
Full Depth Reclamation

A. General

Full depth reclamation (FDR) is a pavement rehabilitation technique in which the full depth asphalt pavement section and a predetermined amount of the underlying materials are uniformly crushed, pulverized, or blended, resulting in a stabilized base course that may be further enhanced through the use of additives.

FDR conserves existing sources since the existing pavement materials are incorporated into the base materials to form a new base. In some instances, a portion of the blended materials will need to be removed from the site if elevation restrictions are involved. FDR is distinguished from other pavement rehabilitation methods by the fact that the cutting head penetrates completely through the asphalt pavement section into the underlying subgrade or subbase. FDR can be utilized to depths up to 18 inches, but reclaimed depths of 6 to 12 inches are more typical.

Pavement distresses that can be addressed by FDR include:

- Excessive cracking of all types
- Surface deformations such as rutting, shoving, depressions, and patches
- Inadequate structural capacity and subgrade instability
- Loss of bond between pavement layers
- Corrections to roadway geometry
- Flexural distress in the wheel paths

By pulverizing the existing asphalt pavement and the underlying materials to build and strengthen the base, FDR rehabilitates the roadway without the need to change elevations or increase right-of-way widths. The reclaimed pavement alone can often serve as the base for the new surface course. If there is a need to improve the reclaimed materials, there are three methods of stabilization that can be used:

- Mechanical
- Chemical
- Bituminous

Mechanical stabilization is accomplished through the addition of new aggregates or recycled asphalt or crushed concrete pavements. Bituminous stabilization involves the addition of emulsified asphalt or foamed asphalt. Chemical stabilization adds cement, lime, Class C fly ash, cement kiln dust, lime kiln dust, calcium chloride, magnesium chloride, or proprietary products. FDR performance may be enhanced with a combination of stabilizing materials.

Full depth reclamation is an effective rehabilitation strategy if the asphalt roadway exhibits the following conditions:

- Problems with subbase/subgrade to the point of cracking and rutting are occurring
- Damaged pavement that is beyond resurfacing
- Repair strategy would involve in excess of 20% of the pavement requiring full depth patching
- Current pavement is inadequate for future traffic loading
- Corrections to geometrics are needed and can be accomplished within vertical constraints present in the roadway

B. Pavement Assessment

Basic information about the existing pavement is important to the FDR process. This includes the thickness of the asphalt pavement, the type and content of the asphalt binder, the aggregate gradation, the soil plasticity, and presence of any unusual elements such as fabrics in the existing pavement.

The presence of larger surface patches is also critical since it may affect the consistency of the reclaimed material. Patches may also indicate locations of poor drainage or poor subgrade support that may need to be specifically addressed as part of the rehabilitation project.

Two elements of structural capacity must be determined. The first relates to the ability to support the future traffic loading. The second relates to the ability of the underlying subgrade to support the construction equipment. In the thickness design process, the reclaimed material is considered a stabilized base. The structural layer coefficients for a bituminous stabilized base range from 0.20 to 0.30. If a combination of bituminous and cement or Class C fly ash are used as stabilizers, the layer coefficient will be higher. Cementitious materials if used as stabilizers alone will have layer coefficients ranging from 0.20 to 0.27 depending on the product and amount used. Lime will be on the lower end of the range.

In order to determine the strength of the underlying subgrade to support the construction processes, the existing subgrade needs to be analyzed with either a dynamic cone penetrometer (DCP) or a falling weight deflectometer (FWD). These test results should be obtained when conditions are similar to when the construction is expected to take place so they will be representation of the actual support values for the equipment.

Some of the underlying materials should be incorporated into the reclaimed mixture as a means of limiting wear on the equipment, improving productivity, and controlling costs. The determination of how much of the underlying materials to include in the pulverized material is dependent upon the following items:

- Thickness of the asphalt layers compared to the underlying materials
- Gradation of the pulverized asphalt layers
- Gradation of the pulverized underlying materials
- Whether or not a stabilizing agent will be used
- Which stabilizing agent, if any, is to be used
- Desired structural properties of the FDR section
- Subgrade stability

Field cores or block sampling of the existing asphalt pavement should be completed for each area of similar materials. Those materials should be crushed to produce gradations similar to expectations during the FDR process. The crushed materials will be evaluated during the mix design process.

The roadway geometry should be evaluated to determine if any realignment, lane changes, medians, or other modifications are needed to meet future traffic projections.

