Performance of Concrete Overlays over Full Depth Reclamation (FDR)

A Research Proposal for the National Road Research Alliance

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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. The environmental effects of the projects will be lower.

Concrete overlays can serve as a sustainable and cost-effective solution. They do not need major rehabilitation and they usually perform longer than expected. 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 infrastructure with lower environmental impacts.

In this proposal we will investigate the current situation of concrete overlays that were built over different types of FDR.

Pavement condition data such as transverse cracking, longitudinal cracking, D-cracking, joint spalling, and faulting 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.

Introduction and Background

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.

What is FDR?

Full Depth Reclamation(FDR), is a reconstruction of the existing pavement with recycling existing pavement and its bases and subbases into a new base layer. In FDR, the reclaimer pulverizes the existing asphalt pavement, its base, and subbase.

Full Depth Reclamation (FDR) is the process of pulverizing a roadway's flexible pavement section and a portion of its underlying base, and crushing and blending the recovered material to create a uniform base material. Stabilized Full Depth Reclamation (SFDR) pulverizes the flexible pavement section and a portion of the underlying base in the same way as FDR. In SFDR, stabilizing agents are added.

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 asphalt 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

- Bituminous stabilization

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

The following benefits achieved with SDFR [1] ;

- 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

Full depth reclamation increases the structural capacity of the new pavement, so there is a less expectancy of faulting in joints.

In Table 1, different types of FDR stabilizer additives for different base materials are given. As you can see, different stabilizers can be applied with different soil types.

Table 1. Correlation of stabilization additive as a function of soil type, percent passing No. 200 sieve and plastic index [2]

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								■		■		■	■

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. [3]

Climate also has an effect in choosing the most appropriate stabilization additive. As you can see in Table 2, different stabilizing agents can be applied in different climates.

Table 2. Weather Limitations [2]

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.

In full depth reclamation, the base under the pavement, becomes more homogeneous. This decreases the amount of faulting and cracks caused by differential settling. In Figure 1 [4] , you can see original pavement and pavement after FDR. FDR with stabilizing agent provides a more homogenous base under the pavement. [4]

Little is known about the effect of spring thaw on SFDR pavements. The 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. [1]

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 2 [4] and Figure 3 [4] you can see subgrade resilient modulus of different stabilizing agents. As you can see from Table 3, State Route 13 is stabilized with cement. Cement performs better in variability and differentiation during seasons. It also gives a more reliable and homogenous base for the pavement.

Table 3. Average Layer Thickness (in) for Full Depth Reclamation Demonstration Projects [4]

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

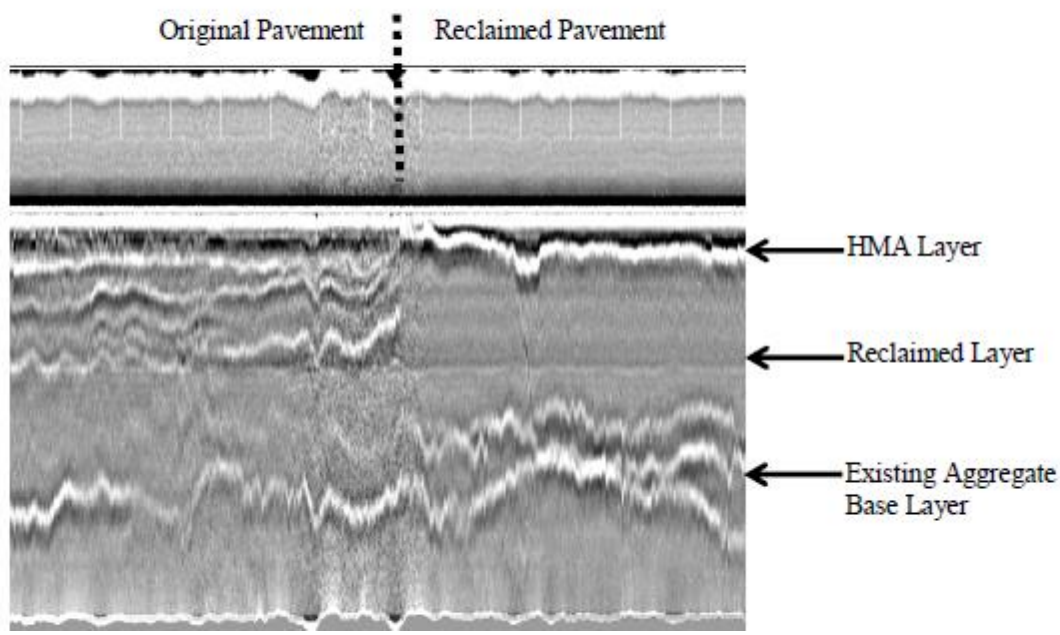

Figure 1. State 40 Ground Penetrating Radar Results. HMA =hot-mix asphalt [4]

