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Full Depth Reclamation Resource Guide

FOR URBAN AND SUBURBAN STREET APPLICATION

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15. Supplementary Notes

Appendix A – MN Local Agency FDR Survey Results (Report number: 2021RIC02A)
https://www.mndot.gov/research/reports/2021/2021RIC02A.pdf

Appendix B – Shoreview Special Provisions Example - Editable Word doc (Report number: 2021RIC02B) https://www.mndot.gov/research/reports/2021/2021RIC02B.pdf

16. Abstract (Limit: 200 words)

Full-depth reclamation (FDR), a common strategy on rural roadways to reduce costs for materials and hauling, was validated to be a viable long-term and cost-effective option for urban and suburban asphalt pavement rehabilitation. These findings were published in two Minnesota Local Road Research Board studies from 2016. However, statewide application of Urban FDR is yet to be attained in Minnesota or widely adopted by city and county public works departments.

To help cities and counties determine feasibility, the Minnesota Local Road Research Board developed informational materials on how to conduct Full-Depth Reclamation (FDR) within urban areas (i.e. curb-and-gutter, utilities, storm sewers, manholes, etc.).

Topics include:

- Basic Overview of FDR
- FDR Candidate – What to Consider
- Specification/Construction Inspection
- Cost

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Introduction

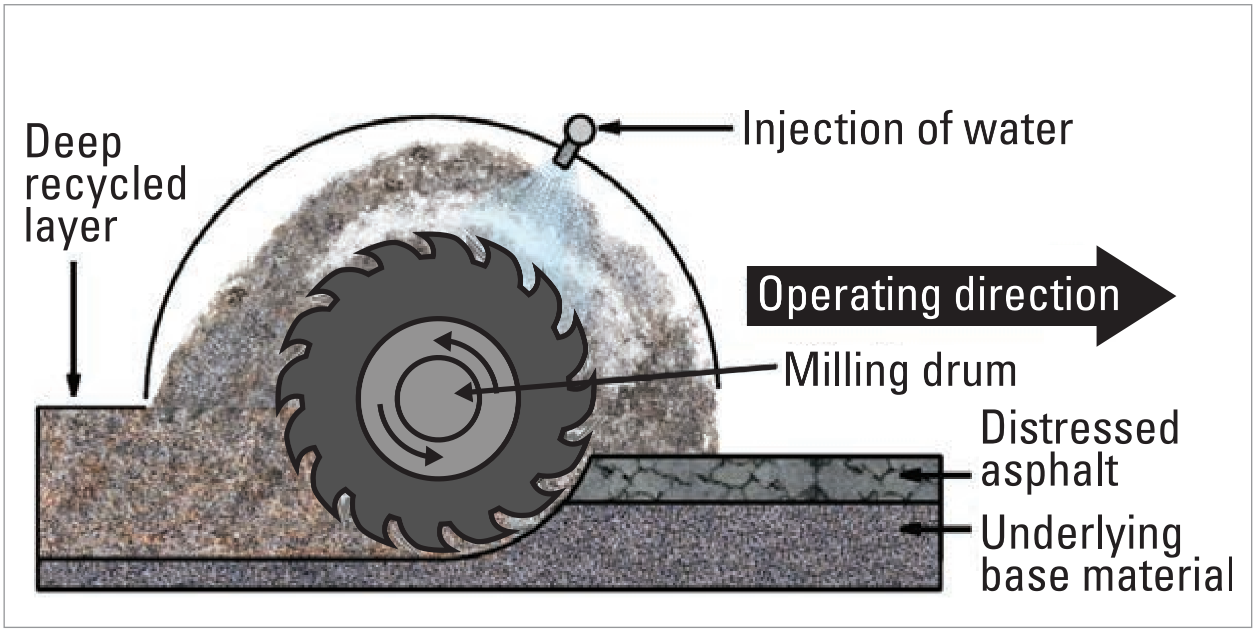
The question of feasibility of Full Depth Reclamation (FDR) in an urban setting has been asked by city and county engineers across Minnesota. FDR is a viable strategy in an urban environment when a simple mill and overlay is insufficient. In fact, several Minnesota cities have been programming this cost-effective strategy with strong support from the communities they serve.

