Research Report

Assessment and Update of TIB Urban Program and Small City Preservation Program

Part 3: Full Depth Reclamation State-of-the-Practice

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SUMMARY

This document summarizes the research done by the University of Washington (UW) for the Washington State Transportation Improvement Board (TIB) on full depth reclamation (FDR) state-of-the-practice and project scoping, part 3 of a research contract between TIB and UW.

FULL DEPTH RECLAMATION (FDR) STATE-OF-THE-PRACTICE

Major findings:

- Current use trends
    - FDR is a viable alternative to full reconstruction and its use in the U.S. is growing.
    - FDR is appropriate for all levels of traffic and works well with most geometric road features.
    - FDR can be successful at depths as shallow as 2-4 inches.
    - FDRs are usually finished with an overlay or chip seal.
- Typical project selection process. Most guidance comes from the State DOT level and involves: visual distress survey, historical information review, pavement properties assessment, distress evaluation, preliminary rehabilitation selection, and economic analysis.
- Stabilizing agents are typically cement or asphalt.
- Properly designed and built FDR pavements should last 10-20 years or more.
- FDR shows substantial life-cycle cost savings over full reconstruction.

ANALYSIS OF EXISTING TIB FDR PROJECTS

Major findings:

- The median cost of FDR based on 4 TIB projects is $6.37
- FDR may cost 30-60% less than an equivalent reconstruction design

STAKEHOLDER INTERVIEWS

Major findings:

- FDR can be faster than typical reconstruction projects
- TIB FDR mix designs generally use cement stabilizer and aim for 200-300 psi unconfined 7-day compressive strength
- FDR projects require the input of a pavement engineer

NEED FOR A PAVEMENT ENGINEER

A pavement engineer is needed to verify scoping efforts, design a structural pavement section, and perform a laboratory mix design. The pavement engineer may need to be on-site for at least the start of construction in case structural or mix designs need adjusting based on field conditions.

FULL DEPTH RECLAMATION STATE-OF-THE-PRACTICE

Existing literature was reviewed to describe the current state-of-practice for Full Depth Reclamation (FDR) rehabilitation projects within the U.S. and Canada. A list of FDR specification examples and resources for more in-depth information are included.

CURRENT USE TRENDS

Much of the findings summarized below come from *NCHRP Synthesis 421: Recycling and Reclamation of Asphalt Pavements Using in-Place Methods* (Stroup-Gardiner, 2011).

- **FDR is a viable alternative to a full reconstruction.** There are numerous examples of successes (e.g., Lane and Kazmierowski, 2012; Miller et al., 2011, Lewis et al., 2006), however, examples of failure either rarely exist or are not reported on extensively.
- **The use of FDR by state DOTs has grown in the past decade and is nationwide.** Of the 33 states and 28 contractors surveyed about FDR experience in *NCHRP Synthesis 421*, 27% of state agencies has less than 5 years of experience with FDR projects. 18% of the state agencies has had experience with FDR projects for 5 to 10 years. The use of FDR by state agencies is well distributed throughout the nation (Stroup-Gardiner, 2011).
- **State agencies primarily rely on pavement distress surveys to determine the feasibility of a preservation method.** 61% of state agencies and 71% of contractors surveyed rely on distress surveys to identify structural distresses. A limited number of state agencies (24%) and contractors (14%) perform ride quality assessments to determine the smoothness of the existing pavement (Stroup-Gardiner, 2011).
- **State agencies typically use FDR for at depths of 6 inches or greater, however FDRs have been performed successfully with depths as shallow as 2 to 4 in.** State agencies prefer to use FDRs with depths greater than 6 inches (Stroup-Gardiner, 2011) however this may be due to most state highway pavements being relatively thick compared to local roads. Contractors surveyed in *NCHRP Synthesis 421* (Stroup-Gardiner, 2011) indicated FDR to depths of only 2 to 4 inches can and have been successful, especially on low-volume roadways (Stroup-Gardiner, 2011).
- **Stabilized FDR layers can support traffic levels up to and beyond 30,000 AADT**. The level of traffic is not a major factor in the scoping process for FDR projects, especially for low volume roads (Stroup-Gardiner, 2011).
- **FDR works great with most geometric features.** FDR is very good at accommodating roadway geometry and features. It can be used on tight turns, steep grades, manhole or other castings within pavement layer, widening, minor profile correction, and curb and gutters (Stroup-Gardiner, 2011).
- **FDRs are usually finished with an overlay or chip seal after the stabilized layer has cured.** Depending on the traffic volume and loading conditions, structural and non-structural overlays are frequently used as well as chip seals for lower volume roads (Stroup-Gardiner, 2011).

