



# Cement Stabilization of Unpaved Roads

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<p><b>Abstract:</b></p> <p>In an effort to address the local citizens' preference for preserving existing gravel roads, personnel of the Northern Virginia District of the Virginia Department of Transportation (VDOT) have been exploring various options for improving the effectiveness of current maintenance practices. The purpose of this study was to explore the effectiveness of chemical stabilization practices on unpaved roads. A 550-ft-long segment of Hurley Lane, a gravel road in Loudoun County, was selected for testing. Traffic counts measured by VDOT personnel in early 2016 indicated approximately 340 vehicles per day, including 3% trucks.</p> <p>The construction technique known as full-depth reclamation (FDR) was used. The existing unpaved road section was pulverized to a depth of 12 in and subsequently blended with 5% cement by weight using road reclaiming equipment. The surface was then covered with a double chip seal. The main objective of this project was to provide stability while still maintaining the appearance and "feel" of a gravel road.</p> <p>Construction was completed in mid-November 2015, and problems with surface durability became evident approximately 3 months later. Excessive rutting and soil contamination at the surface were observed. Follow-up field testing was conducted to determine the cause of failure. A falling weight deflectometer was used to measure the response of the road section to impulse loads. Test results and visual observation indicated that the lack of durability of the chip seal was the most likely cause of substandard performance. Prior to stabilization, the test section at Hurley Lane required frequent maintenance activities. The need for extensive road maintenance decreased substantially after completion of the project, indicating that the underlying cement-stabilized road section was performing adequately.</p> <p>The study concluded that cement stabilization using the FDR approach is a viable option for improving some unpaved roads. It can be particularly attractive in situations where placement of conventional cement-treated aggregate is impractical because of time constraints on delivery.</p> <p>The study recommends that VDOT consider using FDR with chip seal surfacing for maintenance of areas identified as maintenance nuisance (each road segment under 0.1 mile long) and for roads qualified under the Rural Rustic Road Program (designed to keep a traditional rural lane appearance while improving the riding surface within the current right of way). FDR projects need to be planned adequately and monitored during construction. Particular attention should be directed to field testing of compaction, weather-related limitations on construction activities, and chip seal application procedures. The study also recommends the use of a falling weight deflectometer to prioritize maintenance needs.</p>				

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## ABSTRACT

In an effort to address the local citizens' preference for preserving existing gravel roads, personnel of the Northern Virginia District of the Virginia Department of Transportation (VDOT) have been exploring various options for improving the effectiveness of current maintenance practices. The purpose of this study was to explore the effectiveness of chemical stabilization practices on unpaved roads. A 550-ft-long segment of Hurley Lane, a gravel road in Loudoun County, was selected for testing. Traffic counts measured by VDOT personnel in early 2016 indicated approximately 340 vehicles per day, including 3% trucks.

The construction technique known as full-depth reclamation (FDR) was used. The existing unpaved road section was pulverized to a depth of 12 in and subsequently blended with 5% cement by weight using road reclaiming equipment. The surface was then covered with a double chip seal. The main objective of this project was to provide stability while still maintaining the appearance and "feel" of a gravel road.

Construction was completed in mid-November 2015, and problems with surface durability became evident approximately 3 months later. Excessive rutting and soil contamination at the surface were observed. Follow-up field testing was conducted to determine the cause of failure. A falling weight deflectometer was used to measure the response of the road section to impulse loads. Test results and visual observation indicated that the lack of durability of the chip seal was the most likely cause of substandard performance. Prior to stabilization, the test section at Hurley Lane required frequent maintenance activities. The need for extensive road maintenance decreased substantially after completion of the project, indicating that the underlying cement-stabilized road section was performing adequately.

The study concluded that cement stabilization using the FDR approach is a viable option for improving some unpaved roads. It can be particularly attractive in situations where placement of conventional cement-treated aggregate is impractical because of time constraints on delivery.

The study recommends that VDOT consider using FDR with chip seal surfacing for maintenance of areas identified as maintenance nuisance (each road segment under 0.1 mile long) and for roads qualified under the Rural Rustic Road Program (designed to keep a traditional rural lane appearance while improving the riding surface within the current right of way). FDR projects need to be planned adequately and monitored during construction. Particular attention should be directed to field testing of compaction, weather-related limitations on construction activities, and chip seal application procedures. The study also recommends the use of a falling weight deflectometer to prioritize maintenance needs.

## **FINAL REPORT**

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## **INTRODUCTION**

At the beginning of the 20th century, Virginia's highways consisted of an assortment of deeply rutted county roads (Virginia Department of Transportation [VDOT], 2006). Today, VDOT is responsible for maintaining a statewide network of approximately 58,000 miles of interstate, primary, and secondary roads. This is the third largest highway system in the United States.

There are approximately 9,500 miles of VDOT-maintained unpaved secondary roads in Virginia (Schuler et al., 2015). Gravel surfacing is a commonly accepted practice in sparsely populated rural areas. In some parts of Northern Virginia, gravel roads, when subjected to high traffic volumes, require frequent and intensive upkeep by VDOT maintenance crews.

Although asphalt paving may be considered an appropriate engineering solution for many gravel roads, there are numerous instances where the prevalent public opinion is to maintain the natural rustic character of a rural area. In an effort to address the local citizens' preference for preserving existing gravel roads, personnel in VDOT's Northern Virginia District have been exploring various options for improving the effectiveness of current maintenance practices. The main focus of this effort has been to stabilize gravel roads without affecting their original layout and appearance.

## **PURPOSE AND SCOPE**

The purpose of this study was to explore the effectiveness of chemical stabilization practices on gravel roads in Loudoun County, Virginia. Recently, maintenance personnel of VDOT's Leesburg Residency have been experimenting with the use of cement-treated aggregate (CTA). Field performance varied and additional options were sought to improve the outcome. An alternative means of cement stabilization through the full-depth reclamation (FDR) process was considered. A typical FDR project involves rehabilitating an existing asphalt pavement by pulverizing and then stabilizing the pavement section to some predetermined depth. Stabilizing agents can be hydraulic (portland) cement, lime, fly ash, bitumen, or other additives designed to increase structural capacity. The stabilized layer becomes a base or subbase for new pavement structure. This recycling approach allows for economical rehabilitation of deteriorated pavements by eliminating the need to deliver additional material (Diefenderfer and Apeageyi, 2011).

Although FDR has been used on Virginia's paved roads, there has been very little field experience with FDR applied to unpaved roads. The researchers decided to experiment with the FDR method on an approximately 550-ft-long section of a gravel road in Loudoun County. The objective was to identify optimal construction practices under challenging field conditions. A similar effort, involving unpaved road stabilization using FDR with different stabilizing agents, was previously carried out on Old Wheatland Road in Loudoun County (Bushman et al., 2004). No protective chip seal layer was applied in that study, and the results indicated a need for further investigation. Personnel of VDOT's Northern Virginia District approached the Virginia Transportation Research Council (VTRC) with a request for technical assistance with the project evaluation.

The scope of this study included documenting the construction methods and assessing post-construction performance. Although it was recognized that constructing a longer test section would be more economical on a unit-cost basis, the primary concern was to mitigate the extent of potential damage if field problems developed.

## **METHODS**

To achieve the study objectives, seven tasks were conducted:

1. The location of a suitable test section was identified.
2. The underlying geology of the site was identified.
3. A suitable stabilization method and parameters were selected.
4. Contract procurement for the FDR work was executed.
5. The test section was constructed.
6. Fieldwork was monitored, and materials were tested.
7. Post-construction performance was assessed.

### **Selection of Site**

Maintenance personnel of VDOT's Leesburg Residency selected a 550-ft-long section of Hurley Lane in Loudoun County for testing. The site location, including the endpoint coordinates, is shown in Figure 1. The existing gravel road is approximately 16 ft wide in this area. The traffic count, as measured by VDOT personnel in early 2016, is approximately 340 vehicles per day, including 3% trucks.

The test section is located on sloping ground. According to VDOT maintenance crews, this road segment has required frequent regrading, especially after heavy rainfall events. Surface gravel was being washed out of the road, accumulating at the bottom of the hill and clogging adjacent drainage ditches. The need for extensive maintenance, exacerbated by heavy traffic including logging trucks, made this road segment a prime candidate for stabilization.



