Performance of Concrete Overlays over Full Depth Reclamation (FDR)

Literature Review

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Abstract

As the infrastructure ages, it is getting harder for the agencies to maintain it. Full Depth Reclamation has several advantages and combining these advantages with the durability of concrete overlays might be the answer for agencies to provide high quality infrastructure with lower public funds.

Full Depth Reclamation (FDR) decreases the landfilled materials and transportation demands. This will not only decrease the cost but will also be more environmentally friendly and with lower environmental effects.

Concrete overlays can serve as a sustainable and cost-effective solution. They do not need major rehabilitation and they usually perform longer than designed. With lower need for maintenance and longer service life, concrete overlays offer lower life cycle costs and lower environmental impacts.

When you combine these benefits of FDR with concrete overlays, there is promise of more durable and environmentally friendly infrastructure.

In this research the current situation of concrete overlays that were built over different types of FDR will be investigated.

Pavement condition data such as pavement distress (transverse cracking, longitudinal cracking, D-cracking, joint spalling, faulting etc.) will be collected. Coring will be done to investigate thickness and strength of concrete pavement and FDR. Falling Weight Deflectometer (FWD) and Ground Penetrating Radar (GPR) will also be done to evaluate the situation of the concrete pavement and its bases.

Concrete overlay parameters, such as overlay type, thickness, age, and joint spacing; and full depth reclamation properties such as type, strength and thickness properties will be investigated; and long-term performance trends will be established.

I. Literature Review

As pavements age, it is getting harder for agencies to maintain them. Full Depth Reclamation has several advantages and combining these advantages with the durability of concrete overlays might be the answer for agencies to provide high quality infrastructure with less public funds.

The resources of the world are scarce and limited. Using materials available at the site might be more economical and environmental choice. Full Depth Reclamation (FDR) can be the answer for those quests.

FDR is the process of using old pavement, subbase and sometimes subgrade to produce a subbase for the new pavement.

A. Pavement Structure

Pavements generally have the structure as shown in Figure 1.

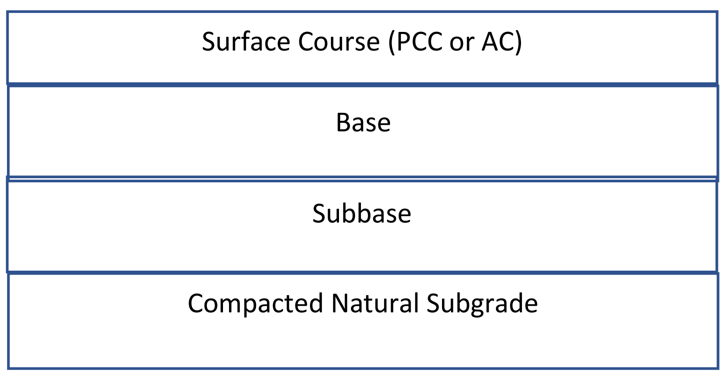


Figure 1. Typical Pavement Structure

Subgrade: It can be the natural soil or borrow material or embankment. The top surface of the soil is compacted to support and provide a platform for the pavement structure. The upper layer of this natural soil may be compacted or stabilized to increase its properties (strength, stiffness, and/or stability). It is the foundation of the pavement structure. [[1]]

Subbase: The course below the base course. If the subgrade soil has adequate support, it may serve as the subbase. Layers of selected materials with designed thickness placed on a subgrade to support a base course. The subbase layer is usually lower quality than the base layer. The subbase may be treated with Portland cement, asphalt, etc. to increase its structural capacity. Adding a subbase layer is primarily an economic issue.

Other advantages of subbase: [[2]]

• Preventing the intrusion of fine-grained subgrade soils into the base layer.

• Minimizing the damaging effects of frost action. (insulation to frost-susceptible subgrades and, or increase the height of the pavement surface above the groundwater table etc.)

• Provide drainage

• Provide working platform

Base Course: The layer below the pavement. It can be composed of crushed stone, crushed or uncrushed gravel, sand etc. It is a layer or layers of select material of designed thickness placed on a subbase or subgrade. This layer provides uniform platform and supports the pavement surface. It increases structural capacity and improves the foundation stiffness. It acts as a separation layer between subgrade and pavement. It usually consists of higher quality materials. Sometimes these materials are treated with stabilizing admixtures, such as Portland cement, asphalt, lime, fly ash, or a combination of these treatments, to increase their strength and stiffness. Base layer stabilization may reduce the total thickness of the pavement structure, resulting in a more economical overall design.

Surface Course: Asphalt Concrete or Portland cement concrete layer. This layer transfers the load received to the layers below. Concrete is rigid and behaves as a plate and does not localize stress. This layer also accommodates traffic load, resist skidding, provide traffic abrasion and resist climate conditions. The surface also minimizes infiltration and protects other layers against freeze and thaw.

In rigid pavement construction generally, portland cement concrete pavement slabs are constructed on a granular base layer over subgrade. The base layer serves to increase the effective stiffness of the slab foundation and makes the stiffness uniform over the cross section. The base may also be stabilized with asphalt or cement to improve its ability to perform this function and uniformity. Unstable, ununiform base can be a cause for the early distress.

With aging, pavements service condition degrades. At this point the agency has several options. The rehabilitation option can be either overlay, replace or FDR (for asphalt) the existing pavement and place a new surface course. Comparison of different strategies are given in Table 1. Reclamation benefits are very similar to a structural overlay, but sometimes the pavement structure degrades so much that a structural overlay cannot be applied.

Table 1. Comparison of different strategies for rehabilitation of asphalt pavement

	Reclamation	Structural Overlay	Removal and Replacement
Fast Construction	Yes	Yes	No
Traffic disruption lower	Yes	Yes	No
Minimal material hauling	Yes	Yes	No
Conserve resource	Yes	Yes	No
Maintain existing elevation	Yes	No	Yes
Low cost	Yes	Yes	No

As given in Figure 2., a rehabilitation strategy can be implemented if the service condition gets lower levels than expectations. FDR and a new overlay can be one of the rehabilitation options.