This Resource Guide is a research synthesis that borrows/leverages other technical documents to help cities and counties determine feasibility and conduct FDR within urban areas. The Basic Asphalt Recycling Manual (BARM) by the Asphalt Recycling and Reclamation Association was predominantly sourced. A list of all technical documents may be found under Resources.

Basic Overview

Full Depth Reclamation (FDR) is a cost-effective, greener alternative "rehabilitation method in which the full thickness of the asphalt pavement is pulverized and blended with a predetermined portion of underlying materials (base and/or subbase) to provide an upgraded, homogeneous material"[1]. FDR does not include stabilizing agents; this unbound blended material alone is enough to act as a new surface base. "The use of a laboratory mix design and addition of a stabilizing additive redefines FDR as Stabilized Full Depth Reclamation or SFDR" [2].

“SFDR is the method of performing a Full Depth Reclamation through pulverization of a bound surfacing layer and blending a stabilization/modification additive into the pulverized/reclaimed material to produce a homogeneous base material” [2].



Source: BARM Figure 16-2

There are three different methods of stabilization, which include the following varying stabilizing agents: (For more information see Chapter 15 of the BARM) [1]

- **Mechanical Modification** – granular materials (e.g. new aggregate) or recycled materials (e.g. reclaimed asphalt pavement (RAP), add rock or crushed concrete) to improve load carrying capacity of the FDR layer.
- **Chemical Additive** – cement (portland or hydraulic), lime (hydrated or quicklime), self-cementing class C fly ash, class F fly ash (when used in combination with other additives), cement kiln dust, lime kiln dust, calcium chloride, magnesium chloride or proprietary products.
- **Bituminous Additive** – emulsified asphalt or foamed (expanded) asphalt.

“Modifiers or additives that may be used in similar ways for stabilization/modification and include proprietary products, in general do not have design procedures or laboratory and field verification testing to identify contributions to the pavement structure and confirm long term sustained performance” [2]. In other words, stabilization is a result of a laboratory mix design process from materials extracted from the field. Without a mix design, the additives should be referred to as modifier, because the improved material properties cannot be accurately or fully accounted for in the pavement design prior to construction.

Description of Process, Equipment, Materials

Although FDR equipment continues to evolve and will vary from contractor to contractor, the outcome remains relatively the same. The Pavement Preservation & Recycling Alliance (PPRA) is a great online resource for full depth recycling; go to roadresource.org for more information. The minimum equipment required for the FDR process, as described on PPRA, includes:

- Self-propelled reclaimer (typical length is 30-35 feet)
- Motor grader
- Water truck with spray bar
- Pneumatic-tired, pad foot and/or double drum vibratory rollers for compaction

Optional equipment for use in an urban setting may include skid steers and/or small mill machines to traverse around utilities in small spaces or along curb lines.

For FDR projects that include an application of a stabilizing agent and additive, additional equipment is needed. As described on PPRA, they include a variation of the following:

- End or bottom dump haul trucks
- Windrow sizer or calibrated aggregate spreader
- Calibrated bulk spreader for dry stabilizing agents and additives
- Mixer and/tankers for slurry application of stabilizing agents and additives
- Emulsified or hot asphalt tankers for bituminous stabilization
- Computerized emulsified asphalt or foamed asphalt injection system on the reclaimer

Aggregate material type and gradation influence reclamation and stabilization design choices. Pulverization is the process in which the full thickness of asphalt pavement and a predetermined portion of the base or subgrade is uniformly pulverized and blended to provide an upgraded, homogeneous material. In many cases, pulverization will result in a suitable base for a new surface course. This is full depth reclamation. If FDR without stabilization is not sufficient, then a stabilizing by mechanical, chemical or bituminous means maybe determined through a mix design process to provide the necessary structural support. (summarized from PPRA)

Additives most used in Minnesota, sometimes in combination include:

- Granular Materials (new aggregate or reclaimed asphalt pavement (RAP) or crushed concrete)
- Emulsified Asphalt or Engineered Emulsion
- Base One (proprietary product)
- Other less common options include cement, lime, magnesium chloride or other proprietary products such as Dust Ex from Lignotech (currently being tested in Grant County and used extensively in Norway)

Pros and Cons of FDR?

