{\text{DRY MASS SAMPLE}}$$

   NOTE: All weighing of the sample shall be recorded to the nearest 0.5 gm.

   Example:

   Given Wet Mass Sample = 980 gms
   Given Dry Mass Sample = 951 gms

   $$\% \text{ MOISTURE} = \frac{(980 - 951)(100)}{951} = 3.0\%$$

2. Using the nuclear gauge moisture content measurements and the in-place moisture content measurements, determine a correction factor to apply to the subsequent nuclear gauge moisture measurements after at least 4 tests are taken.

   Determine correction factor in kg/m^3 (lb./ft.^{3}) using the following formulas:

   Actual in-place moisture in kg/m^3 (lb./ft.^{3}) (minimum of 4 sites):

   $$\text{Actual Moisture} = \frac{(\% \text{ MOISTURE})(\text{GAUGE WET DENSITY})}{\% \text{ MOISTURE} + 100}$$

   Example:

   Gauge Wet Densisty = 2090.6 kg/m3 (130.5 lb./ft.3)
   % Moisture = 3.0 %

   $$\text{Actual In-Place Moisture} = \frac{(3.0)(2090.6)}{3.0+100} = \frac{6271.8}{103.0} = 61 \text{ kg/m}^3 = \frac{(3.0)(130.5)}{3.0+100} = \frac{391.5}{103.0} = 3.8 \text{ lb./ft.}^3$$

   Correction factor in kg/m^3 (lb./ft.^{3}):

   Determine the average of 4 (or more) actual moisture contents obtained using the above equation.

   Determine the average of 4 (or more) gauge moisture readings obtained at moisture sample sites.

   CORRECTION FACTOR = AVG GAUGE MOISTURE – AVG ACTUAL MOISTURE

Average of gauge Moisture	185.8	11.6
Average of Actual In-Place Moisture	- 57.7	- 3.6
Correction Factor	128.1 kg/m^3	8.0 lb./ft.^{3}

This correction factor may seem large due to the fact that the nuclear gauge measures both asphalt and water in the moisture reading. The following is an example (in English Units) of a field book entry for showing the determination of a correction factor:

GAUGE WET DENSITY PCF	GAUGE MOISTURE CONTENT PCF	WET WEIGHT OF SAMPLE	OVEN DRY WEIGHT OF SAMPLE	PERCENT MOISTURE (W1-W2)/W2*100 %	ACTUAL IN-PLACE MOISTURE CONTENT (PCF)	CORRECTION FACTOR PCF
130.5	10.5	1250	1222	2.3	2.9	7.6
129.5	11.3	1390	1345	3.3	4.1	7.2
131.4	11.7	1268	1233	2.8	3.6	8.1
128.9	12.8	1111	1078	3.1	3.9	8.9
AVG=130.1	**11.6**			**2.9**	**3.6**	**8.0**

<u>NOTE:</u> Any significant change in the characteristics or components of the surface of the surface being recycled requires a new correction factor to be established.

3. Determine the dry density of each subsequent test location using the formula:

   DRY DENSITY = GAUGE WET DENSITY – GAUGE MOISTURE + CORRECTION FACTOR

   <u>Example:</u>

Field Compacted Gauge Wet Density	2090.6	=	130.5
Gauge Moisture	-168.2	=	-10.5
Correction Factor	<u>+128.1</u>	=	<u>+8.0</u>
FIELD COMPACTED DRY DENSITY	2050.5 kg/m^3	=	128.0 $lb./ft^3$