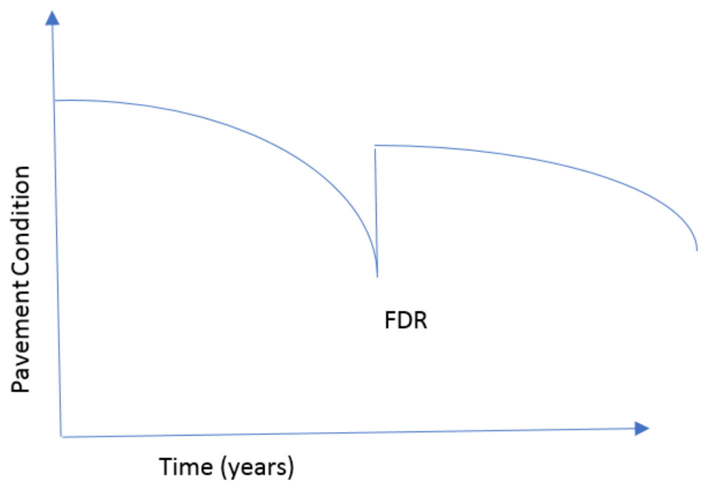


Figure 2. Pavement Service Condition and rehabilitation

Maintaining the existing elevation may sometime be important. If the existing elevation is not maintained, the agency might have to adjust curbs, infrastructure (manholes etc.) in urban areas or remove some of the pulverized material to other areas. In rural areas, if the elevation is not maintained more fill might be needed for the shoulders.

B. FDR Construction

Full Depth Reclamation (FDR), is a reconstruction of the existing pavement involving the recycling of surface and sometimes its bases and subbases into a new base layer. In FDR, the reclaimer pulverizes the existing surface, its base, subbase sometimes subgrade. Blending, stabilizing and compacting the recovered material creates an upgraded and uniform base material.

FDR Construction process is shown in Figure 3. a reclamation machine pulverizes the existing pavement, base course and sometimes portion of the subgrade together according to the required thickness. Sometimes the geometry of the pavement changes and the extra pulverized material can be used for extra lane, shoulders etc. If you want to keep the elevation the same, some of the material might need to be removed.

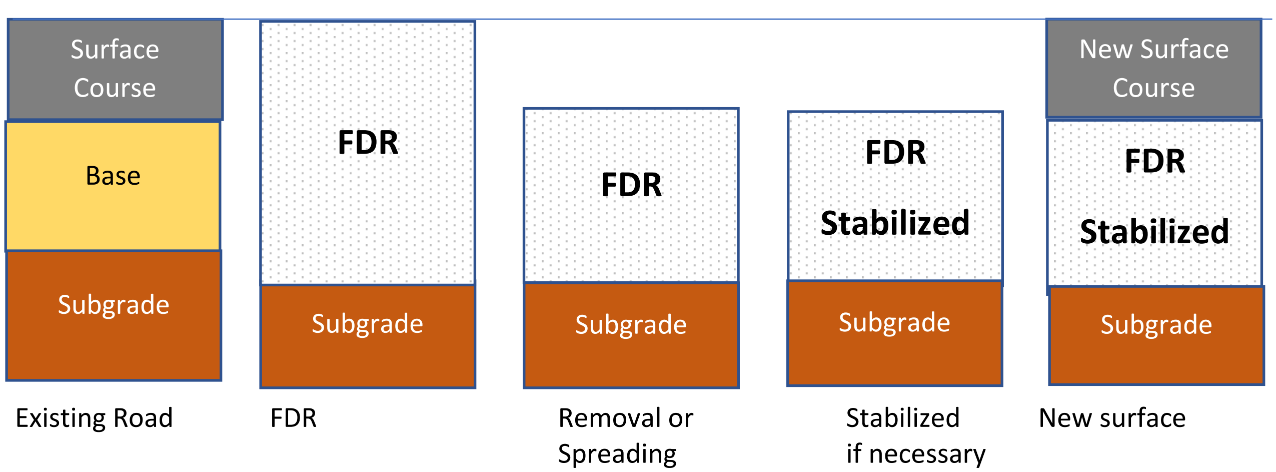


Figure 3. FDR Construction Process

FDR Treatment depths vary depending on the thickness of the existing pavement structure, but generally range between 4 to 12 inches (100 and 300 mm). It can be as thick as 24 inches. But if it is too thick these sections might need to be compacted in multiple lifts. With FDR the materials in place are utilized and service life of the pavement is renewed (Figure 2) . Sometimes more material is added if necessary. Figure 4 shows how stabilizing agents are added. It can be either added by the reclaimer or spread and mixed with the pulverized material. Stabilizing agent is added to increase the stiffness against the loads.