TYPICALY PROJECT SELECTION PROCESS

Literature on project selection guidelines comes from either DOTs or other owner agencies, or trade organizations and equipment manufacturers (e.g., Asphalt Recycling and Reclaiming Association – ARRA, WIrtgen, etc.). Most guidance tends to converge on the basic steps described here. Much of this description comes from the ARRA's *Basic Asphalt Recycling Manual* (Dunn and Cross, 2001).

Visual distress survey. Visual distress surveys are conducted to identify existing surface distresses of the pavement. Classification of distresses typically include surface defects, deformations, cracking, maintenance activities, base and subgrade deficiencies, ride quality, and safety. For each of these surface distress types, the severity and extent of the distress is recorded. The observed distresses can be related to material and construction deficiencies as well as by pavement loading conditions and climate effects.

Historical information review. This includes information on how the existing pavement was originally designed and constructed, construction testing data, any pavement management system data, and maintenance activity records. Historical information, if available, can help determine the causes of the pavement distresses observed from the visual distress survey, and can aid in the selection of an appropriate rehabilitation method.

Pavement properties assessment. This involves determining physical pavement properties in the field and in the laboratory in order to further determine the cause of pavement distress and an appropriate rehabilitation method. Field measurements can include roughness, rutting, friction, deflection and material properties measurements. Typically roughness and rutting can be obtained from existing distress records, while strength is estimated using deflection measurements from devices such as a Benkleman Beam or Falling Weight Deflectometers (FWD). These methods can be costly and time consuming so, simpler alternatives can provide useful but less detailed data. For instance, excavating test pits or obtaining core samples can identify the depths of the existing pavement layers. Samples from each layer and the subgrade can be obtained for further lab testing to determine the classification and other relevant properties of the existing pavement structure. Some common laboratory tests described in the Wirtgen *Cold Recycling Technology* manual (2004) include sieve analysis, Atterberg limits, and California Bearing Ratio (CBR) tests.

Distress evaluation. Information from the previous steps is used to determine the cause of existing pavement distress. Sometimes, the predominant distress mode changes over the length of the project, perhaps indicating differing subgrade conditions or traffic patterns.

Preliminary rehabilitation selection. A preliminary rehabilitation selection is made based on existing distresses and their causes. This selection depends upon a number of parameters such as extent of pavement damage and existing pavement strength, availability of materials, design life, traffic and anticipated traffic growth, pavement loading, surface and subsurface drainage, anticipated maintenance efforts, geometric corrections needed, location of subsurface utilities,

environmental issues, construction limitations, availability of quality contractors, and budget. In general, FDR is typically recommended for more severe and structural pavement issues that cannot be corrected by a simple surface treatment or thin overlay.

Economic analysis. Candidate rehabilitation techniques are compared over a common life-cycle to determine their overall lifetime costs and benefits. Ideally, the lowest life-cycle cost candidate is selected.

STABILIZING AGENTS OVERVIEW

The *Wirtgen Cold Recycling Technology Manual* (Wirtgen, 2004) is an excellent resource for FDR and provides good specifics on the mix design process. This section provides a brief overview of stabilizing agents as excerpted from Wirtgen's manual.