Pros: (Verbatim from PPRA)

- 40 to 80% less expensive than alternative reconstruction techniques
- Reuses up to 100% of existing materials
- Same day return to light traffic
- Importing and exporting of materials can be reduced by 90%
- Cuts down on greenhouse gasses
- Elimination of all existing surface distresses
- More flexible in application than CIR

Green technology
Reuses up to 100% of materials.

Cons:

- Lack of mechanics-based material testing procedures and performance-based specifications
- Higher initial cost than CIR/HIR or mill and overlay
- More complex traffic control
- Initial public reaction, length of disturbance
- Destroys survey monuments
- In curb and gutter sections, the economics of hauling excess materials off-site in order to maintain the centerline and curb line profile may be prohibitive.
- Challenging in high traffic areas
- Generally, must be surfaced with HMA overlay to achieve adequate ride quality.

How many years of service can be expected from FDR/SFDR projects?

According to Pavement Preservation & Recycling Alliance, FDR can extend the life of the road for up to 25 years. "The limiting factor for service life of FDR treated pavements is typically the service life of the surface course and not the FDR mixture itself." (PPRA)

A Tale of One City – Shoreview's Strategic Investment In SFDR

The City of Shoreview has been using Stabilized Full Depth Reclamation (SFDR) as a pavement rehabilitation technique since 2007. For urban applications, the City of Shoreview has by far the most comprehensive documentation and experience with SFDR as a strategic tool in managing 100 miles of local and state-aid streets. Prior to 2007, the City's approach was primarily mill and overlays, crack filling, sealing, patching and chip sealing. Shoreview researched SFDR as a new tool with the goal to reduce/eliminate reflective cracking and more importantly, extend the pavement life 25 years and beyond. "Engineering the appropriate mix design based on in place conditions heads off most problems upfront, this is an intelligent risk versus past practices", says Director of Public Works Mark Maloney.

Based on performance, SFDR has become the City standard for pavement rehabilitation, significantly optimizing infrastructure investments from a life cycle costing perspective. Shoreview also experienced the added benefit of increased public satisfaction in higher performing pavements (little to no cracking) and expanding construction intrusion beyond the traditional mill and fill life expectancy. City Engineer Tom Wesolowski noted, "In the service life of our SFDR pavements, we would have had two overlay projects in that same time frame had they stayed with their mill and overlay program. This is important because public expectations and patience for repeated construction inconvenience is limited".


WIRTGEN

FDR Candidate – What to Consider

Existing deficient pavement structure can be improved into a new homogenous section with increased structural capacity and/or better flexibility with the addition of a stabilizing/modifying additives. Varying the depth of treatment and stabilizing agent allows optimization of surface course type and thickness.

Required minimum thicknesses (asphalt, base)

There is no minimum thickness of existing asphalt surface or aggregate base required before implementing FDR. Future performance expectations will determine the mix design of the reclamation and use of stabilization along with economic considerations. Uniformity is important. Thus, pavements with variable patches in size and depth may require additional coring to determine best mix design or multiple mix designs. Required layer thickness is determined through pavement design, which considers future traffic levels and loading.

How much material can/should be reclaimed?

Reclamation can range from 4 inches to 20 inches in a single pass, although typically the upper limit is 14 inches with current equipment. The desired thickness is determined during the pavement and mix design procedures. In a rural environment, several inches of asphalt surface maybe milled and removed prior to the reclamation process. Typically, in an urban setting, all the material is reclaimed with any excess reclaimed material either incorporated on site or removed for use on other projects.

Compaction of any FDR or SFDR layer thicker than 6 inches also needs to be considered. It should be expected that the FDR material will need to be placed and compacted in more than one layer when the thickness exceeds 6 inches, unless the contractor can demonstrate the ability to achieve density throughout the thicker layer.