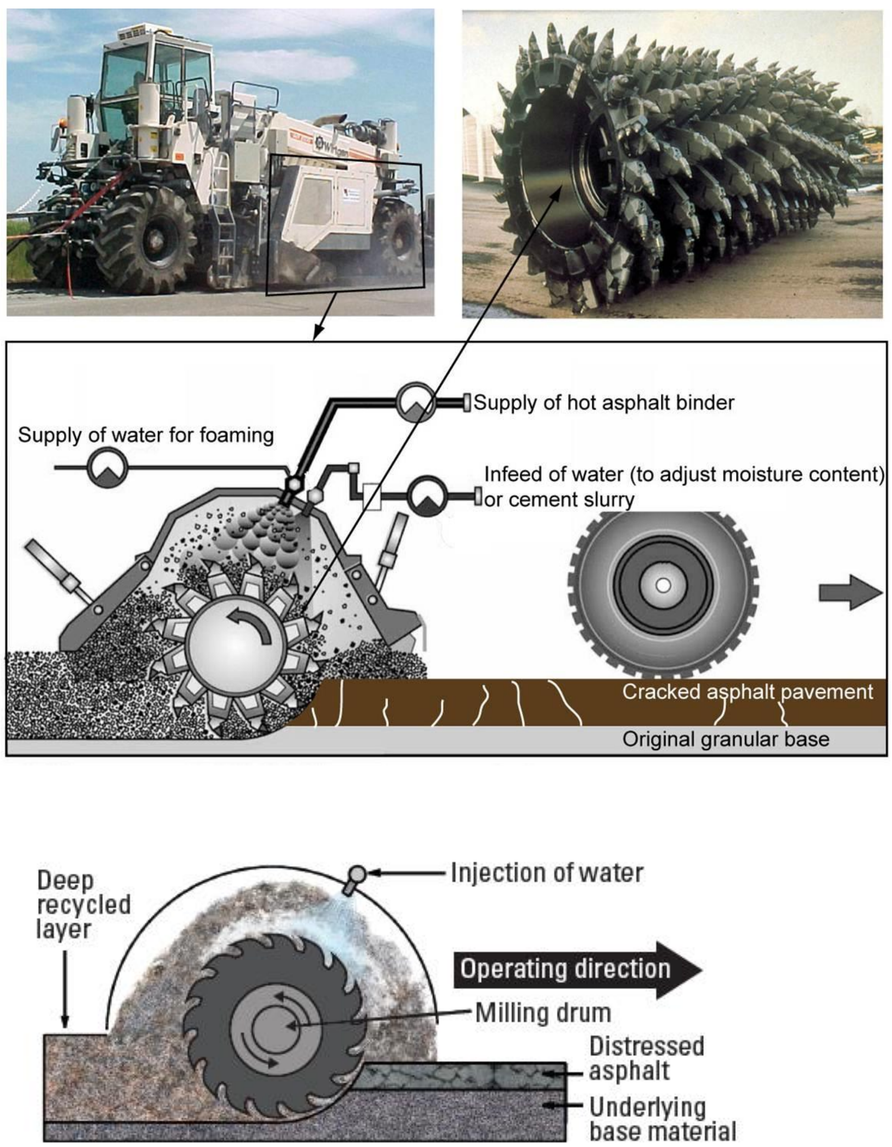


Figure 4. Schematic of a reclaimer [[3]], [[4]]

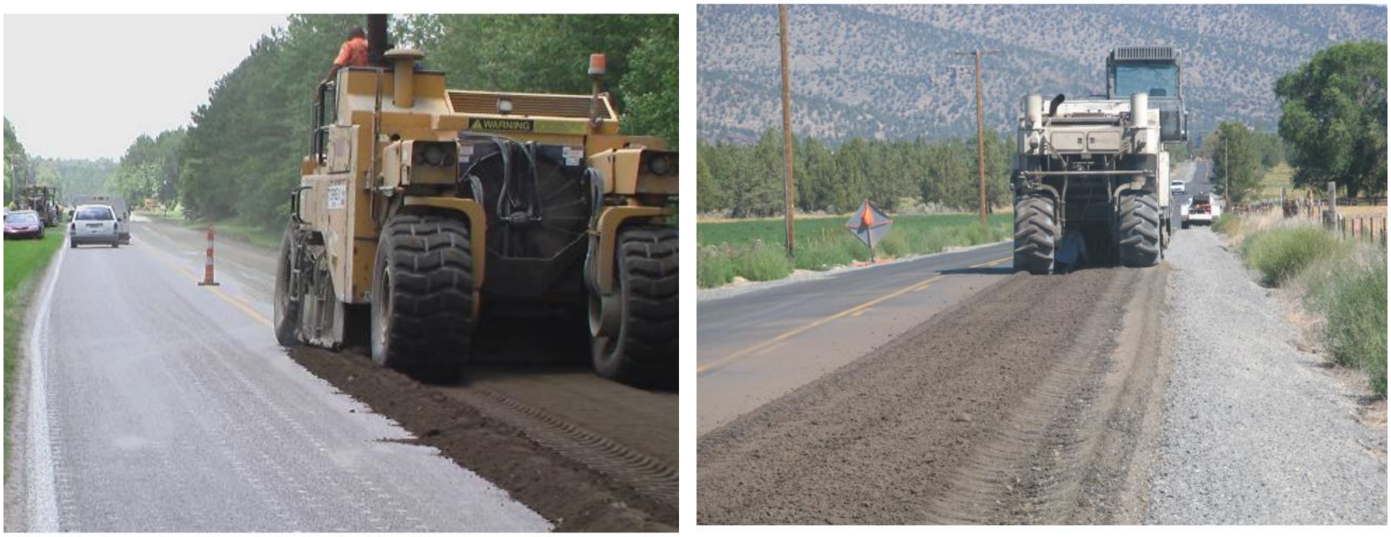


Figure 5. Reclaimed existing pavement [[4]]

FDR reclaimer working mechanism is given in Figure 4. Milling drum is driven over the existing pavement. Drum pulverizes pavement with bases according to required depth. In Figure 5 pulverized base is shown behind the reclaimer. After or during pulverizing stabilizing agent is added if needed. After pulverizing FDR is compacted as close as possible to maximum dry density. (Figure 6)

Figure 6. Final compaction of FDR with tamping roller and smooth wheeled vibrating roller [[4]]

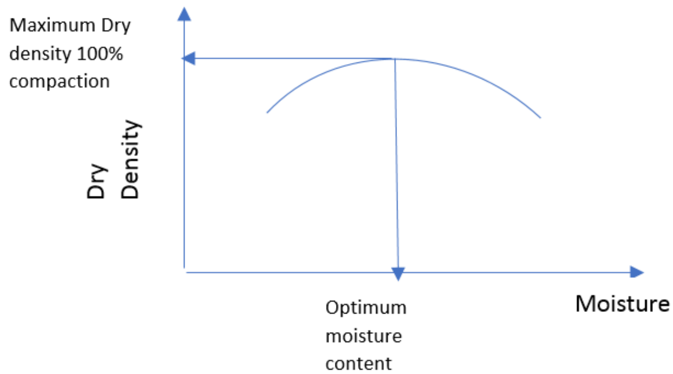


Figure 7. Finding optimum moisture content for maximum dry density

If the base is at the optimum moisture content maximum dry density can be achieved as given in Figure 7. If the base is too wet or too dry the maximum dry density may not be reached. Before starting the project, tests are done to determine optimum moisture content. Water is added during or after pulverizing FDR to reach the optimum moisture content. FDR is compacted as close as to dry maximum density as possible. In Figure 8 density and compressive strength relation is given. As the density increases the strength of FDR also increases. Material is compacted to optimum density. Generally, 95-98 percent minimum standard Proctor density.