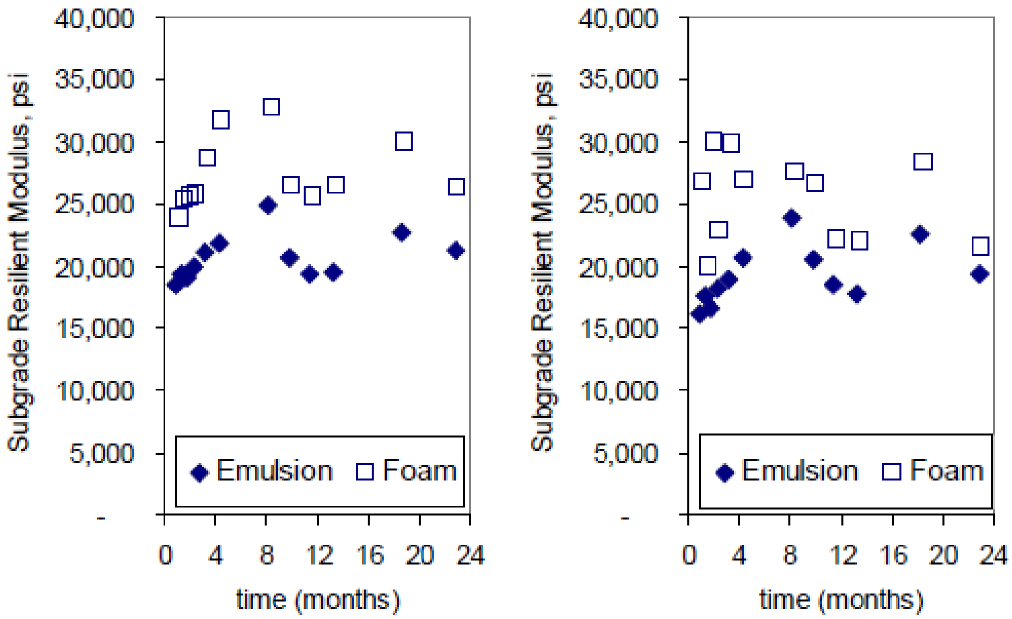

Figure 2. Subgrade resilient Modulus, state route 40: eastbound (left), westbound (right) [4]