**Figure 1. Site Location: Hurley Lane, Loudoun County. Endpoint coordinates are shown.**

### **Identification of Site Geology**

The area is underlain by the Catoctin Formation, characterized by extrusive igneous rocks, primarily basalts (C. Hall, personal communication). These rocks are made up of silica and feldspar. Over time, feldspars tend to weather into very-fine-grained plastic soils. It is fairly common to encounter soft clayey soils overlying this rock formation. Typically, the soil mantle over basalt bedrock is not very thick, usually less than 10 ft, and the soil may contain boulders and cobbles of unweathered rock.

### **Selection of Stabilization Method and Parameters**

Recent stabilization experiments on Loudoun County gravel roads were conducted by VDOT maintenance personnel using CTA, which was trucked to a project site and then compacted in place. The field performance varied, with the main reason for inconsistent outcomes being traced to the excessively long time needed to deliver CTA material from the batch plant. Conventional practice requires that on-site compaction be performed within 2 hr of initial mixing (American Concrete Institute, 1990). This requirement can be difficult to attain under the typical traffic constraints experienced in Northern Virginia. If the CTA material is placed and compacted after the onset of hydration, the effectiveness of the cementation process becomes marginal.

The alternative approach is to introduce the stabilizing agent directly on site. This task can be accomplished with the use of reclaiming equipment that is routinely used to remediate severely deteriorated pavements. The process, known as FDR, involves pulverizing the existing road section to a predetermined depth and then blending it in place with a stabilizing agent. The FDR process was selected for this experimental field study.



## **Contract Procurement for FDR Work**

A private contractor, Slurry Pavers, Inc., of Richmond, Virginia, was awarded the work of cement stabilization. It was decided by VDOT residency personal to perform the subsequent chip seal surfacing operation with VDOT maintenance crews. This decision was predicated on the specific requirements for chip seal placement that are typically carried out on gravel roads in Loudoun County.

### **Construction of Test Section: Sequence of Construction**

#### **FDR**

The work was authorized in mid-November 2015. VDOT crews prepared the site by clearing road ditches of debris and accumulated crushed stone. Some ditch sections were lined with asphalt emulsion to improve drainage. Local residents were advised of the impending road project. A nearby staging area was secured for construction equipment.

On the day of construction on November 20, 2015, the weather was sunny, with an ambient air temperature of 50 °F and a wind speed of 4 mph. Slurry Pavers used a Wirtgen Road Reclaimer for this project. The test section was scarified to a depth of 12 in. A layer of hydraulic cement was then spread on the road surface. The quantity of cement was metered to deliver 5% concentration by weight within the 12-in-deep road profile. The decision to use 5% cement stabilizer was based on the contractor's experience with similar soils. Uniform blending of cement into the existing roadway was performed with the reclaimer. Water was added prior to the compaction phase to achieve proper hydration of the cement stabilizer. The typical compaction effort consisted of four passes with a padfoot roller. A grader was used to shape the final road profile. A single smooth roller was used to achieve the surface finish.

Figures 2 through 6 show the progress of FDR work on the Hurley Lane test section. It took approximately 6 hours to complete the FDR work on the 550-ft-long test section. The contractor provided the required traffic control. There was minimal interruption to vehicle movement during construction.



**Figure 2. Spreading Cement Stabilizer**



**Figure 3. Blending Cement With Wirtgen Reclaimer**



**Figure 4. Adding Water**



**Figure 5. Compacting**



**Figure 6. Grading**

## **Chip Seal**

The chip seal surfacing operation was performed 3 days later by VDOT crews. At the time of construction, the weather was sunny and windy, with an ambient air temperature of 39 °F. VDOT residency personal decided to proceed with the work despite the relatively low air temperature out of concern that weather conditions might deteriorate further in the coming days. After problems with the flow of the asphalt emulsion were resolved, the work began around noon and continued for approximately 3 hours.

The chip seal application consisted of one layer of VDOT No. 57 crushed stone, followed by two layers of VDOT No. 8 stone. The crushed stone material originated from Stuart Perry Quarry. Asphalt emulsion was applied between each stone layer. The emulsion temperature was 170 °F at the time of construction. The emulsion application rate was 0.5 gal/yd<sup>2</sup> for No. 57 stone and 0.3 gal/yd<sup>2</sup> for No. 8 stone. This particular chip seal installation method has been routinely used by VDOT crews in Loudoun County in order to provide a coarse gravel road surface appearance. Figure 7 shows the chip seal application. Figure 8 shows the finished road surface.



**Figure 7. Chip Seal Application on Hurley Lane**



**Figure 8. Final Road Surface on Hurley Lane**

### **Material Sampling**

Subgrade soil samples were collected for grain size distribution analysis, and FDR material samples were collected for compressive strength testing.

## Post-Construction Performance

Visual observations were conducted on a monthly basis. Structural evaluation was performed using a falling weight deflectometer (FWD) after 4 months of construction

## RESULTS AND DISCUSSION

### Materials Testing

Figure 9 shows the grain size distribution of a soil sample collected from a drainage ditch adjoining the test section. It represents the underlying subgrade material. According to ASTM soil classification, this fine-grained soil is sandy SILT (ML) with approximately 70% of particles passing the No. 200 sieve.

Two samples of the reclaimed material were collected at the road surface during construction. Figure 10 shows the representative grain size distribution of the reclaimed mixture of crushed stone with some underlying subgrade soil.