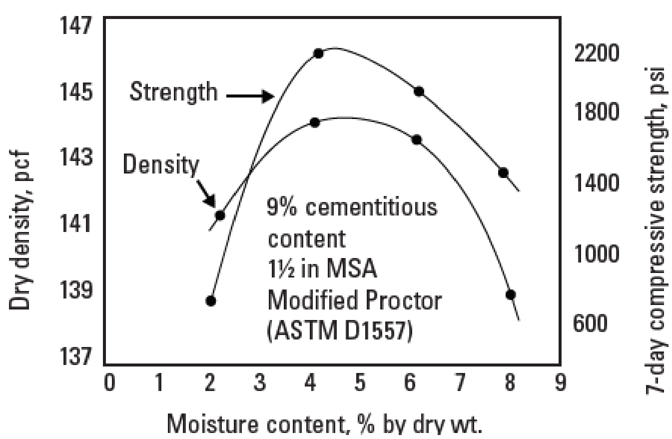


Figure 8. Relationship between density and compressive strength[[4]]

C. Different FDR and stabilization types

Types of Full Depth Reclamation with stabilization:

- Mechanical stabilization (addition of aggregate)

Mechanical stabilization relies on the particle interlock between the pulverized mixture of existing pavement and subsurface layers.

- Chemical stabilization (addition of cement or other stabilization additive)

In chemical stabilization, bond is achieved with one of the following;

Portland Cement

Lime

Class C or Class F Fly ash

Lime kiln dust

Calcium chloride

Magnesium chloride

Other proprietary materials (Baseone etc.)

- Bituminous stabilization

Bituminous stabilization is achieved by mixing pulverized asphalt pavement and subsurface materials with emulsified asphalt or foamed asphalt.

- Geosynthetic Stabilization

Geotextiles are either woven or nonwoven fabrics can be used for separation, filtration, stabilization, and reinforcement of bases or subgrades. Woven fabrics are typically used in reinforcement applications. Nonwoven geotextiles are used mainly for separation and filtration. Geotextile provides lateral restraint of the base and subgrade and provides stabilization, reinforcement and increases stiffness of the base. Geotextile increases interface friction, which reduces horizontal deformations and increasing stability.

Geogrids are mesh-like structure formed by tensile elements with openings. The granular fill materials gets through these holes and interlock with geogrids. Geogrids are primarily used for reinforcement and confinement. They can provide reinforcement uniaxial, biaxial, or in triaxial.

The following benefits achieved with SDFR [[4]] ;

- Cost effective
- Increased structural capacity
- Increased durability
- Road geometry can be changed
- Shorter construction schedule
- Early opening to traffic
- Reduced impacts on community during construction
- Reduced environmental impact

In Table 2 and Table 3, different types of FDR stabilizer additives for different base materials are given. As you can see, different stabilizers may be applied with different soil types.

Table 2. Stabilization additive recommendations with different types of soil [[5]]

Percent Passing No.200	Plastic Index	Stabilizer	Soil Type												
			Granular Material								Silt-Clay Material				
											LL<50			LL≥50	
			Well Graded Gravel	Poorly graded gravel	Silty gravel	Clayey gravel	Well-graded sand	Poorly graded sand	Silty sand	Clayey sand	Silt, silt with sand	Lean clay	Organic silt/organic lean clay	Elastic silt	Fat clay, fat clay with sand
			GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	MH	CH
			A-1-a	A-1-a	A-1-b	A-1-b or A-2-6	A-1-b	A-3 or A-1-b	A-2-4 or A-2-5	A-2-6 or A-2-7	A-4 or A-5	A-6	A-4	A-5 or A-7-5	A-7-6
<25	<6	Bituminous	■	■	■	■	■								
	<10	Cement	■	■	■	■	■	■	■	■					
	>10	Lime								■					
≥	10	Cement				■			■	■	■				
	10-30	Lime								■		■		■	■
	>30	Lime+cement								■		■		■	■

Table 3. Stabilization additive selection guide [[6]]

TABLE 1. STABILIZATION ADDITIVE SELECTION GUIDE [2]

Reclaimed Material Type	Well-Graded Gravel	Poorly Graded Gravel	Silty Gravel	Clayey Gravel	Well-Graded Sand	Poorly Graded Sand	Silty Sand	Clayey Sand
USCS(1) Classification	GW	GP	GM	GC	SW	SP	SM	SC
AASHTO(2) Classification	A-1-a	A-1-a	A-1-b	A-1-b A-2-6	A-1-b	A-3 A-1-b	A-2-4 A-2-5	A-2-6 A-2-7
Asphalt Emulsion SE(3)>30 or PI(4)<6 P200(5)<20%	■	■	▨	▨	▨	▨	□	□
Foamed Asphalt PI<10 5%<P200<20%	□	□	■	■	□	□	▨	□
Cement, CKD, and Fly-ash PI<20	▨	▨	■	■	▨	▨	■	■
Lime, LKD PI>20 P200<25%	□	□	□	▨	□	□	□	■

□ Not recommended ▨ Recommended ■ Highly Recommended

(1) Unified Soil Classification System, ASTM D 2487
(2) American AASHTO Association State Highway Transportation Officials, AASHTO M 145
(3) Sand Equivalent (AASHTO T 176 or ASTM D 2419)
(4) Plasticity Index (AASHTO T 90 or ASTM D 4318)
(5) Percent passing No. 200 (0.075 mm) sieve

Climate also has an effect in choosing the most appropriate stabilization additive. As you can see in Table 4, different stabilizing agents can be applied in different climates.

Table 4. Weather Limitations [[5]]

Type of Additive	Climatic Limitation for Construction
Lime, Fly Ash or Lime-Fly Ash	Do not perform work when reclaimed material could be frozen. Air temperature in the shade should be no less than 4ºC (39ºF) and rising. Complete stabilization at least one month before the first hard freeze. Two weeks minimum of warm to hot weather is desirable after completing the stabilization work.
Cement or Cement Fly-Ash	Do not perform work when reclaimed material could be frozen. Air temperature in shade should be no less than 4ºC (39ºF) and rising. Complete stabilization should be at least one month before the first hard freeze.
Asphalt Emulsion	Do not perform work when reclaimed material could be frozen. Air temperature in the shade should be no less than 15ºC (59ºF) and rising. Asphalt emulsion stabilization should not be performed if foggy or when other high humidity conditions (humidity >80%). Warm to hot dry weather is preferred for all types of asphalt stabilization involving cold mixtures because of improved binder dispersion and curing.
Calcium Chloride	Do not perform work when reclaimed material could be frozen. Air temperature in shade should be no less than 4ºC (39ºF) and rising. Complete stabilization should be at least one month before the first hard freeze.