A summary flow chart for the project selection process can be found in Figure 3.4 of the *Guide to Full Depth Reclamation (FDR) with Cement*. The designer may chose other stabilizing materials besides cement.

In urban areas especially it is important to identify manholes, vaults, water valves and other structures in the pavement. The critical element is to determine if these structures can be lowered at least 4 inches below the FDR treatment depth. This will allow the reclaiming process to be uninterrupted and the material consistency maintained. If the structures cannot be lowered, the material around the structures must be pulled away and placed so the reclaiming process can be applied to that material. It can later be brought back and placed around the structure.

C. Mix Design

A laboratory mix design should be developed in order to optimize the quantity of stabilizing agent and the physical properties of the reclaimed mixture to meet the project requirements. The mix design will identify the need for a stabilizing agent, the type and percent of stabilizing agent, the recommended water content, and the type and amount of additives, if any is needed. From this information, a job mix formula is developed.

Currently there are no national standards for design of FDR mixtures. If mechanical stabilizers such as recycled asphalt pavements (RAP) are to be added, no mix design is necessary. The only thing needed to be determined is the optimum moisture content and the maximum dry density of the modified reclaimed material.

FDR mix designs should include the following:

- Obtain field samples of the existing asphalt pavement, base and underlying subgrade materials, and crush to generate RAP
- Determine gradation and plasticity index for the RAP materials
- Determine need for stabilizing agents and additives needed to meet structural requirements
- Determine dry density and optimum moisture content
- Mix, compact, and cure samples with varying amounts of stabilizing agent
- Test mixtures for strength and durability
- Establish job mix formula

The top size of the mixture gradation should not exceed 25% of the depth of the compacted reclaimed layer.

The properties of the FDR layer are highly dependent on the properties of the asphalt pavement layer, the subgrade, the stabilization materials used, and the thoroughness of mixing, compaction, and curing.

D. Stabilization Methods

If pulverization and compaction of the existing pavement and underlying materials does not meet the structural needs of the project, additional methods of stabilization will be necessary. There are three different types of stabilization.

1. **Mechanical:** If the pulverized material is either too coarse or has too many fines, then the appropriately sized granular material can be added to the mix to create a well-graded material. The granular material can be virgin crushed aggregates, asphalt grindings, or crushed concrete.

The existing roadway geometry, including curb heights and bridge elevations may limit the amount of granular material that can be added. If elevation restrictions are encountered, additional work to remove some of the pulverized material prior to adding the granular material should be undertaken. If pulverized material is to be removed, it may be necessary to undertake additional gradation evaluations prior to adding finally the granular material.

The mechanical stabilizer material can be added by spreading ahead of the pulverization pass or incorporated into the blending pass after pulverization and shaping. Spreading prior to pulverizing will likely create a more uniformly blended FDR.

2. **Chemical:** Chemical stabilization includes the use of cementitious products to increase the strength of the reclaimed mix. Typically these mixes use cement, lime, Class C fly ash, Class F fly ash with other additives, cement kiln dust, lime kiln dust, calcium chloride, magnesium chloride, or proprietary products.

Although most subgrade materials have very little chemical impact on the performance of the FDR, soils with certain characteristics can disrupt the hydration process. When the pH is lower than four, the cement may not react properly and will not bond the particles of the FDR together.

Sulfate-induced heave can result from the expansive material ettringite, which is formed when lime or cement reacts with clay, sulfate minerals, and water. This should not be problematic if the soluble sulfate content is less than 3,000 ppm.

Additional cement may be required if the organic content of the FDR layer is 2% or greater.

Atterberg limits should be performed on the soil to determine the plasticity of the materials on the site. Highly plastic soils may require special treatments.

The required chemical stabilization application rate is the rate needed to improve the strength, durability, and moisture sensitivity of the reclaimed mixture without causing excessive dry shrinkage cracking.

The chemical stabilizing additives can be applied by spreading ahead of the pulverizing process in dry powder form or can be disbursed in slurry form, on the ground ahead of the pulverizer or through a spray bar integrated into the reclaimer's mixing chamber.

The use of calcium chloride and magnesium chloride can also be accomplished in dry or liquid form. These products do result in some strength gain, but the more important result is the lowering of the mixtures freezing point, which helps reduce cyclic freeze/thaw events.

- 3. Bituminous:** Bituminous stabilization involves the use of emulsified asphalt or foamed asphalt. These liquids can be blended into the reclaimed material through the reclaiming machine's integrated liquid injection system either during the pulverization pass or a subsequent blending pass if a multiple pass process is employed.