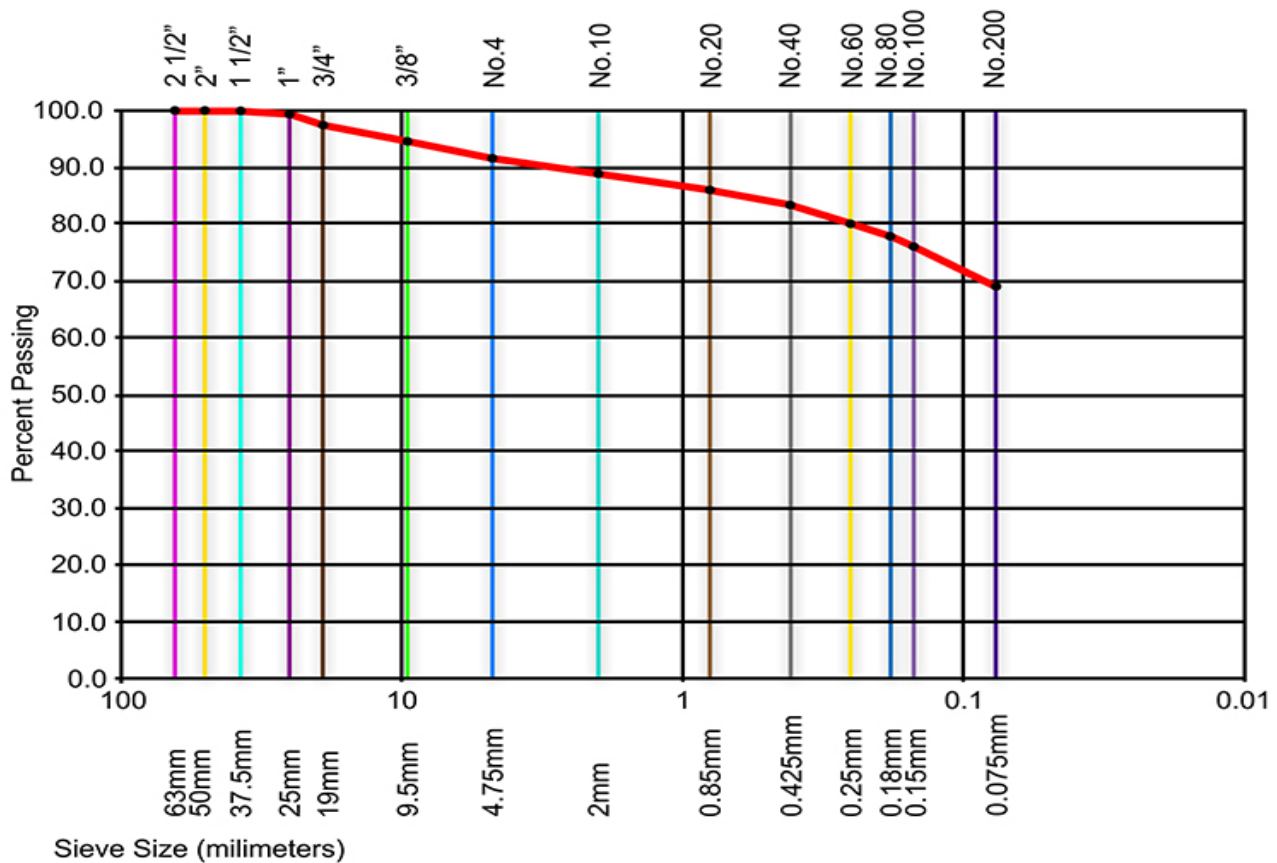
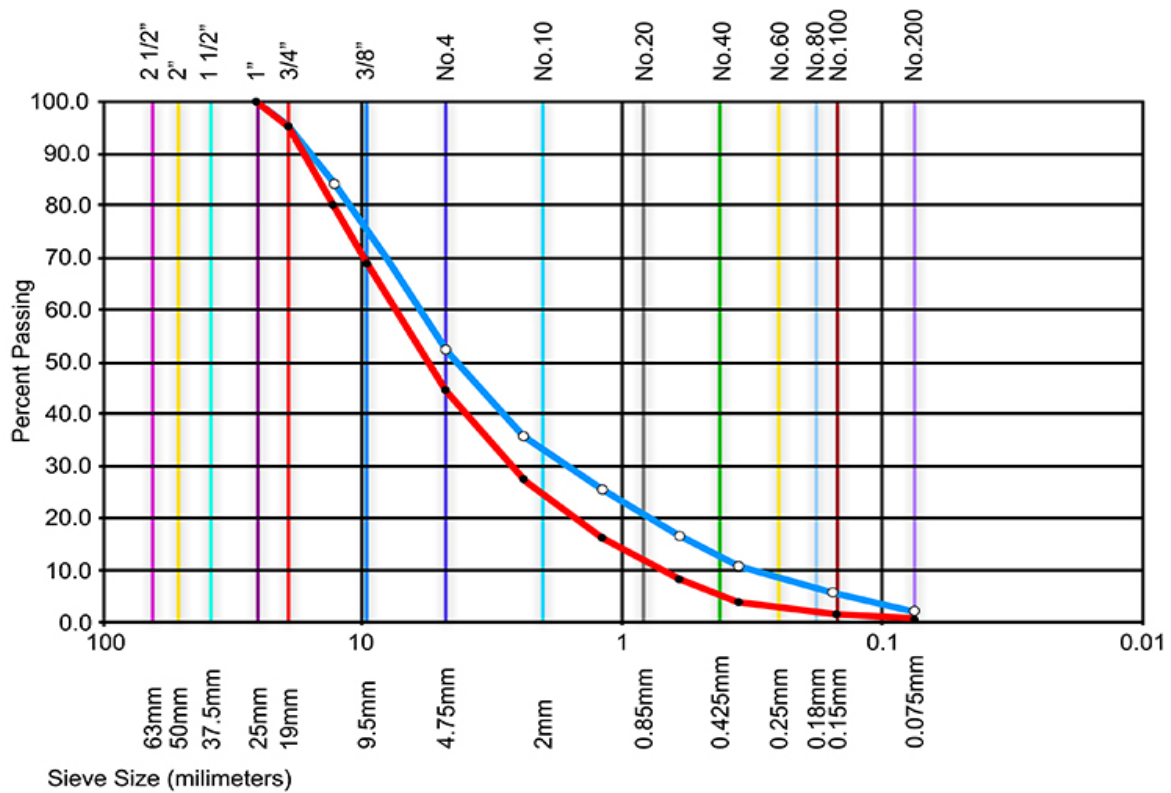


Figure 9. Gradation of the Subgrade Soil



**Figure 10. Gradation of the Reclaimed Material**

Field compaction tests were conducted with assistance from materials personnel of VDOT’s Northern Virginia District. The results were based on the one-point Proctor test performed in the field, accounting for the No. 4 grain size correction in accordance with Virginia Test Method 12 (VDOT, 2016c). Four compaction tests, carried out at uniform intervals along the entire length of the test section, indicated field compaction values ranging from 92% to 98% of the maximum dry density using the nuclear density gauge.

During the construction, three sets of samples of cement-stabilized roadway material were collected and compacted with a vibratory hammer into 6-in-diameter by 12-in-long test cylinders. These cylindrical samples were subsequently tested for compressive strength at the VTRC laboratory following a 10-day curing period in the moisture room (in accordance with ASTM D1633, without soaking the specimens). The results are presented in Table 1.

**Table 1. Ten-Day Compressive Strength of FDR Samples (5% Cement Content)**

Sample	Density (pcf)	Strength (psi)
A1(South end)	138.5	170
A2(South end)	143.1	182
B1(center)	138.0	122
B2 (center)	133.9	82
C1(North End)	140.1	156
C2 (North End)	141.6	171

FDR = full-depth reclamation.

## **Post-Construction Performance**

### **Visual Condition Assessment**

Some loose aggregate material was observed in the drainage ditches approximately 1 month after construction, indicating a potential problem with the durability of the chip seal. At that point, the road surface was in a satisfactory condition. Significant deterioration occurred by the time of another follow-up visit in February 2016, approximately 3 months after construction and shortly after a major snowfall. Most of the chip seal aggregate had washed away and filled up adjacent drainage ditches. The road surface exhibited significant rutting in some locations, with a marked presence of fine-grained soils. Figure 11 shows the time sequence of photographs collected at the test section.

### **Field Testing**

In an effort to determine the apparent cause of deterioration of the test section, the researchers decided to conduct structural testing using an FWD. The FWD applies a series of impulse loads to the road surface and records the resulting deflection responses using a series of sensors that extend radially from the point of impact. Nine sensors were used at different radial offsets for the measurement of vertical deflections. Sensors were placed at 0, 8, 12, 18, 24, 36, 48, 60, and 72 in away from the loading plate. Surface deflections were measured using loadings of 6,000, 9,000, and 12,000 lb. Personnel of VDOT's Lynchburg District performed FWD testing on March 8, 2016, after approximately 4 months of service. Figure 12 shows the equipment used in the study.

### **Structural (FWD) Testing**

Figure 13 shows surface deflection measurements conducted along approximately 2,500 ft of Hurley Lane, including the experimental test section and the adjoining gravel road segments. Testing began at the bottom of the hill and proceeded uphill, in the southerly direction. The FDR test section, labeled "Chip Seal over Cement Stabilized Gravel Road," is represented on the x-axis by the distance of approximately 330 to 880 ft from the starting point. It can be seen that the test section exhibits generally lower deflections in comparison with the "Chip Seal over Gravel Road" section, indicating improvement in the overall stiffness. However, it is also evident that the deflection pattern is not uniform, possibly because of variability in the field compaction effort and material properties. The adjoining unimproved gravel road section at the bottom of the hill (from 0 to 330 ft) is also characterized by very low deflections, most likely attributable to the proximity of bedrock in this area, but this cannot be ascertained without further exploration.