SFDR has been regarded as a cost-effective method for pavement rehabilitation. Some recommendations have been proposed on the mix design of SFDR based on field experience. Experimental investigation of the deformation characteristics of SFDR materials has also been performed. However, there is still a lack of understanding of how the SFDR properties could influence the overall long-term behavior of the pavement, which is important for developing a method to determine the desirable SFDR properties for a given application. [[7]]

D. Comparison of different cement soil applications

Cement-treated base (CTB) is a fully bound, compacted, engineered mixture of aggregate, water, and cement. CTB results in a stronger, durable, frost-resistant layer within the pavement structure. Typical seven-day confined strength for CTB range from 300 to 400 psi. More detailed information about CTB can be found in the PCA publication [[8]]

In Table 5 distinctions between different cement application on bases are given. The differences between different cement based products are given in Figure 9. FDR has low cement and water content compared with other products.

Table 5. Differences between different cement application on pavement base[[9]]

Soil-Cement Type	Cement-Modified Soil (CMS)	Cement-Stabilized Subgrade (CSS)	Cement-Treated Base (CTB)	Full-Depth Reclamation (FDR)
Purpose	• Promotes soil drying • Provides a significant improvement to the working platform • Provides a permanent soil modification (does not leach)	• Provides all the benefits of CMS plus the following: - Potentially allows for a reduction in pavement thickness or increased pavement life - Increases the bearing capacity for building slabs, footings, and other structural elements	• Provides a strong, frost-resistant base layer for asphalt or concrete pavements	• Provides a strong, frost-resistant base layer for asphalt or concrete pavements
Materials	• Primarily fine-grained soils • 2%–4% cement	• Primarily fine-grained soils • 3%–6% cement	• Primarily coarse-grained manufactured materials • 3%–6% cement	• Pulverized asphalt blended with existing pavement base, subbase, and/or subgrade • 3%–6% cement
Material Properties	• Reduced moisture susceptibility	• 100–300 psi (0.7–2.1 MPa) seven-day compressive strength	• 300–600 psi (2.1–4.1 MPa) seven-day compressive strength	• 300–600 psi (2.1–4.1 MPa) seven-day compressive strength
Construction Practices	• Minimum 95% of maximum density • Mixed in place	• Minimum 95% of maximum density • Mixed in place	• Minimum 95%–98% of maximum density • Mixed in place or at a plant	• Minimum 95%–98% of maximum density • Typically mixed in place

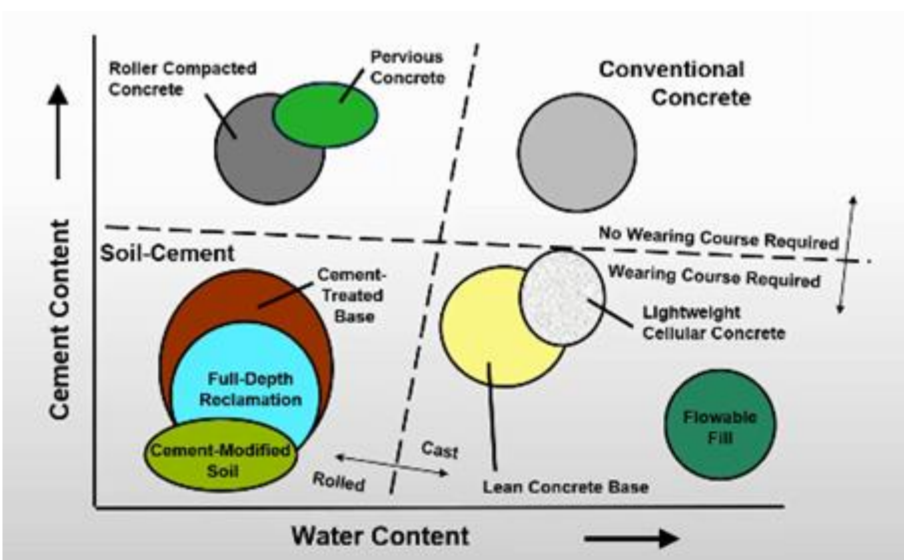


Figure 9. Cement Based Pavement Materials [[10]]

E. Quality Control of FDR During Construction

Following tests and more may be done during FDR construction for Quality Control.

- Sieve Analysis (ASTM D 422 C136)
- Atterberg limits (ASTM D4318)
- Moisture Density (ASTM D558):
- Durability Tests (Wet-Dry ASTM 559, Freeze Thaw D560)
- Soluble Sulfate (ASTM C1580)
- Compressive Strength (ASTM D1633)

i. Sieve Analysis:

Different sieve analysis may be required. ASTM D422 or ASTM C136 may be specified.

Standard Test Method for Particle Size (Analysis of soils ASTM D422)

Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates (ASTM C136)

Portland Cement Association recommend the following gradation for FDR with cement stabilization:

3inch sieve passing 100%

2inch sieve passing min 95%

#4 sieve passing min 55% [[10]]

ii. Moisture - Density

Moisture test is done regularly to have the optimum moisture content to achieve maximum dry density. (Figure 7)

iii. Compressive Strength (For cement stabilization)

Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders

Generally specified for cement stabilized FDRs. 7 day strengths are generally specified ranging from 300psi to 600psi.

Total structural capacity of the FDR base layer increases with the thickness and strength. But especially with the cement stabilized FDR with the increased strength base is more susceptible to shrinkage and cracking.

Cement and water content of the mix is lower for FDR with cement stabilization compared with conventional concrete as given in Figure 9. In Figure 9 different cement mixes are compared according to their cement and water content. If cement is used for stabilization curing is necessary. FDR is sealed with bituminous compounds or externally cured with water.