Pavement condition/distresses (when/when not to):

FDR can be used on most pavement conditions and distresses. FDR is especially successful in improving ride quality on pavement surfaces with patches, rutting, settlement, heaves, cracking or other surface distresses. FDR can remedy pavement structure failures with excessive stripping or debonding of pavement layers. Even if a pavement has minimal surface distresses, FDR may be selected if the added goal is increasing structural capacity.

Subgrade soils (and what to do/consider when poor):

FDR can be used to correct subgrade problems. Where limited aggregate base exists, adding virgin granular material, otherwise referenced as 'add rock,' on top of the pavement section before reclaiming can enhance the structural capacity of the base course. In addition to mechanical modification/stabilization, bituminous or chemical modification can improve performance of the overlay by reducing cracking and tensile stresses.

Consideration of the subgrade strength to support the reclamation operation, as well as interim local traffic needs prior to the placement of the final surfacing, should be determined in advance. The subgrade should be firm and able to support, without yielding, the construction equipment and compaction of the reclaimed material.

Excess Material

There are few limitations on where not to use full depth reclamation. There can be considerations regarding excess material in constrained environments like curb and gutter sections or where there is limited right-of-way to accommodate stockpiling which may dictate hauling reclaimed material off-site. Generally, the reclaimed material exceeds a one to one ratio but may be incorporated into the design of increasing the cross slope. In some cases, excess material may be removed via milling ahead of the reclamation and used as RAP or in hauling excess reclaimed material away from the project for use on other projects, which may not be cost effective. Rarely a disqualifying factor for use of urban full depth reclamation, none the less, the cost of hauling excess material needs to be considered with the improved cross section versus say a mill and fill project type.

What to know/consider regarding condition of below ground utilities

Even where subgrade improvement for drainage/poor soils is required or where limited utility replacement is necessary, FDR can be applied with additional steps. Reclaimed material can be stockpiled on or off-site ahead of subgrade/utility work and then placed after compaction is achieved.

Addressing issues with underground utilities while using FDR is like a mill and overlay. There are two common practices:

- Castings and valve boxes can be removed and covered with metal plates to a depth 4 inches below the planned reclamation.
- Manholes/valve boxes may be left in place, marked well and squared off from the reclamation.

Many urbanized applications have found that full depth bituminous patches around structures mitigates settlement issues and compaction challenges near manholes/valve boxes.

How to evaluate, what inspection/testing should be done?

Prior to performing a mix design, identifying the existing typical section and if there is a uniform pavement section in place is important. Review of the construction plans, if available, is a good start. A thorough site assessment leads to successful mix designs and may include:

- coring and aggregate base sampling
- ground penetrating radar (GPR) identifying any variability in asphalt or aggregate base thicknesses
- Falling Weight Deflectometer (FWD) testing
- soil borings to determine subgrade soil conditions

The site assessment may indicate that FDR or stabilized FDR is not the appropriate approach for the roadway. Limiting factors that may be identified during the site assessment include:

- Weak underlying subgrade that will not withstand the construction process.
- Roadways where the aggregate base has high p200, or the aggregate base is contaminated with fines from the underlying subgrade, that will not lend itself to a stabilizing agent.
- If the pavement structures in place vary and are different throughout the length of the project, it may be difficult to maintain a uniform, consistent design.
- Areas with a high-water table or wet aggregate base that has not been corrected with subsurface drainage and could affect construction or compaction.
- Roadways with significant grade changes, which would require a lot of moving the reclaimed material prior to stabilization. A more economical approach may be more feasible.

When to stabilize

Designers may consider stabilizing the full depth reclamation to enhance the physical properties of the existing base and subgrade. Stabilization can increase the flexibility, shear strength of a soil and/or control the shrink-swell properties of a soil; thus, improving the load bearing capacity of a sub-grade to support pavements and expected traffic loads.

Mechanical, bituminous, or chemical processes can all increase the structural integrity of the base material. Most agencies default to mechanical stabilization due to upfront costs. Injecting bituminous or chemical stabilizers can result in greater flexibility, increased base strength and reduced surfacing layer. Economic evaluation of various pavement and mix designs can help an agency optimize their investment.