**Figure 11. Time-Lapse Photographs of Surface Conditions at Test Section**





Figure 12. Falling Weight Deflectometer at Test Section

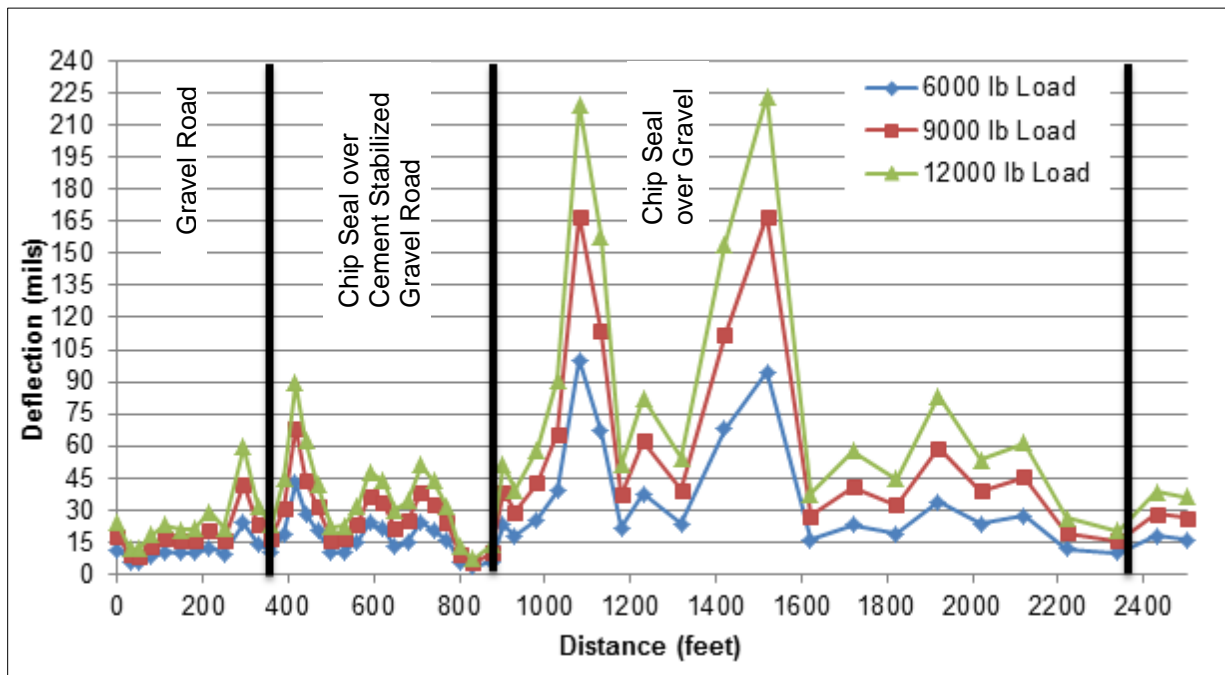


Figure 13. Results of FWD Testing

FWD deflection analysis was conducted using the ModTag software (VDOT, 2007) in accordance with the *AASHTO Guide for Design of Pavement Structures* (American Association of State Highway and Transportation Officials [AASHTO], 1993). The capacity of a road section to support traffic loads can be quantified by calculating the effective structural number ( $SN_{eff}$ ).  $SN_{eff}$  is computed as the sum of the individual layer thicknesses multiplied by their respective empirically based layer coefficient. Using the FWD deflection data,  $SN_{eff}$  can be determined by Equation 1:

$$SN_{eff} = 0.0045 \times D \times \sqrt[3]{E_p} \quad [\text{Eq. 1}]$$

where

$SN_{eff}$  = effective structural number

$D$  = total pavement thickness above the subgrade (in)

$E_p$  = effective pavement modulus of all layers above the subgrade (psi).

$E_p$  is calculated using Equation 2:

$$d_o = 1.5 \times p \times a \times \left[ \left( M_R \sqrt{1 + \left( \frac{D}{a} \times \sqrt[3]{\frac{E_p}{M_R}} \right)^2} \right)^{-1} + \frac{1 - \left( 1 + \left( \frac{D}{a} \right)^2 \right)^{-1}}{E_p} \right] \quad [\text{Eq. 2}]$$

where

$d_o$  = deflection at the center of the load plate (mils)

$p$  = contact pressure (psi)

$M_R$  = subgrade resilient modulus (psi)

$a$  = radius of load plate (in).

The subgrade resilient modulus ( $M_R$ ) is a fundamental engineering property that quantifies the subgrade strength and the ability to resist deformation under repeated traffic loadings. It is computed using the relationship in Equation 3:

$$M_R = C \times \left( \frac{P \times (1 - \mu^2)}{\pi \times r \times d_r} \right) \quad [\text{Eq. 3}]$$

where

$M_R$  = subgrade resilient modulus (psi)

$P$  = applied load (lb)

$\mu$  = Poisson's ratio

$r$  = radial distance at which the deflection is measured (in)

$d_r$  = measured deflection at a radial distance, r (mils)

$C$  = correction factor as per the AASHTO guide (AASHTO, 1993).

The value of pavement thickness above the subgrade ( $D$ ) was estimated at between 8 and 10 in, based on commonly encountered thicknesses of gravel roads. Figure 14 shows the resulting effective structural numbers distributed along Hurley Lane. It can be seen that  $SN_{eff}$  values for the FDR test section ranged from approximately 1 to 3.5. They were generally higher than the corresponding  $SN_{eff}$  values at the adjoining chip seal over gravel road section (0.6 to 1.8), indicating that the cement stabilization with FDR was beneficial.

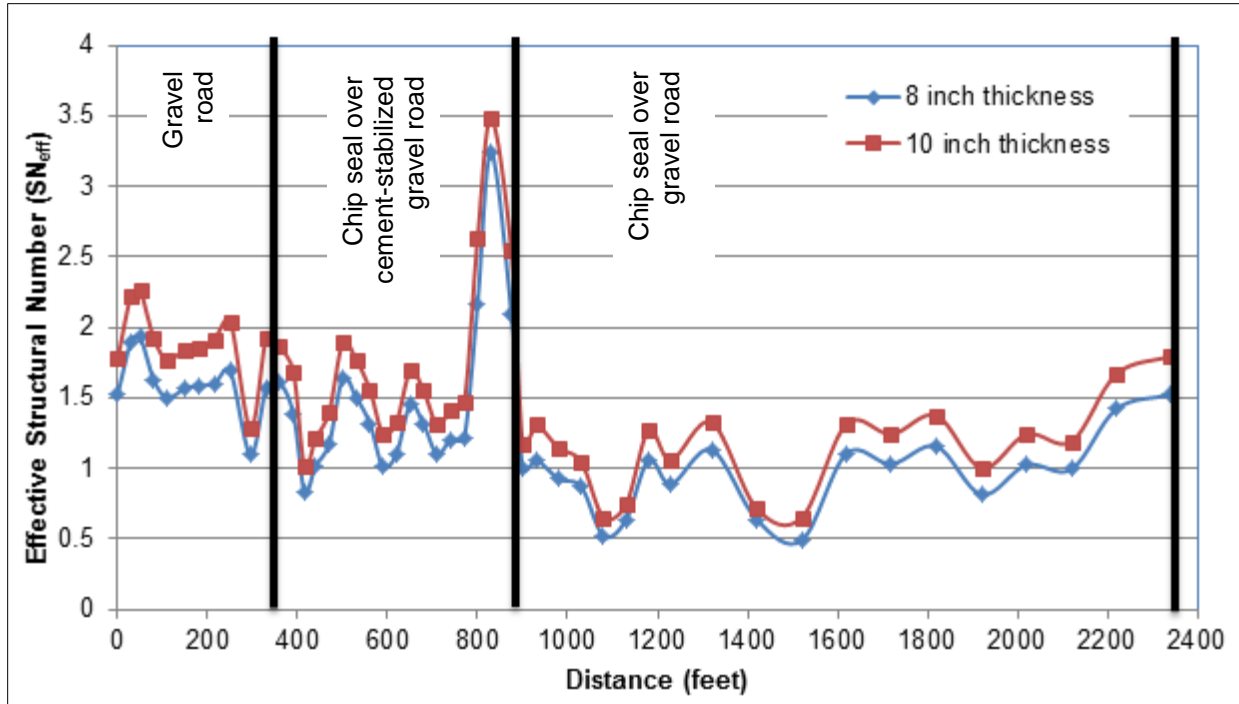


Figure 14. Values of  $SN_{eff}$  Along Hurley Lane

The results of FWD testing can also be used to prioritize maintenance needs on the road network. This task can be accomplished by determining the required structural number ( $SN_{required}$ ) for a given road segment and comparing it with a value obtained ( $SN_{eff}$ ) from FWD data analysis. The thickness of the road section is sufficient to handle current traffic if  $SN_{eff}$  is higher than  $SN_{required}$ . Areas where discrepancies in these values are detected can be mapped for further assessment.

The structural number reflects the capacity to carry traffic loads for a given combination of soil, traffic, terminal serviceability, and environment. Serviceability is commonly expressed as an index value ranging from 0 to 4.2, where 4.2 corresponds to a newly constructed flexible pavement. Serviceability is the ability of a specific section of pavement to serve traffic in its existing condition. VDOT's *Manual of Instructions* recommends the terminal serviceability (at the end of service life) value of 2.0 for unpaved roads (VDOT, 2016a). The required structural number for a road section is calculated as follows:

$$\log W_{r18} = Z_R S_0 + 9.36 \log(SN + 1) - 0.2 + \frac{\log[\Delta PSI / (4.2 - 1.5)]}{0.4 + 1094 / (SN + 1)^{5.19}} + 2.32 \log M_R - 8.07 \quad [\text{Eq. 4}]$$

where

$W_{r18}$  = number of equivalent 18-kip single axle load (ESAL) applications

$SN$  = structural number

$\Delta PSI$  = loss of serviceability

$M_R$  = effective subgrade resilient modulus

$Z_R$  = normal deviate for a given reliability,  $R$

$S_0$  = standard deviation.