After blending of asphalt emulsions with the pulverized material, there is a period of time in which the emulsion "breaks". This involves the point at which the water dissipates from the emulsion and the bitumen droplets rejoin, thus reverting to a continuous film that coats the reclaimed material particles. It is important to begin the breakdown compaction as soon as the emulsion breaks.

The other asphalt material used to stabilize the mix is foamed asphalt. Asphalt foaming occurs when small amounts of water come into contact with hot asphalt. The main advantage of using foamed asphalt is that there are no additional costs after the initial investment in the foaming apparatus. Foamed asphalt stabilized mixtures can be placed, shaped, compacted, and opened to traffic immediately after mixing. A disadvantage of using foamed asphalt over asphalt emulsions is that foamed asphalt requires a minimum of 5% of fine material passing the No. 200 sieve. If insufficient fines are present, the foamed asphalt does not disburse properly and forms asphalt rich stringers that sit in an unstable state. Small amounts of cement or lime may be added to meet the minus No. 200 fraction.

- 4. Stabilizer Selection:** The characteristics of the reclaimed material must be considered in selecting the stabilizer to be used. Testing of the mixture using the selected stabilizer to determine the correct amount to use in combination with the reclaimed mixture to achieve the required structural strength is required. The following guidelines should be used in the selection process.

Table 5J-3.01: General Guidelines for Selecting Stabilizers for FDR

Type and Typical Trial Percent of Stabilizer	Characteristics of Reclaimed Pavement Materials
Hydrated Lime or Quicklime (2% to 6% by weight)	RAP having some amount of silty clay soil from subgrade with a plasticity index greater than 10.
Class C Fly Ash (8% to 14% by weight)	Material consists of 100% RAP or blends of RAP and underlying base or soil. The soil fraction can have plasticity indices similar to soils acceptable for lime treatment.
Portland Cement ¹ (3% to 6% by weight)	Materials consisting of 100% RAP or blends of RAP and underlying base, non-plastic, or low plasticity soil. There should be sufficient fines to produce an acceptable aggregate matrix for the cement treated base produced, which contain no less than 45% passing the No. 4 sieve.
Emulsified or Foamed Asphalt ² (1% to 3 % by weight)	Materials consisting of 100% RAP or blends of RAP and underlying base, non-plastic, or low plasticity soil. The maximum percent passing the No. 200 sieve should be less than 25%; the plasticity index less than 6 or the sand equivalent 30 or greater; or the product of multiplying the plasticity index and the percent passing the No. 200 sieve is less than 72.
Calcium Chloride	Materials consisting of a blend of RAP and non-plastic base soils with 8% to 12% minus No. 200 material. Small amounts of clay (3% to 5%) are beneficial.

¹ Class C fly ash has been combined with cement in varying ratios for stabilization. Combining of the materials could result in better mix properties at a lower cost than either one used independently.

² Small amounts of cement (1.0%) or hydrated lime (1.5%) can be added with asphalt emulsion to produce mixes with higher early strength and greater resistance to water damage.

E. Construction

Regardless of the type of equipment used by the contractor, the following steps should be completed:

- Pulverizing and sizing of the existing asphalt layers
- Incorporating and mixing of the existing underlying materials
- Applying mechanical, chemical, or bituminous stabilizing agent and additives, if required
- Mixing of reclaimed materials with stabilizing agents and additives, if used
- Breaking down compaction
- Rough grading or initial shaping
- Intermediate compaction
- Intermediate shaping
- Final compaction
- Final trimming or tight blading
- Removing any loose material
- Curing
- Microcracking, if needed
- Applying the surface course

All utilities should be field located according to Iowa One Call laws. Shallow underground facilities should be exposed by pot holing (vacuum excavations) to determine exact elevations to prevent unnecessary accidents from occurring during the pulverization process. Any utilities within 4 inches of the bottom of the reclaimed material should be relocated or lowered. Manholes, valves, and other castings should be lowered to at least 4 inches lower than the anticipated FDR depth. Work to bring the casting to final grade can take place after the surface course has been placed. If it is not possible to lower the structures, the material surrounding the structures can be pulled away to the depth of the FDR treatment and carefully pulverized and mixed with stabilizing agents that can then be replaced and compacted.

The most efficient temperature for proper sizing of the reclaimed material is between 50°F and 90°F. An FDR project should not commence when the air temperatures are below 40°F.