Many municipalities may avoid stabilized full depth reclamation based on a perception of operational challenges due to the length of the 'train'. The addition of a liquid stabilizing agent injected into the reclaimer's pulverization/mixing chamber requires a "nurse" truck, a tanker connected to the reclaimer as shown below. Most communities can accommodate this configuration.

Source: BARM Figure 16-8

Limitations to stabilization and FDR

- Poor weather conditions
- Significant utility conflicts
- Lack of contractor capability
- Weak underlying subgrade that will not withstand the construction process
- Existing section includes geotextiles
- Roadways where the aggregate base has high p200, or the aggregate base is contaminated with fines from the underlying subgrade.
- Variability in the pavement or base across the width of a pavement, such as when additional lanes have been added after original construction, and the materials used and potentially the pavement structures in place are different.
- Areas with a high-water table, that potentially would affect construction or compaction.
- Areas with a wet aggregate base that has not been corrected with subsurface drainage.

- Roadways with insufficient aggregate base in place beneath the SFDR layer to provide adequate subsurface drainage.
- Roadways with significant grade changes, which would require a lot of moving the reclaimed material prior to stabilization.

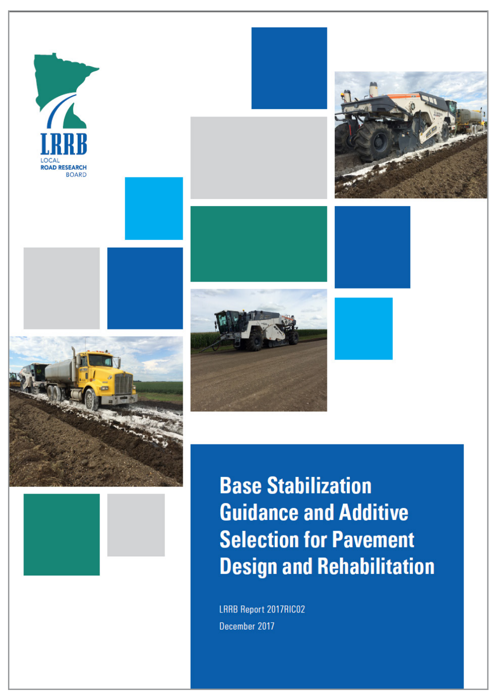
How is the amount/application process of stabilizing agent determined?

With base stabilization a stabilizing agent is added to an aggregate base material to improve the physical properties and/or improve the load carrying capacity of the aggregate base. The mix design determines application rates. Performance tests used in mix designs are very different for various products and must be understood for proper selection. Cure time recommendations for in-situ conditions can also be recommended as part of the mix design process. The selection of a stabilizing agent is a function of:

- Planned thickness of the pavement structure
- Aggregate material properties (gradation, plasticity, etc.)
- Amount of strengthening required
- Availability of stabilizing agents
- Economics
- A wide range of bituminous and chemical stabilizing agents are currently available and are used to improve physical properties and/or moisture resistance of aggregate base materials.

How to pick the most appropriate stabilizing agent

The selection of a stabilization additive depends heavily on the properties and uniformity of the aggregate material (gradation, plasticity, etc.), experience, and economics. The Base Stabilization Guidance and Additive Selection for Pavement Design and Rehabilitation, December 2017 is an excellent resource for binder selection. Bituminous stabilization is better suited for cleaner aggregate materials, including sands and gravels, that are not infiltrated by marginal silty or clayey material. Chemical stabilization is better suited for aggregate materials that are finer or have been infiltrated by marginal silty and/or clayey materials.



Mix designs can be performed in house with qualified lab staff or can be performed through a professional services contract. Typical cost of mix designs varies based on the site assessment work included. Below is an example of mix designs and what to consider.

Option A:

A six-inch-thick asphalt pavement with 6 inches of aggregate base

The intent is to mill 3 inches, stabilize 6 inches and overlay with 3 inches of new bituminous. In this case, the required mix design will be a 50/50 blend of bituminous and aggregate base.