The number of equivalent single-axle load (ESAL) applications can be calculated using Equation 5.

$$ESAL = ADT \times T \times T_f \times G \times D \times L \times Y \times 365 \quad [\text{Eq. 5}]$$

where

$ADT$  = average daily traffic

$T$  = fraction of trucks in the ADT

$T_f$  = truck factor (single unit ESAL factor: 0.46) (VDOT, 2000)

$G$  = growth factor, 1%

$D$  = directional distribution factor, 50%

$L$  = lane distribution factor, 60%

$Y$  = design period.

The required structural number for Hurley Lane is estimated at 0.93 using Equation 4. FWD test results, as shown in Figure 14, demonstrate that the test section provides adequate structural capacity for the current traffic loads; however, portions of the adjoining chip seal over gravel road section indicate a potential need for improvement.

## Discussion

Although it may be advisable to stabilize unpaved road to a depth of 12 in, the influence of the subgrade material should be adequately considered. The FDR process causes the underlying soils to become intermixed with crushed stone throughout the entire profile, which could potentially affect the structural capacity of the road section. This may be an issue in parts of Loudoun County, where the soft subgrade soils contain plastic fines, but it can be effectively addressed by performing site exploration and trial mix design at the planning phase of a project. Additional gravel material may be required in some cases to ensure structural stability. Although the compressive strengths of FDR samples collected from the Hurley Lane test site can be considered acceptable, they were lower than the recommended target values of 300 to 600 psi, as reported in *Recommended Practice for Stabilization of Subgrade Soils and Base Materials* (Little and Nair, 2009). Either too little or too much cement content can reduce the quality of the final product. Designing at the lower end of the range is usually preferred because of concerns about cracks developing at higher cement contents. VDOT developed the Special Provision for Full-Depth Reclamation (FDR) (see the Appendix) for asphalt pavement roads. The special provision provides details about materials, mix design requirements, quality control plans, equipment, construction methods, and acceptance criteria.

The following steps are important for future projects involving FDR stabilization of unpaved roads:

1. Trial mix design and laboratory density tests should be carried out in the planning stage as specified in the special provision.

2. Field compaction testing and laboratory compressive strength testing should be routinely conducted during construction to ensure the uniformity and quality of the final product. Some field tests performed on Hurley Lane indicated a less than optimum degree of compaction.
3. Cement-stabilized gravel roads should be promptly covered with a surfacing material to prevent excessive dust problems that may be exacerbated by the presence of cement. Chip seal surfacing provides a very effective protective layer for the underlying stabilized section and reduces objectionable dust problems. Surface treatment durability is essential to the project success. Ideally, a chip seal should be applied as soon as FDR work is completed.

A properly placed chip seal surface increases skid resistance and reduces the amount of material loss and dust on a gravel road. Although it typically adds no appreciable structural capacity, it preserves the integrity of the stabilized section by preventing the ingress of water. Properly constructed FDR can provide a stable foundation for the chip seal. The benefits of a chip seal over the FDR layer include improved dust control, increased durability, and an improved gravel road appearance.

Chip seals are typically used as pavement preservation techniques in VDOT practice. The appropriate emulsion type is selected based on surface condition, climate, aggregate properties, and cost considerations. VDOT's Special Provision for Asphalt Surface Treatments (VDOT, 2012) specifies CRS-2, CRS-2H, RC-250, and CRS-2M emulsions. Proper emulsion and aggregate application rates result in durable, long-lasting chip seals. Aggregate chips should be embedded in the asphalt emulsion to approximately 50% to 70% of their diameter after rolling. The weather should be warm and dry to ensure proper setting and curing. The ambient air temperature should be above 50 °F and the surface temperature should be above 70 °F (VDOT, 2016b). Chip seals should be rolled with a pneumatic tire roller immediately after spreading (Ali and Mohammadafzali, 2014; North Carolina Department of Transportation, 2015).

Chip seal applications by VDOT maintenance crews on gravel roads usually differ from the procedure used for asphalt pavement preservation. Although the general guidelines for surface treatments are specified in VDOT's Location and Design Division Memorandum IIM-LD-158.12 (VDOT, 2014), individual VDOT residencies develop their own practices. In most cases, a layer of No. 57 or No. 68 stone is placed, followed by placement of a smaller diameter stone, such as No. 8 or No. 78 (K. Wright, personal communication). Recommended application rates are 30 lb/yd<sup>2</sup> and 20 to 25 lb/yd<sup>2</sup> for No. 68 and No. 8 stone, respectively (VDOT, 2014). Asphalt emulsion for the prime seal is normally applied at a rate of 0.4 to 0.5 gal/yd<sup>2</sup>, but the application rates and material types for the final seal vary. The method developed by VDOT maintenance crews in Loudoun County reflects the objective of preserving the gravel road appearance.

Despite significant performance issues with the chip seal, this study showed that cement stabilization by FDR provides a viable alternative to the use of CTA, especially when the timely delivery of CTA material is a problem. The test section at Hurley Lane required frequent

maintenance activities prior to stabilization, sometimes necessitating re-grading at 2-week intervals. Based on reports from VDOT maintenance crews, the need for extensive road maintenance decreased substantially after the project completion. The most likely cause of surface durability problems was inadequate chip seal performance attributable to cold weather placement.

On September 7, 2016, a VDOT maintenance crew from the Hillsboro Area Headquarters repaired the experimental test section on Hurley Lane. The crew patched the potholes with asphalt emulsion and No. 57 stone and then applied new chip seal surfacing consisting of two layers of No. 8 stone. The asphalt emulsion was type CRS-2, applied at a rate of 0.5 and 0.3 gal/yd<sup>2</sup> for No. 57 and No. 8 materials, respectively. Figure 15 shows the repaired test section. A significant reduction in dust emissions was observed at the test section during the field visit on September 13, 2016. As of February 2017, no surface distress was reported and no maintenance activity was required on the FDR-stabilized section.

It should be recognized that FDR work requires extensive mobilization of specialized construction equipment. This approach can be economically justified only on a relatively large project (at least 2,000 ft). It is estimated that the cost of FDR stabilization will be approximately \$6 to \$7/yd<sup>2</sup> (D. Stowell, personal communication). The use of FDR with a chip seal surface may be an attractive alternative in areas where the durability of asphalt pavement combined with the gravel road appearance is sought. Typically, the cost of FDR work combined with chip seal overlay compares favorably with the cost of conventional paving.



**Figure 15. Repaired Cement-Stabilized Test Section on September 13, 2016**

## **CONCLUSIONS**

- *This study identified lessons learned from the experimental field project and provides forward guidance for implementation of the FDR method suitable for the chemical*

*stabilization of gravel road segments identified as a maintenance nuisance (each segment under 0.1 mile long) and for roads qualified under the Rural Rustic Road Program. Gravel roads can easily rut or form potholes in periods of prolonged wet weather. During periods of dry weather, traffic tends to displace loose gravel from the surface to the shoulder and ditch areas. Managers and equipment operators have the continual responsibility of keeping the roadway surface properly shaped and maintained.*

- *Cement stabilization of unpaved roads using the FDR construction method is a technically viable option. The method lends itself to projects where the mobilization and the use of specialized equipment can be economically justified.*
- *FDR mix design and field testing during construction are required to achieve optimum results.*
- *Adherence to proper chip seal placement procedures is essential to long-term performance.*
- *The use of the FWD can be helpful in prioritizing maintenance needs for high-volume unpaved roads.*