F. Spring Thaw Effect on FDR

After full depth reclamation, the base under the pavement becomes more homogeneous. This decreases the amount of future faulting and cracks caused by differential settling. In Figure 10 [[11]] , you can see original pavement and pavement after FDR. FDR with stabilizing agent provides a more homogenous base under the pavement. [[11]]

Little is known about the effect of spring thaw on SFDR pavements. Previous research indicated the FDR with cement process provided positive benefits for agencies that had previously experienced heaving in the winter or loss of shear strength during spring thawing events with their existing pavements. [[4]]

Moisture intrusion is also another aspect in choosing the right FDR stabilization additive. Moisture can infiltrate into un-stabilized FDR more easily and cause softening of the base material and reduce its strength and stiffness.

In Figure 11 [[11]] and Figure 12 [[11]] you can see subgrade resilient modulus of different stabilizing agents. As you can see from Table 6, State Route 13 is stabilized with cement. Cement performs better in reducing variability and differentiation during seasons. It also gives a more reliable and homogenous base for the pavement.

Table 6. Average Layer Thickness (in) for Full Depth Reclamation Demonstration Projects [[11]]

Material	Route 40				Route 13		Route 6	
	EB	WB	EB	WB	EB	WB	EB	WB
	Foamed asphalt		Asphalt emulsion		Portland cement		Portland cement	
HMA	2.5	2.2	2.2	2.2	3.3	3.9	3.4	3.8
Reclaimed layer	10.4	8.3	9.1	10.5	9.1	9.3	10.1	8.1
Aggregate layer	3.8	3.6	3.0	2.5	2.5	2.4	1.8	2.0

EB: East Bound, WB: West Bound

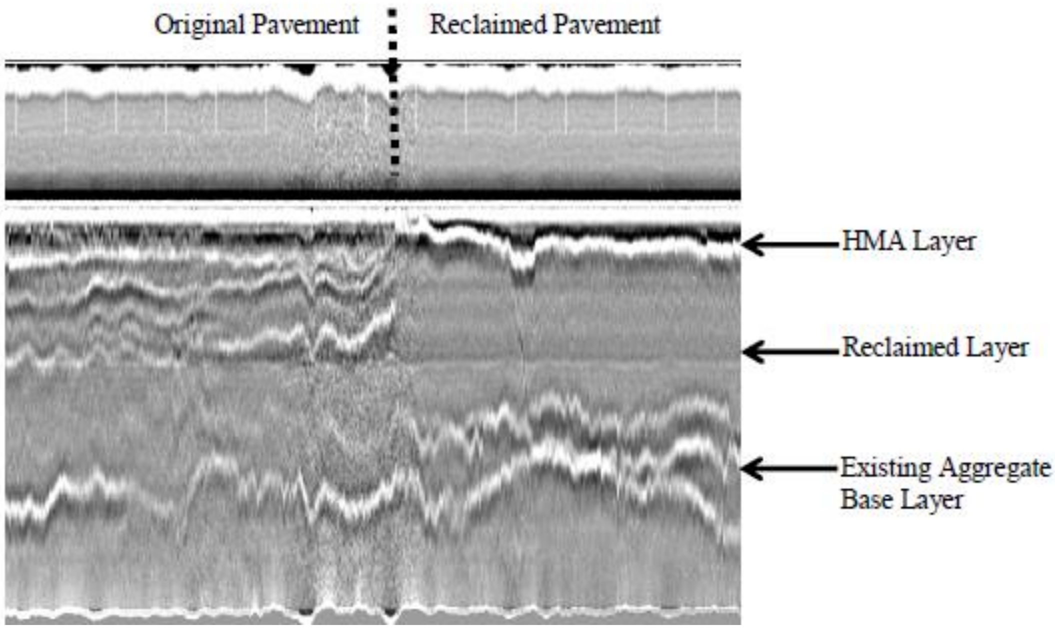


Figure 10. State 40 Ground Penetrating Radar Results. HMA =hot-mix asphalt [[11]]

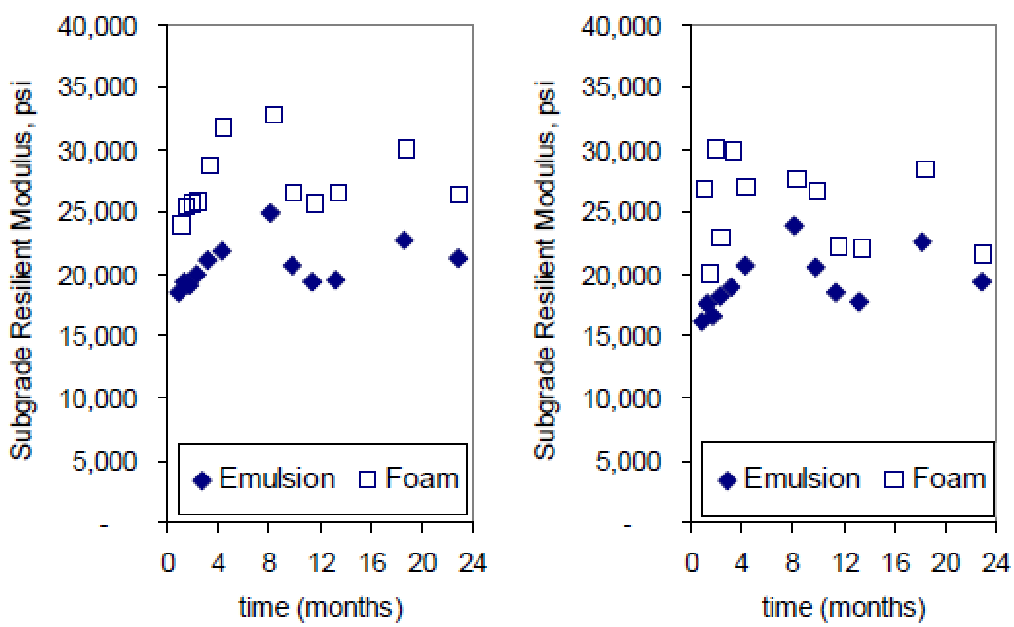


Figure 11. Subgrade resilient Modulus, state route 40: eastbound (left), westbound (right) [[11]]