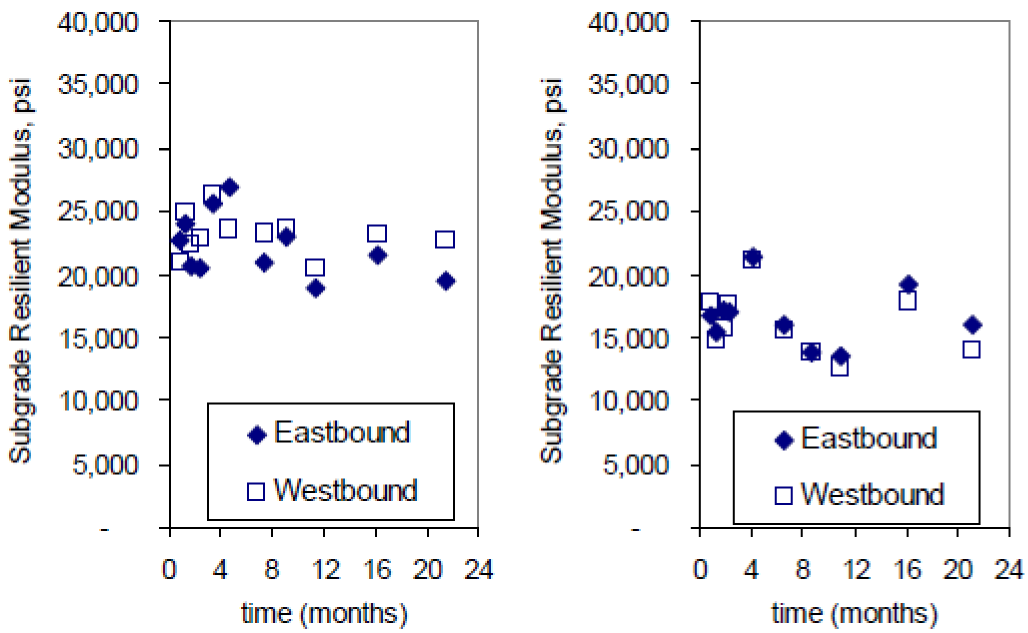

Figure 3. Subgrade Resilient Modulus for State Route 13 (left) and State Route 6 (right) [4]

Previous FDR Researches in Minnesota

In MnROAD, full depth reclamation with rigid overlay has not been investigated. There were three stabilized full depth reclamation (SFDR) sections (Cells 2, 3, and 4) constructed at the Minnesota Road Research Facility on I-94 in 2008. Cells 2 and 3 on mainline each were constructed using a bituminous overlay. Each was constructed over 6” of full depth reclaimed surface course treated with an engineered emulsion. Cell 4 had 3” of the same bituminous mix as in Cells 2 and 3 over 8” treated FDR.

FDR was investigated for local streets in “Full-Depth Reclamation (FDR) for Suburban/Urban and Local Roads Application” research by LRRB December 2016. [5]

Concrete overlays over FDR has not been fully investigated, and design procedures have not been fully established. This initial phase study will help to develop a potential second phase to study new research cells with concrete overlays over FDR.

Proof of Concept

There have been several projects completed in Minnesota and other states with FDR and concrete overlays. Wabasha CSAH 2 & 25 (2015), Rice CSAH 46 (2016), Fillmore CSAH 1 (2018), The Freeborn County Road 46(2008) and Mcleod County overlay are example projects.

These projects will be included in the investigation if approved by TAP. There are also concrete overlay projects that were completed on FDR in other states like Iowa, Michigan, Wisconsin and Illinois. The projects that will be included in the research will be decided with TAP from NRRA. This research will help us understand the differences between bases and their effects on concrete overlays.

Objectives

The objective of the study is to measure the performance of concrete overlays on different Full Depth Reclamations.

Variables

For this research variables will be properties of concrete overlays and full depth reclamation. Thickness and joint spacing of concrete overlay; and type (un-stabilized or stabilized with different materials), strength and thickness of FDR; and current concrete overlay condition to include faulting, cracking, D cracking, GPR and FWD.

Hypothesis

Hypothesis of this research is that properties of Full Depth Reclamation affects concrete overlay performance. FDR should be made with optimum density and strength. Reflection of cracks and FDR properties will be related. Concrete pavement design over FDR is not fully established. The conditions of the pavements will be evaluated and correlation with FDR properties will be made.

Methodology

To verify the hypothesis the following tests will be done on FDR:

1. Compressive Strength ASTM C42 [6]
2. Thickness measurement
3. GPR (Ground Penetrating Radar)

The following tests will be done on concrete overlay:

1. Compressive strength ASTM C42 [6]
2. Joint lay out and faulting
3. Thickness measurement
4. Crack mapping (visual) and width measurement (D cracking, fatigue cracking, crack reflection etc.)
5. FWD (Falling Weight Deflectometer)
6. GPR (Ground Penetrating Radar)

Data on surface rating, and pavement quality index will be obtained. The relations supporting the hypothesis will be investigated.

The results will be shared with Concrete Pavement Design professionals. The next phase of the study, which is to establish a design methodology for concrete overlays over FDR, will be established. Papers will be prepared for NCC, TRB and NRRA Meetings. For the next construction season in MnROAD, the outcomes of this research will be used to design different concrete overlays on FDR. (Bonded, unbonded, RCC with joints, RCC without joints)

Schedule

This project will be completed in two years. Progress deliverables will be submitted at periods given in the schedule. Progress presentation will be given every 6 months. Reviews of TAPs will be considered during all phases. Five different projects will be chosen from different states. The project details (mix design, base properties, soil properties, traffic data, IRI etc.) will be included in the final report if available. Bonding condition will be investigated visually during coring.