## **RECOMMENDATIONS**

1. *VDOT's Leesburg Residency should consider the option of using the FDR method for cement stabilization of unpaved roads where deemed economically feasible and in areas identified as maintenance nuisance (each road segment under 0.1 mile long) and for roads qualified under the Rural Rustic Road Program (designed to keep the traditional rural lane appearance while improving the riding surface within the current right of way). VDOT's Special Provision for Full-Depth Reclamation, as provided in the Appendix, should be followed in addition to the following guidelines from this study:*
  - *Trial mix design and laboratory density tests should be carried out in the planning stage as specified in the special provision.*
  - *Field compaction testing and laboratory compressive strength testing should be routinely conducted during construction to ensure the uniformity and quality of the final product. Some field tests performed on Hurley Lane indicated a less than optimum degree of compaction.*
  - *Cement-stabilized gravel roads should be promptly covered with a surfacing material to prevent excessive dust problems that may be exacerbated by the presence of cement. Chip seal surfacing provides a very effective protective layer for the underlying stabilized section and reduces objectionable dust problems. Surface treatment durability is essential to project success. Ideally, chip seal should be applied as soon as FDR work is completed.*

2. *VDOT's Leesburg Residency should request materials testing and construction assistance on FDR projects from VDOT's Materials Division.*
3. *VDOT's Leesburg Residency should evaluate the use of the FWD on high-traffic gravel roads for prioritizing maintenance needs*

## **BENEFITS AND IMPLEMENTATION**

### **Benefits**

With regard to Recommendation 1, using the FDR method provides the opportunity for VDOT residencies to renew deteriorated gravel roads, particularly if surfaced with a thin surface treatment such as a chip seal. A chip seal provides an excellent water-resistant barrier for the underlying FDR layer. Moreover, the combination of the FDR and chip seal approach offers enhanced durability while maintaining the gravel road appearance. In addition, the combined approach eliminates the expense of frequent grading and replacement of the gravel material. Finally, the combined approach would eliminate the use of chloride solutions for gravel stabilization and dust control.

With regard to Recommendation 2, attaining proper compaction of the FDR layer is critical for optimal performance. Proper mix design work and proper construction quality control are necessary for a successful FDR project.

With regard to Recommendation 3, characterizing an existing section with a nondestructive evaluation method such as FWD testing will help to identify areas that require structural improvement to handle current and future traffic levels. FWD testing also helps to determine actual in-place strength and to assess strength improvement after the FDR process.

### **Implementation**

VDOT's Leesburg Residency is responsible for maintaining approximately 300 centerline miles of gravel roads in Loudoun County, which is substantially more than in any other county in Virginia. The aim of the residency is to reduce maintenance costs substantially on gravel roads. For this purpose, the Leesburg Residency will consider more FDR projects using the guidelines developed in this study for gravel roads under the Rural Rustic Road Program. The study recommendations are intended to minimize the number and severity of construction problems associated with this effort. All recommendations are expected to be readily implementable in the routine VDOT practice.

With regard to Recommendation 1, in the 2017 VDOT construction season, a 0.7-mile section of Hogback Mountain Road in the Leesburg Residency will be upgraded using the FDR method with cement stabilization and chip seal surfacing.



With regard to Recommendation 2, VDOT's Materials Division will provide material testing and construction assistance on this project.

With regard to Recommendation 3, FWD testing will be used to evaluate the performance of this project and to select future candidate FDR projects from high-traffic gravel roads. VTRC will provide technical assistance with project monitoring and reporting.

## ACKNOWLEDGMENTS

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**APPENDIX**

**VIRGINIA DEPARTMENT OF TRANSPORTATION  
SPECIAL PROVISION FOR  
FULL-DEPTH RECLAMATION (FDR)**



VIRGINIA DEPARTMENT OF TRANSPORTATION  
SPECIAL PROVISION FOR  
**FULL-DEPTH RECLAMATION (FDR)**

August 7, 2015

**I. DESCRIPTION**

Full-depth reclamation (FDR) is defined as those processes in which all of the asphalt pavement layers and some portion of the underlying bound and unbound layers are pulverized, stabilized, and compacted in place. This is most commonly performed using hydraulic cement, lime, foamed asphalt or asphalt emulsion as the primary stabilizing additives.

The Contractor shall furnish all labor, materials, and equipment required for completing the work. The Contractor shall select the final mix design (job mix formula- JMF) and construction methods to meet the performance requirements specified herein.

**II. MATERIALS**

**Stabilizing Agent(s)** – The amount of stabilizing agents to be used shall be determined by the Contractor by means of a mixture design process. Hydraulic cement shall conform to the requirements of Section 214 of the Specifications. Lime shall conform to the requirements of Section 240 of the Specifications. Fly ash shall conform to the requirements of Section 241 of the Specifications. All liquid asphalts used for stabilizing agents shall be emulsions and PG binders on the VDOT Approved List for emulsions and PG binders, Approved List 50 and 50.1. Liquid asphalts not currently on the Approved List shall be submitted to VDOT for approval. Asphalt emulsions shall conform to the requirements of Section 210 of the Specifications; liquid asphalts shall meet the requirements of Section 211.02 (a) of the Specifications.

1. **Water** – Any water used for mixing shall meet the requirements of Section 216 of the Specifications.
2. **FDR** – The FDR material shall have 100% of all particles passing the 2.0 inch (50mm) sieve size and 55% of all particles passing the 3/8 inch (9.5mm) sieve size prior to the addition of any stabilizing agents.
3. **Other Additives** – If necessary, additional additives may be used by the Contractor to meet the requirements in **TABLE 4**. In the case where an additional additive is used, the type and dosage must be described in the JMF's submitted to the Engineer. For FDR using asphalt emulsion, hydrated lime shall be added according to the requirements in Section 211.02(i) of the Specifications.

4. **Addition of Crushed Reclaimed Asphalt Pavement (RAP) Material** – RAP material may be added by the Contractor and shall meet the requirements of Section 211.02(j) of the Specifications and **TABLE 1**.

**TABLE 1 – ADDITIONAL CRUSHED RAP**

Tests	Method	Limit
Deleterious Materials: Clay Lumps and Friable Particles in Aggregate	AASHTO T 112	0.2% maximum
Maximum Sieve size, 2.0 in. (50 mm)	AASHTO T 27	100% passing

5. **Additional aggregate** – Based on the results of the mixture design or other requirements, the Contractor shall determine if additional aggregate is required. If the Contractor determines additional aggregate is required any additional aggregate shall meet Section 203 of the Specifications and the requirements in **TABLE 2**, and it shall produce a product which meets the mixture requirements given in **TABLE 4** and final mix gradation specified in **Section IV-1**.

**TABLE 2 – ADDITIONAL AGGREGATE**

Tests	Method	Limit
Los Angeles Abrasion Value	AASHTO T 96	45% maximum loss
Sand Equivalent	AASHTO T 176	45% minimum
Maximum size, 100% Passing, Sieve Size	AASHTO T 27	2.0 in. (50 mm)
Water absorption	AASHTO T 85	3% maximum

6. **Handling and Storage** – Store cement to prevent moisture degradation and partial hydration. Do not use cement that has become hard, caked or lumpy. Store aggregates and RAP so that segregation and inclusion of foreign materials are prevented. Do not use the bottom six (6) inches of aggregate or RAP piles in contact with the ground.

### **III. QUALITY CONTROL PLAN**

The Contractor shall also be responsible for developing and implementing a Quality Control Plan to ensure that operational techniques and activities provide integral and finished material of acceptable quality. Contractor sampling and testing shall be performed to control the processes and ensure material compliance with the requirements of the Contract. The Contractor shall provide their Quality Control Plan and Job Mix Formulae to the District Materials Engineer for approval no less than 30 calendar days prior to the start of FDR operations.

For each FDR project, the Contractor is required to furnish a project specific Quality Control Plan that shall include, at a minimum, the following information:

1. A description of the Contractor's Quality Control organization, including the number of full-time equivalent employees or Sub-Contractors with specific Quality Control responsibilities, including an organizational chart showing lines of authority and reporting responsibilities
2. A listing by discipline with the name, qualifications, duties, responsibilities and authorities for all persons proposed to be responsible for Construction Quality Control
3. A Quality Control Sampling, Testing and Analysis Plan with methods that include a description of how random locations for testing and sampling are determined
4. Identification and description of qualifications of the laboratory(s) to be used for each type of testing
5. Specific listing of documentation for Quality Control activities
6. Procedures to meet contract requirements for corrective action when Quality Control criteria are not met
7. Procedures to protect stabilized material from receiving excessive moisture from weather events (i.e. rain, fog, etc.) and corrective actions when criteria are not met
8. Contingency Plan including but not limited to:
  - Inclement weather
  - Equipment breakdowns
  - Materials shortages
  - Excessive fluff - (greater than approximately 10%). Fluff is defined as the increase in material thickness of the recycled layer over the specified recycling depth due to remixing in place.
  - Deficient density of installed FDR
  - Material doesn't break or cure in timely manner
  - Gradation is outside tolerance(s)
  - Production modifications based on changes in ambient and/or material temperature.