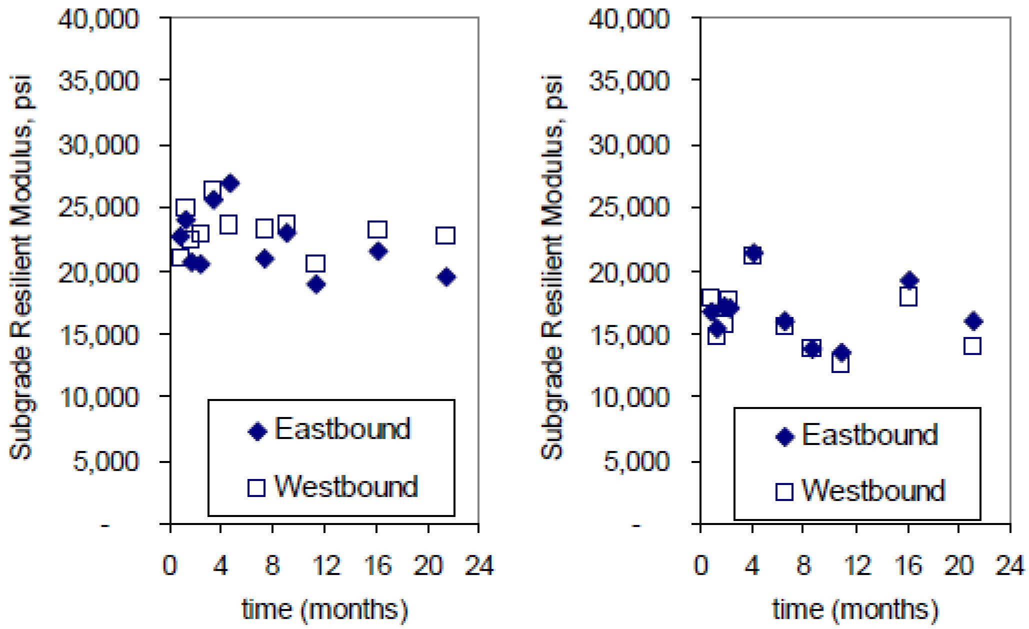


Figure 12. Subgrade Resilient Modulus for State Route 13 (left) and State Route 6 (right) [[11]]

G. Methodology

The following tests will be done on FDR:

1. Thickness measurement:

The thickness of the base effects the pavement performance. The thickness of the base will be compared with plans and the measured thickness will be used to evaluate the condition of the pavement.

2. If stabilized strength of the base.

If the base is stabilized with cement, fly ash or other chemical stabilizing agent the strength of the base will be obtained. This strength will be as substructure properties.

3. DCP (Dynamic Cone Penetrometer) value

DCP value will be used to evaluate substructure properties to use in calculations.

4. If the base is unstabilized sample will be taken for gradation (from shoulder if open)

FDR gradation and its effect of substructure properties that obtained above will be compared.

5. GPR (detail will be given in concrete overlay section):

GPR will be used to evaluate whether the layers are homogeneous, layer thicknesses, observe voids.

The following tests and documentation will be done on each concrete overlay:

1. Coring: Compressive strength ASTM C42 [[13]] (Thickness measurement)

Concrete strength will be used as a property to evaluate the condition of the pavement.

2. GPR (Ground Penetrating Radar)

GPR values will be used to evaluate the thicknesses of the layers, voids and pavement profile.

3. Joint lay out and faulting

Joint layout will be used in calculations and evaluation of concrete pavement condition.

4. Crack mapping (visual survey) and width measurement (D cracking, fatigue cracking, crack reflection etc.)

Pavement distress will be done and concrete pavement condition will be evaluated.

5. FWD (Falling Weight Deflectometer)

FWD values will be used to evaluate the pavement condition and load transfer capability and observe base effects.

The Tests will be performed as given below:

1. Coring:

Compressive strength will be measure on the cores that are obtained from cement stabilized FDRs. These cores will be subjected to unconfined compressive strength testing.

Each core will be measured to the nearest ¼-in. Cores will be cut with a 4 or 6-in. diameter bit, and the holes can be filled with cold mix patch or mortar. The core samples will be obtained to a depth of 6 in. below the anticipated bottom of the FDR layer at each sample location, as the FDR thickness may be adjusted based on the material gradation.

Visual inspection of the cores will be made and recorded before compressive strength testing. Any segregation or voids in the core will be recorded. Also the density of the cores prior to testing will be taken. If the material is not stabilized a sample will be taken for sieve analysis.

After coring the pavement, a DCP (Dynamic Cone Penetrometer) test will be applied on the FDR and subgrade layers.

3 cores will be taken for strength measurement of the concrete overlay. Density of cores will be measured and they will be investigated visually. 2-3 cores will be taken from cracked areas. The crack propagation to FDR layer will be investigated.

A rotary core drill will be used, accompanied by a hollow cylindrical barrel (perpendicular to the pavement), to cut into the pavement and obtain the sample for testing. Core drill bit of 4 or 6 inches will be used.

Thickness of the concrete pavement will be measured at three different sides of the core and average will be taken.

2. Thickness measurement

The thickness measurement of the base will be done visually, if it is not stabilized, after coring. (If the core is intact from the core , if not from dredged material from the core hole.) If high PH stabilizers are used phenolphthalein will be used to identify the depth.

3. GPR(Ground Penetrating Radar)

Ground penetrating radar (GPR) is a non destructive method for analyzing pavements and subbases. We can get the map the conditions of pavement , base and subbases. GPR can detect thicknesses and anomalies of the pavement and subbases.[[15]]

Ground Penetrating Radar (GPR) uses a short pulse of electromagnetic energy which is transmitted to ground and reflected signals are returned to the receiver. The time taken for a pulse to travel to and from the target gives information about its depth and location. The reflected signals are interpreted.[[15]].

Using GPR on the pavements following properties can be obtained:[[14]]

i. Depressions
ii. Layer thicknesses
iii. Voids
iv. Pavement profile

GPR analysis will provide the following information about the pavement:

- Road surface depressions
- Voids or anomalies
- Pavement and subgrade thicknesses

4. Condition Survey: Joint layout, faulting, Crack mapping (visual) and width measurement (D cracking, fatigue cracking, crack reflection etc.)