Option B:

Same six-inch-thick asphalt pavement with 6 inches of aggregate base

Instead of planning a mill and SFDR project, the City/County chooses to do a 9 inch reclaim prior to stabilization and then remove 3 inches of the reclaimed material. This approach is sometimes chosen when doing some crown corrections or if there are some locations where the roadway profile is being changed and the extra reclaimed material can be moved to these locations, which would allow the mix design to be consistent throughout the project. This approach would result in a 67% asphalt/33% aggregate base blend, which typically would require less emulsion or foamed asphalt to stabilize due to the higher bitumen content in the blended material.

The BARM FDR201A: Recommended Mix Design Guidelines is a great resource.

Specification/Construction Inspection

Customize for local agency (vs MnDOT)

With the 2018 MnDOT specification update, Section 2215 was revised and now includes stabilized full depth reclamation. The City of Shoreview has a great deal of experience in this area and their special conditions are attached as Appendix B.

Construction Observation/Quality Control

At a minimum, field staff should monitor the following:

- Chunks of oversized material is a common challenge on reclamation projects. Prior to compaction, contractor personnel and inspector can monitor for larger chunks and manually place back in front of the reclaimer. Inspectors should monitor the speed of the reclaimer and the door openings of the cutting chamber to ensure proper blending and gradation.
- Verify that the stabilizing agent is being mixed to the required depth and that the blending/mixing of water and stabilizing agent is adequate to ensure a homogenous, consistent blend throughout the treatment section.
- Monitor the amount of water introduced to maintain the specified range of optimum moisture content.

- Verify that the reclaimed mixture is placed to the proper depth, grade and cross-slope. Verify that the width of reclaiming overlaps the previous pass by the required minimum amount.
- If chemical stabilization is used, restrict overall time from initial blending of chemical stabilizers through final rolling to no more than 2 hours and in some cases within 30 minutes.
- Optimal moisture and compaction should be monitored as the rolling pattern is established.

The Federal Highway Administration has developed a useful [FDR Construction Checklist](#).

Cost

The City of Shoreview has calculated the general cost (per SY): $16 - $32 for FDR. Selecting FDR or SFDR needs to factor in life cycle value, environmental benefits, structural enhancement, etc.

Agencies could utilize [roadresource.org](#) program which is one of the most comprehensive tools currently available. While not a design tool, this online resource quickly identifies opportunities for project type selection with just a few inputs of the existing conditions. Users should also keep in mind that the tool is geared towards structural coefficients rather than granular equivalencies. The City of New Ulm evaluated their future North Broadway project using the Structure and Cost Comparison tool offered at [roadresource.org:](#)

Conventional: Reconstruction

Many agencies are learning that the use of limited funds toward a "worst first" approach accelerates the decline of their overall network, as miles of good roads go untreated each year.

Layer Type	Depth (in)	Co-Eff	$/SY/in	Cost	SN
Cold Planing	4	0.00	$1.00	$4.00	0.00
Remove Granular Base	8	0.00	$0.33	$2.64	0.00
HMA	4	0.44	$4.65	$18.60	1.76
Granular Base	8	0.14	$1.88	$15.04	1.12

Cost/SY: $40.28
Overall Structural Number: 2.88

VS.

Optimized: Full Depth Reclamation

Consider an Optimized approach, which reallocates funds across more efficient strategies to keep good roads good and help you get ahead of the curve.

Layer Type	Depth (in)	Co-Eff	$/SY/in	Cost	SN
HMA	2	0.44	$4.65	$9.30	0.88
Cementitious FDR	8	0.23	$1.23	$9.84	1.84
Existing Granular Base	4	0.10	-	-	0.40

Cost/SY: $19.14
Overall Structural Number: 3.12

When compared to conventional methods, FDR can achieve...

Project cost depends on many factors that are constantly changing:

- Increasing the structural capacity through stabilization can reduces aggregates needed by 30-50%.
- By improving the characteristics of aggregates, a lower quality aggregate can be used, thus offering increased savings by using lower quality aggregates.
- Using in-place base stabilization reduces trucking costs.
- Using in-place base stabilization reduces construction time compared to removal and replacement.
- When considering years of added life expectancy, urban full depth reclamation may be equivalent or even exceed reconstruction expectations.