The Contractor shall have a technical representative at the project site during the mixing and placement operations for the trial section and first day of production. At a minimum, this person must:

- Have 2 years minimum experience with the FDR process
- Have personally supervised a minimum of 5 successful FDR projects
- Have personal experience in developing FDR mix designs
- Have the experience to perform and supervise field process control testing
- Submit a list of references, with current telephone numbers, who are able to verify the experience required herein

The Contractor may use consultants or manufacturers’ representatives to satisfy the requirements of this section provided they meet the requirements above and are on-site or available for contact while construction operations are being performed.

**IV. Job Mix Formula (JMF)**

1. **Mixture Designs** – FDR mix designs in the form of a job-mix formula (JMF) shall be submitted to the Engineer for the Department’s approval no less than 30 calendar days prior to the start of FDR operations. More than one JMF may be required. The gradation of each JMF shall fall within the bands shown below.

**TABLE 3 - DESIGN RANGE**

Sieve Size	Percentage by Weight Passing Square Mesh Sieves (in)	
	Lower	Upper
2.0”	100	100
3/8”	55	--

The Contractor shall obtain sufficient samples of the material to be reclaimed directly from each roadway within the project for laboratory testing and mix design analysis. Samples shall be obtained from every 2500 linear feet, within each lane and to the proposed total recycling depth, with a minimum of six locations for each mix design. Sample locations from each lane may be offset or adjacent from each other. Additional locations may also be selected based on pavement conditions and variability.

2. **Mixture Designs Submittal** – The design shall be performed by the Contractor in accordance with these specifications and submitted to the Engineer for approval (30)

working days prior to the planned start of the work. The mix design submittal shall include, at a minimum, the following information:

- A. Target field density
- B. Percent by weight of all stabilizing agents to be added to the recycled mix
- C. Percent water content (at room temperature) required
- D. Expansion ratio and half-life characteristics and temperature of asphalt binder at the time of injection into foaming chamber (for mixtures using foamed asphalt)
- E. Minimum curing time/set time for the asphalt emulsion
- F. Temperature of asphalt emulsion at the time of incorporating into the mixture (for mixtures using asphalt emulsion)
- G. Target gradation (including any aggregate to be added)

**TABLE 4 – FULL-DEPTH RECLAMATION MIX DESIGN REQUIREMENTS**

Test	Test Method	Criteria
Liquid Limit, Plastic Limit, and Plasticity Index of Soil	VTM-7	Report
Dry Preparation and Mechanical Analysis of Soils, Select Material, Subbase and Aggregate Bases	VTM-25	Report
Classification of Soils	AASHTO M 145	Report
Moisture-Density Relations of Soil-Cement Mixtures	AASHTO T 134	Report
Moisture Density Relations for Bituminous Stabilizing Agents	AASHTO T 180	Report
Compressive Strength of Soil-Cement Cylinders	ASTM D 1633	Min. 250 psi (Max. 450 psi) at seven (7) days
Determining the Strength of Soil-Lime Mixtures	VTM-11	Min. 150 psi
Dry Indirect Tensile Strength (ITS) for Foamed Asphalt Stabilizing Agent	AASHTO T 283 Section 11*	45 psi minimum
Marshall Stability Test for Asphalt Emulsion Stabilizing Agent	ASTM 5581 (6 inch specimens), AASHTO T 245 (4 inch specimens)**	2500 lbs minimum (6 inch (150mm) diameter specimen), or 1250 lbs (4 inch (100mm) diameter specimen)

\* Three specimens shall be produced using either 75 blows per side (per VTM-57) or 30 gyrations (per AASHTO T 312) compacted at or below Optimum Moisture Content and cured as follows: 4 inch (100 mm) diameter specimens, oven dry at 104°F (40°C) for 72 hrs and cool to ambient air temperature for 24 hrs; 6 inch (150 mm) diameter specimens, air dried for 24 hours, then an additional 48 hours at 104°F (40°C) in sealed plastic bag, cool to ambient air temperature for 24 hrs.

\*\* Three specimens shall be produced at 75 blows per side (or 30 gyrations per AASHTO T 312) and cured at 140°F (60°C) to constant mass, hold specimens at 104°F (40°C) for 2 hours in a forced draft oven immediately prior to testing.

If a change in source materials is made during construction, a new JMF's shall be created and approved by the Engineer prior to use on the project. The JMF's shall meet the above criteria at the approved stabilizing agents content.

## V. EQUIPMENT

1. **Pulverizing** – The equipment used to reclaim existing pavements shall be capable of pulverizing existing pavement, as well as any additional materials, to meet the gradation provided in the approved job mix design, for the widths provided in the Plans, to the depth specified in the approved pavement design.
2. **Stabilizing** – The equipment used to stabilize the pulverized materials shall be capable of incorporating the stabilizing agents at the rate provided in the approved job mix design, automatically metering dosage and mixing the full depth and width of pulverized material to a homogenous mixture.
3. **Grading** – The equipment used to grade the stabilized material shall be capable of working within the constraints of the excavation and grading the full width of stabilized material in conformity with the lines and grades provided in the Plans.
4. **Compacting** – The equipment used to compact the stabilized material shall be capable of working within the constraints of the excavation and compacting the stabilized material in conformity with the lines and grades provided in the Plans, as well as in conformity with the density requirements provided in the approved job mix design.

## VI. TRIAL SECTION

One week before planned start of full production, stabilize a 2,500 foot long trial section, one-lane wide, at the designated thickness and designed optimal stabilizing agents content provided in the approved job mix design. Construct the trial section on the project at an approved location.

Construct the trial section using construction procedures intended for the entire project. Cease production after construction of the trial section until the trial section is evaluated

and accepted by the Engineer. The trial section shall be considered a lot and payment will follow the payment tables established in this specification.

## **VII. CONSTRUCTION METHODS**

1. **Grass and Other Vegetation** – All grass and other vegetation shall be removed from the edge of the existing pavement to prevent contamination of the pulverized bituminous material during the milling operation.
2. **FDR** – Recycling shall be performed to the depth provided in the plans, while incorporating stabilizing agents, mineral filler, additional aggregate and water. Mixing shall continue until, and the speed of the recycling unit adjusted to ensure, a homogenous mixture of the above materials and pulverized materials is achieved.
  - A. Pre-cutting, grading and light compacting of the recycled material shall be performed prior to incorporation of the stabilizing agent.
  - B. The application rate of all stabilizing agents shall be continuously monitored using calibrated, automatic meters. The application rate shall be within 0.20 percentage points of the optimal stabilizing agents content provided in the approved job mix design. If the measured application rate falls outside the above tolerance, then the recycling operations shall be stopped and corrected before proceeding.
  - C. The water content of the stabilized material shall be monitored closely to ensure conformance with the approved job mix design within  $\pm 2$  percentage points of optimum and to ensure proper compaction.
  - D. Longitudinal joints between adjacent stabilization passes shall be overlapped at least 4 inches. Transverse joints created by the recycling process shall be saw-cut, if necessary, to provide a vertical, clean face to ensure proper compaction.
3. **Final Grading and Compacting** – The final grading and compacting shall be performed within the constraints of the excavation and the stabilized material shall be compacted in conformity with the lines and grades provided in the Plans. Compaction shall progress across the full width of the stabilized area until maximum density is achieved.
  - A. Once the entire working width (full lane width plus affected shoulder width) has been stabilized, and only after primary compaction has been completed, the entire working width shall be graded to the required profile and cross-slope. Disturbance to the stabilized and primarily compacted material shall be kept to a minimum during this grading and shaping operation.
  - B. Any additional water required to achieve maximum density shall be applied by spraying the surface of the stabilized material with light applications. Care shall be taken not to over-apply additional water to any areas of stabilized material.

4. **Surfacing** – The surface of the compacted material shall be kept moist until covered with an asphalt-based layer in the case of cement stabilized materials. For bituminous stabilized materials, the FDR shall be allowed to cure until the moisture of the material is a maximum of 50% the optimum moisture content or until approval of the Engineer is received. Subsequent asphalt-based layers can be placed any time after finishing, as long as the FDR is sufficiently able to support the required construction equipment without marring or permanent distortion of the surface.