Pavement distress will be measured and recorded according to “Concrete Pavement Distress Assessments and Solutions”. [[16]]. Pavement distresses will be observed and measured according to Table 7.

Table 7. Condition Survey		
Observed Distress	Subset	Parameters
Surface Defects	Map Cracking Plastic Shrinkage Scaling Surface Polishing/wear Popouts / mortar flaking	Photos will be taken with a scale and crack widths will be measured. Affected area will be estimated. If available the depth will be measured.
Surface delamination		Affected area and depth will be measured. Photos with scale will be taken.
Material related cracks: (visually)	D-cracking Alkali-silica reactivity (ASR) Alkali-carbonate reactivity (ACR)	Photo with scale, crack width, affected area.
Transverse and Diagonal Cracking		Photo with scale, crack width, crack length, check faulting, core if necessary
Longitudinal Cracking		Photo with scale, crack width, crack length, check faulting, core if necessary
Corner Cracking		Photo with scale, crack width, affected area, check faulting, core if necessary
Faulting		Measure with scale, photo
Joint Curling and Warping		Measure with scale, photo
Blowups		Photo
Subgrades and Base Support Conditions		Photo

5. Falling Weight Deflectometer

The FWD generates a pulse by dropping a weight that transmits this to the pavement through steel load plate. With the effect of the pulse load at different distances pavement deflects. [[17]]

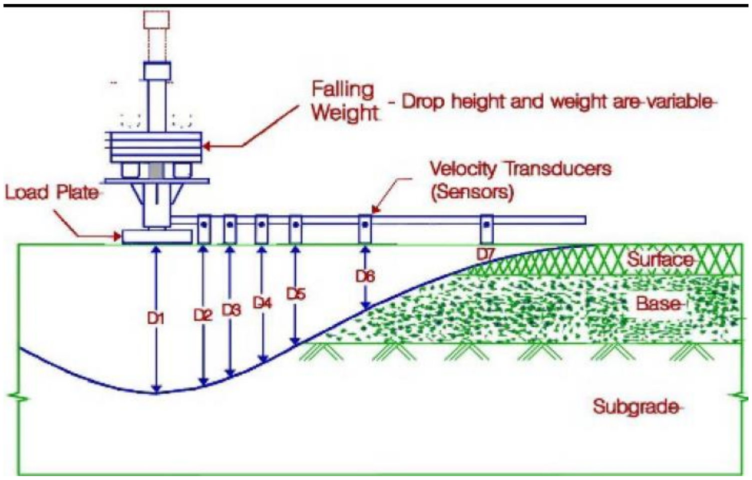


Figure 19. Loading and deflection with FWD [[17]], [[18]]

Some of MnDOT State Aid recommendations are as follows[[17]]:

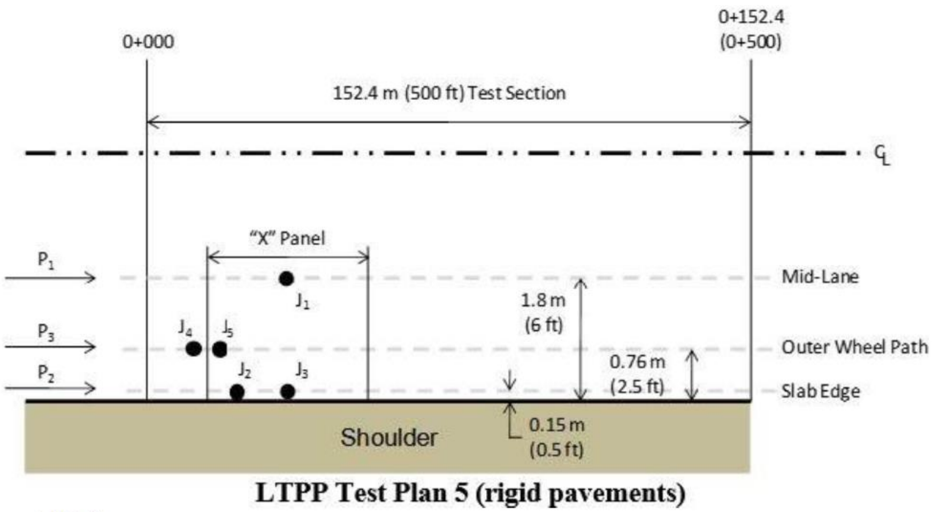
- Specify testing frequency (single lane one direction, two lanes both directions, distance between test locations).
  - Preferred testing frequency is MnDOT standard of every 500 ft. in outer wheel path in both directions.
  - Minimum testing frequency is every 1,000 ft. in outer wheel path in most heavily traveled lane (one direction).

Loading will be applied on the pavement as given in Table 8. The load application will be done on the points given in Figure 20. The sensors will be set in FWD as given in Table 9.

FWD data and other properties obtained from base and pavements will be used in back calculation.

Table 8. Recommended FWD Loading for PCC Pavements[[18]]

Height Designation	Target Load (kN (lbf))	No. of PCC Drops
Seating[b]	N/A	3
1[c]	26.7 (6,000)	N/A
2	40.0 (9,000)	4
3	53.4 (12,000)	4
4	71.2 (16,000)	4



1 m = 3.28 ft.

P_1, P_2, P_3 = Pass through mid-lane, pavement edge, and outer wheel path, respectively.

F_1, F_3 = Measurement location along P_1 and P_3, respectively.

J_1, J_2, J_3, J_4, J_5 = Measurement location along P_1—mid-panel, along P_2—corner, along P_2— mid-panel, along P_3—joint approach, and along P_3—joint leave, respectively.

CL = Center line.

Figure 20. Test Plan for PCC Pavements [[18]]

Table 9. Geophone Locations for PCC Pavements[[18]]

Deflection Sensor	Seven Sensors (PCC) (mm (inches))
D1	0
D2	−305 (−12)
D3	305 (12)
D4	457 (18)
D5	610 (24)
D6	914 (36)
D7	1,524 (60)
D8	N/A
D9	N/A

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