If an FDR project is developed in an urban area, it is important to evaluate the elevation restrictions, especially with curb and gutter. It may be necessary to mill off a portion of the asphalt street prior to pulverizing the remaining portion. The reduction of the RAP will need to be accounted for in the mix design. An alternative method is to pulverize the entire section and then remove the appropriate amount of excess material from the site. This process has the advantage of creating a uniform mixture.

If a stabilizing agent will be added to the mixture, more than one pass of the reclaimer is usually required. The second mixing pass of the reclaimer should maintain a more consistent working speed and thus a more uniform, accurate application of the stabilizing agent. To reduce the risk of a thin layer of untreated reclaimed material being left beneath the stabilized layer, the depth of the pulverizing pass should be 1 to 2 inches less than the mixing pass. The gradation of the pulverized material should be verified to ensure it meets the specified mix design.

Before the mixing pass to add stabilizer, the reclaimed material should be lightly rolled and reshaped as a means to more accurately control mixing depth because the material will be more uniform in depth. The reclaimed material is unlikely to be at the optimum moisture content for compaction. Aeration to dry the material or additional water to moisten it to the optimum point is usually necessary prior to compaction.

Due to the thickness and the material properties of the reclaimed mixture, the compaction rollers are typically large and heavy. Segmented padfoot, vibratory padfoot, pneumatic-tired, and vibratory single or double drum rollers can be used. The degree of compaction achieved has the primary impact on the future performance of the FDR project. The depth of the reclaimed mixture being compacted and specified level of compaction will influence the weight and amplitude/frequency of vibration for the vibratory rollers and the static weight of the pneumatic rollers. The degree of compaction required is typically an average of 98% of Standard Proctor Density with no individual tests being less than 96%. Care should be taken to attain proper compaction without over-compaction. If the FDR layer is over-compacted, aggregate crushing and loosening of the surface layer may occur resulting in a non-uniform and weakened base. Over-compaction can also lead to surface raveling due to premature surface drying.

Correct moisture is critical to achieving proper compaction. A light application of water applied to the surface may be needed prior to final compaction.

The properties of stabilizing agent and additives will dictate the type and length of curing required before the roadway can be opened for traffic and will influence the type and timing of surface course construction. Chemical stabilizing agents require a time of moist cure so they do not dry out and develop severe shrinkage cracks. Moist curing consists of periodic applications of water or placement of a bituminous curing membrane using a diluted emulsified asphalt. If a curing membrane is used, it should be applied as soon as possible but not later than 24 hours after completion of the finishing operations. The dilution rate is up to 60% with water and the application rate for the diluted emulsified asphalt is 0.10 to 0.20 gallons per square yard.

If a cementitious material is used as a stabilizing agent, microcracking is an optional activity. This technique will prevent shrinkage cracking and reduce reflective cracking in the surface course. Microcracking is typically initiated after the surface has gained some initial strength, which is usually after 24 to 48 hours of curing. It is accomplished by a 12 ton vibratory steel drum roller, traveling at a speed of approximately 2 mph and vibrating at maximum amplitude and lowest frequency. Typically, one to four passes are required. After each pass, the stiffness of the FDR section should be checked and activities terminated when a minimum of a 40% reduction is achieved.

An alternative to microcracking is to add a thin (2 inch) interlayer of road stone or a 1 inch, highly polymerized HMA interlayer prior to placement of the surface course. The interlayer will mitigate the potential reflective cracking from the cement-stabilized layer. The use of the interlayer must be considered in the final roadway elevations if the project has vertical constraints.

Field inspection and testing involves the monitoring of five main factors:

- Bituminous and chemical stabilizing agent content
- Moisture content
- Mixing
- Compaction
- Curing

After the FDR section has adequately cured, the surface course can be applied. Surface courses should be applied within 48 hours of the completion of the reclaimed base unless a bituminous membrane is used for curing. Surface courses can range from chip seals and seal coats to thin overlays of asphalt or concrete. In preparation for surfacing, the FDR mixture should be power broomed to remove all loose material from the surface. If an asphalt overlay is to be placed, a tack coat should be applied prior to the overlay.

F. References

Reeder, G.D., Harrington, D., Ayers, M.E., Adaska, W. *Guide to Full-Depth Reclamation (FDR) with Cement*. Portland Cement Association. National Concrete Pavement Technology Center/Institute for Transportation, Iowa State University. 2017.

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