## VIII. ACCEPTANCE TESTING

1. **Field Compaction** – Density shall be determined with a nuclear gauge operating in direct transmission mode conforming to the requirements of VTM-10 to the full depth of the FDR layer. The Contractor shall have had the gauge calibrated within the previous 12 months by an approved calibration service. In addition, the Contractor shall maintain documentation of such calibration service for the 12-month period from the date of the calibration service.

The project will be divided into lots by the Engineer for the purpose of defining areas represented by each series of tests.

2. **Lot** – For the purposes of acceptance, each day's production shall be considered a lot unless the paving length is less than 3,000 linear feet or greater than 7,500 linear feet. When paving is less than 3,000 feet, it shall be combined with the previous day's production or added to the next day's production to create a lot as described below.

For the purposes of acceptance, the standard size of a lot shall be 5,000 linear feet, with 1,000 foot sublots, the full width of the lane (including any affected shoulder width). If the Engineer approves, the lot size may be increased to 7,500 linear foot lots with five 1,500 foot sublots when the Contractor's normal daily production exceeds 7,500 feet. When a partial lot occurs at the end of a day's production or upon completion of the project, the lot shall be either added to the previous lot if the partial lot contains one or two complete sublots, or redefined to be an entire lot if the partial lot contains three or four complete sublots.

Each lot shall be tested for density by taking a nuclear density reading from two stratified-random test sites selected by the Engineer within each subplot. Test sites shall not be located within 18 inches of any longitudinal joint.

The average of the subplot density measurements will be compared to the maximum density from the approved mix design to determine the acceptability of the lot. Once the average density of the lot has been determined, the Contractor will not be permitted to provide additional compaction to raise the average. If two consecutive sublots produce density results less than 97.0 percent of the target density, the Contractor shall immediately notify the Engineer and institute corrective action. By the end of the day's operations, the Contractor shall furnish the test data developed during the day's production to the Engineer.

Payment will be made in accordance with the requirements of **TABLE 5**.

**TABLE 5 - PAYMENT SCHEDULE FOR LOT DENSITIES**

<b>% of Density from Approved Mix Design</b>	<b>% of Payment</b>
97.0 or greater	100
96.0 to less than 97.0	95
95.0 to less than 96.0	90
Less than 95.0	75

- Depth Check** – Depth checks shall be performed by the Contractor twice per lot after compaction and prior to the placement of the next pavement layer. The depth checks shall be performed twice per lot following VTM-38, Method B.

Acceptance testing of FDR for depth will be based on the mean result of measurements of samples taken from each lot of material placed.

A lot will be considered acceptable for depth if the mean result of the tests is within the tolerance of the plan depth for the number of tests taken as shown in **TABLE 6**.

**TABLE 6 – PROCESS TOLERANCE FOR DEPTH CHECKS**

<b>Plan Depth, inches</b>	<b>Tolerance, inches (Plus or Minus)</b>			
	<b>1 test</b>	<b>2 tests</b>	<b>3 tests</b>	<b>4 tests</b>
$>6 \leq 8$	0.9	0.65	0.5	0.4
$>8 \leq 12$	1	0.9	0.7	0.5
$>12$	1.2	1	0.8	0.6

If an individual depth test is in excess of the tolerance for one test, that portion of the lot represented by that test will be excluded from the lot. If an individual test result indicates that the depth of material represented by the test is more than the tolerance for one test, the Contractor will not be paid for that amount of material in excess of the tolerance throughout the length and width represented by the test. If an individual test result indicates that the depth of the material represented by the test is deficient by more than the tolerance for one test, correction of the base course represented by that test shall be made by the Contractor as specified hereinafter.

If the mean depth of a lot of material is in excess of the tolerance, the Contractor will not be paid for that amount of material throughout the length and width represented by the tests. The Department can require excessive material to be removed at the Contractor's expense.

If the mean depth of a lot of material is deficient beyond the allowable tolerance, correction will be required and the Contractor will be paid for the quantity of material that has been placed in the lot. The Contractor will be required to furnish and place material specified for the subsequent course to bring the deficient FDR course depth within the tolerance. This additional material will be placed at the Contractor's expense.

4. **Gradation** – The Contractor will check the unstabilized gradation twice per day.
5. **Stabilizing Agent Dosage Rate** – Contractor shall verify the dosage rate ten times per lot. The dosage rate shall be within 0.20 percentage points of the approved mix design. If the dosage rate is beyond this tolerance, then paving shall stop and the contractor shall take corrective measures.
6. **Construction Records** – The Contractor shall prepare separate test reports meeting the requirements of AASHTO R 18 or may use the current appropriate VDOT forms. Records documenting the dosage rate of stabilizing agents and other test results from Table 4 shall be provided to the Engineer, unless specified otherwise.

## **IX. WEATHER LIMITATIONS**

Recycling operations shall be completed when both the atmospheric temperature and material to be processed (measured in the shade and away from artificial heat) is a minimum 40°F (4 °C). The weather forecast shall not call for freezing temperature within 48 hours after placement of any portion of the project.

## **X. MEASUREMENT AND PAYMENT**

**Full Depth Recycling (FDR)** will be measured by the square yard of the completed sections for the depth specified in the plans and paid for at the Contract unit price per square yard of depth. This price shall be full compensation for removal and processing of the existing pavement; for preparing, hauling, and placing all materials; furnishing additives (not including stabilizing agents); for all freight involved; for all manipulations, including removal of grass and other vegetation; rolling and brooming; testing and documentation; stabilizing agent supplier services; and for all labor, tools, equipment and incidentals necessary to complete the work.

Stabilizing agents will be paid as follows:

**Liquid Asphalt (Emulsion)** will be paid for at the Contract unit price per ton. This price shall be full compensation for furnishing and incorporating the emulsion into the mixture. An emulsion content of 3.0% by weight of the reclaimed material shall be used for bidding purposes prior to the completed design. The actual emulsion content will be adjusted based on the quantity necessary to meet the design requirements in Table 4.

**Liquid Asphalt (foamed)** will be paid for at the Contract unit price per ton. This price shall be full compensation for furnishing and incorporating the foamed asphalt into the mixture. A foamed asphalt content of 2.5% by weight of the reclaimed material shall be used for bidding purposes prior to the completed mix design. The actual foamed asphalt content will be adjusted based on the quantity necessary to meet the design requirements in Table 4.

**Hydraulic Cement** will be paid for at the Contract unit price per ton. This price shall be full compensation for furnishing and incorporating the hydraulic cement into the mixture. A cement content of 5.0% by weight of the reclaimed material shall be used for bidding purposes prior to the completed design. The actual cement content will be adjusted based on the quantity necessary to meet the design requirements in Table 4.

**Lime** will be paid for at the Contract unit price per ton. This price shall be full compensation for furnishing and incorporating the lime into the mixture. A lime content of 5.0% by weight of the reclaimed material shall be used for bidding purposes prior to the completed design. The actual lime content will be adjusted based on the quantity necessary to meet the design requirements in Table 4.

**Other Cementitious Material** will be paid for at the Contract unit price per ton. This price shall be full compensation for furnishing and incorporating the cementitious into the mixture. A cementitious content of 5.0% by weight of the reclaimed material shall be used for bidding purposes prior to the completed design. The actual cementitious content will be adjusted based on the quantity necessary to meet the design requirements in Table 4.

Payment will be made under:

<b>Pay Item</b>	<b>Pay Unit</b>
Full-Depth Reclamation (Depth)	Square Yard
Liquid Asphalt (Emulsion)	Ton
Liquid Asphalt (Foamed)	Ton
Hydraulic Cement	Ton
Lime	Ton
Other Stabilizing Materials	Ton

**Additional Crushed RAP** if required to meet the contract requirements will be measured and paid for at \$ **fill in amount per ton**. This price shall be full compensation for furnishing and incorporating the additional RAP into the mixture. The additional RAP must meet the requirements of **Section II-4** herein for payment purposes.

**Additional Aggregate**, if required, in accordance with the JMF and other contract requirements, will be measured and paid for at \$ **fill in amount per ton**. This price shall be full compensation for furnishing and incorporating the additional aggregate material into the mixture. The additional aggregate material must meet the requirements of **Section II-5** herein for payment purposes.