Project Resources

This Resource Guide and related educational materials produced by the LRRB are available at lrrb.org/fdr-urban, as well as the following direct links:

Full Depth Reclamation Resource Guide:
https://lrrb.org/2021RIC02.pdf

Appendix A – MN Local Agency FDR Survey Results:
https://lrrb.org/2021RIC02A.pdf

Appendix B - Shoreview Special Provisions Example (Editable Word doc):
https://lrrb.org/2021RIC02B.docx

Urban FDR Frequently Asked Questions:
https://lrrb.org/2021RIC02-FAQ.pdf

Urban FDR Education Video:
https://vimeo.com/srfconsulting/review/543675739/8378d53c7a

Link will be posted on the LRRB YouTube site

Other Resources

[1] Asphalt Recycling and Reclamation Association – ARRA (2015). "Basic Asphalt Recycling Manual (BARM)." Federal Highway Administration, Publication No. FHWA -HIF-14-001.

[2] Local Road Research Board (2017). "Base Stabilization Guidebook." http://www.dot.state.mn.us/research/reports/2017/2017RIC02.pdf

Pavement Preservation & Recycling Alliance. https://roadresource.org/

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FAQ's Using FDR Within Urban Settings

Can FDR be used in an urban area or just in the rural area? What are the urban challenges (curb-and-gutter, underground utilities, etc.)?

Yes, many Minnesota cities are now using FDR in urban settings. All the material is reclaimed with any excess reclaimed material either incorporated on site depending on typical section in place or removed for use on other projects. Reclamation around near curb and gutter and utilities is easy with talented operators.

Is there a MnDOT Specification (or Special Provision) available that specifically applies to urban design (i.e. curb-and-gutter/underground utilities)?

MnDOT Specification 2215 Reclamation can be modified by special provisions. The City of Shoreview has shared their special provisions – See Appendix B to the Urban Full Depth Reclamation Reference Guide found at lrrb.org.

What practices or precautions are used when doing reclamation on or around underground utilities? Is any special preparation work necessary?

Castings and valve boxes may be removed and covered with metal plates at a lower elevation out of the depth zone planned for pulverization. After reclamation is completed prior to final surfacing, castings are adjusted and placed to finish grade. Many urbanized applications have found that full depth bituminous patches around structures mitigates settlement issues and compaction challenges near manholes/valve boxes. On the other hand, manholes and/or valve boxes may be left in place, marked well and squared off from the reclamation.

FDR typically results in a thicker pavement structure (higher profile); how should this be accounted for within the confines of existing curb-and-gutter, utilities, intersections, driveways?

The desired thickness is determined during the pavement and mix design procedures. The typical section that exists in the urban setting will guide the use of excess reclaimed material by either incorporating on site for utility replacement backfill as an example or removed for use on other projects.

How close can the reclaimer get to utilities/curb and gutter?

Quality operators can navigate the reclaimer within inches of the curb line. Remaining asphalt can be cleaned up with skid steer operation. When utility castings at the surface remain in place, then the reclamation operator will mill up to one to two feet away. The remaining asphalt near castings can be removed with skid steer operations and typically full depth bituminous material is placed around the structure.

Does urban FDR require any special equipment?

Urban FDR without the use of a stabilizing agent requires the following:

- Self-propelled reclaimer
- Motor grader; loaders
- Water truck with spray bar
- Pneumatic-tired, pad foot and/or double drum vibratory rollers for compaction

Optional equipment for use in an urban setting may include small mill machines to traverse around utilities in small spaces or along curb lines. Milling may be done before or after reclamation if excess material is a concern.

How does the FDR process (equipment train) work within the confines of urban settings?

Cul-de-sacs and tight radii can still be a challenge especially for stabilized full depth reclamation. Where geometrics challenge use of stabilization, material can be removed manually, stabilized in another area of the project and hauled back to the cul-de-sac for placement. Work near curb and gutter and around utilities is easily accommodated as noted above.

Minnesota Local Road Research Board – Minnesota Department
of Transportation Office of Research and Innovation

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