Task	2020-1st half	2020-2nd half	2021-1st half	2021-2nd half
Task 1: Literature Review and investigation of projects	Literature review and candidate projects will be submitted March 2020. **Deliverable:** Literature review and list of candidate projects			
Task 2: Determine 5 projects that will be investigated concrete overlays on FDR	5 projects will be determined by TAP among candidate projects in May 2020 TAP Meeting: **Deliverable** List of projects			
Task 3: Testing Projects (1-2)		**Deliverable:** Test Results of 2 projects November 2020 (FWD, GPR, Core results, joint layout and crack mapping)		
Task 4: Testing (Projects 3-4-5)			**Deliverable:** Test Results of 3 projects June 2021 (FWD, GPR, Core results, joint layout and crack mapping)	
Task 5: Data Analysis			Test data with available project details will be presented to TAP to draw conclusions in June 2021 **Deliverable:** Presentation of results	
Task 6: Draft Report				**Deliverable:** Draft report September 2021
Task 7: Final Report				**Deliverable:** Final Report November 2021

Budget

This research project will be funded through awarded grant, partner resources.

Staff Time	Units (estimate)	Unit Cost(estimate)	Total Cost(estimate)
PI salary *	**60 hours**	**$70/hour**	**$4,200**
Testing			
Coring Labor	40hours	$70/hour	$2,800
Coring Equipment Rental (trailer +generator)	10 days	$300/day	$3,000
Coring Mobilization	200 miles per site 5 different sites	$3.2/mile	$3,200
Compressive & Density Testing	30 specimens	$130/specimen	$3,900
FWD&GPR	5 different sites		
GPR	5hours per site 5 different sites	$216/hour	$5,400
FWD	5hours per site 5 different sites	$225/hour	$5,625
Mobilization (GPR-FWD)	200 miles per site 5 different sites	$3.2/mile	$3,200
Project Engineer	4 hours per site 5 different sites	$197/hour	$3,940
Crack and fault mapping – Labor *	**5 different sites 10 hours per site**	**$120/hour**	**$6,000**
Crack and fault mapping – Mobilization	200 miles per site 5 different sites	$3.2/mile	$3,200
Total			**$44,465**
Industry contribution (in-kind) (PI Salary and Crack and fault mapping – Labor *)			**$10,200**
NRRA Contribution			**$34,265**

* Aggregate Ready-Mix Association of Minnesota, Concrete Pavement Association of Minnesota will make in-kind contribution for PI salary, and crack/fault mapping investigations.

Partnerships

Following associations or firms agreed to support the project with their contribution discussed in the budget, along with their expertise:

1. Concrete Pavement Association of Minnesota (NRRA Associate Member)
2. Aggregate Ready Mix of Minnesota (NRRA Associate Member)

If available, we will ask for support from MnDOT and other state DOTs for historical data of the project and traffic control & testing (FWD, MIRA or GPR).

References

1. Garret D. Reeder, Dale S. Harrington, Michael E. Ayers, Wayne Adaska, *"Guide to Full-Depth Reclamation (FDR) with Cement"*, National Concrete Pavement Technology Center, Iowa State University, Ames IA, March 2017
2. Dennis A. Morian, P.E., Mansour Solaimanian, Ph.D., P.E., Barry Scheetz, Ph.D., P.E., Shervin Jahangirnejad, Ph.D. *"Developing Standards and Specifications for Full Depth Pavement Reclamation"* , Commonwealth of Pennsylvania Department of Transportation, Conneaut Lake PA, May 2012
3. Jia-Liang Le, Mihai Marasteanu and Rose Milavitz, Investigation of Performance Requirements of Full-Depth Reclamation Stabilization, MnDOT LRRB, September 2016
4. Brian K. Diefenderfer, Alex K. Apeagyei, "Analysis of Full-Depth Reclamation Trial Sections in Virginia", Virginia Center for Transportation Innovation and Research 530 Edgemont Road Charlottesville, VA , April 2011
5. Marcella Hartman, Mugur Turos, Debaroti Ghosh, Mihai Marasteanu , Full-Depth Reclamation (FDR) for Suburban/Urban and Local Roads Application, Department of Civil, Environmental and Geo- Engineering University of Minnesota 500 Pillsbury Drive, Minneapolis, MN 55455, December 2016
6. ASTM C42 / C42M-18a, Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete, ASTM International, West Conshohocken, PA, 2018, www.astm.org

Commentary

This study will be the phase I of the project of "Concrete overlays over FDR". In phase II, cells will be constructed using the outcomes of this project.