Cement. Cement and cementitious materials (materials with pozzolanic properties such as lime, fly ash, and slag) are used in FDR to increase bearing strength of the pulverized material. Generally, lime can be used for materials with a plasticity index (PI) > 10%, while cement can be used for PI < 10%. Material strength is related to the amount of stabilizing agent added, however too much stabilizing agent can lead to a brittle material that is subject to shrinkage cracking. PCA's *Soil-Cement Laboratory Handbook* (1992) can be used to determine the amount of cement needed. After stabilizing, cementitious materials usually need a finite amount of curing time to build strength. Over this time (usually around 7 days) the surface must be prevented from drying out; often, a temporary seal is applied and serves as a temporary curing membrane.

Asphalt. When employed as a stabilizing agent, asphalt is used either in the form of an asphalt emulsion or a foamed asphalt. Asphalt stabilizers do not suffer from shrinkage cracking like cementitious stabilizers but may lose strength when used with certain marginal materials. In such cases, a small amount of cementitious material (on the order of 0.5 – 1.0%) can be added to improve retained strength. Asphalt stabilization is recommended if the material being stabilized has inadequate flexibility and sensitivity to moisture. In general, if the material being stabilized has a plasticity index less than 6, the addition of asphalt stabilization is recommended (Kandhal and Mallick, 1997). ASTM D4867/D4867M can be used to determine the amount of stabilization to be used.

Figure 1 and Figure 2 summarize advantages and disadvantages of stabilizing agents.

Cement Stabilisation	
Advantages	**Disadvantages**
• Availability. Cement can be obtained worldwide, always in bags, often in bulk. • Cost. Relative to bitumen, cement is relatively inexpensive. • Ease of application. Cement can always be spread by hand in the absence of bulk spreaders or slurry units. • Acceptance. Cement is well-known in the construction industry. Standard test methods and specifications are usually available. • Significant improvement of compressive strength and durability properties of most materials.	• Shrinkage cracking is unavoidable. However, it can be minimised. • Increases rigidity in flexible pavements. • Requires proper curing and protection from early trafficking, particularly heavy slow-moving vehicles.

Figure 1. Advantages and disadvantages of cement stabilizing agent (Wirtgen, 2004)

Stabilising with Bitumen (Emulsion and Foamed)	
Advantages	**Disadvantages**
• Flexibility. Stabilising with bitumen creates a visco-elastic type of material with improved shear properties, (cohesion and resistance to deformation). • Ease of application. A bulk tanker is coupled to the recycler and the bitumen is injected through a spraybar (special type of spraybar for foamed bitumen). • Acceptance. Bitumen emulsions are relatively well-known in the construction industry. Standard test methods and specifications are available. • Rate of gain of strength. Material can be trafficked soon after placing and compaction, especially with BSM-foam	• Cost. Bitumen is relatively expensive. • Bitumen emulsions are not normally manufactured on site. The manufacturing process requires strict quality control. Emulsifiers are expensive. Transport costs inflated by hauling the water component, not only bitumen. (Foamed bitumen uses standard penetration-grade bitumen. There are no additional manufacturing costs and is therefore less expensive than bitumen emulsion.) • Foamed bitumen demands that the bitumen is hot, usually above 160° C. This often requires special heating facilities and additional safety precautions. • BSM-foam requires strict adherence to grading requirements, especially the filler fraction. (BSM-emulsion is more forgiving in this respect.) • Where the moisture content of the material in the existing pavement is close to OMC, saturation often occurs when emulsion is added. • Curing can take a long time for BSM-emulsion. Strength development is dictated by moisture loss. • Availability. The required formulation for an emulsion that is appropriate for a specific recycling application may not always be available.

Figure 2: Advantages and disadvantages of bitumen stabilizing agent (Wirtgen, 2004)

Figure 3 provides a brief overview of material properties produced by using different stabilizing agents.

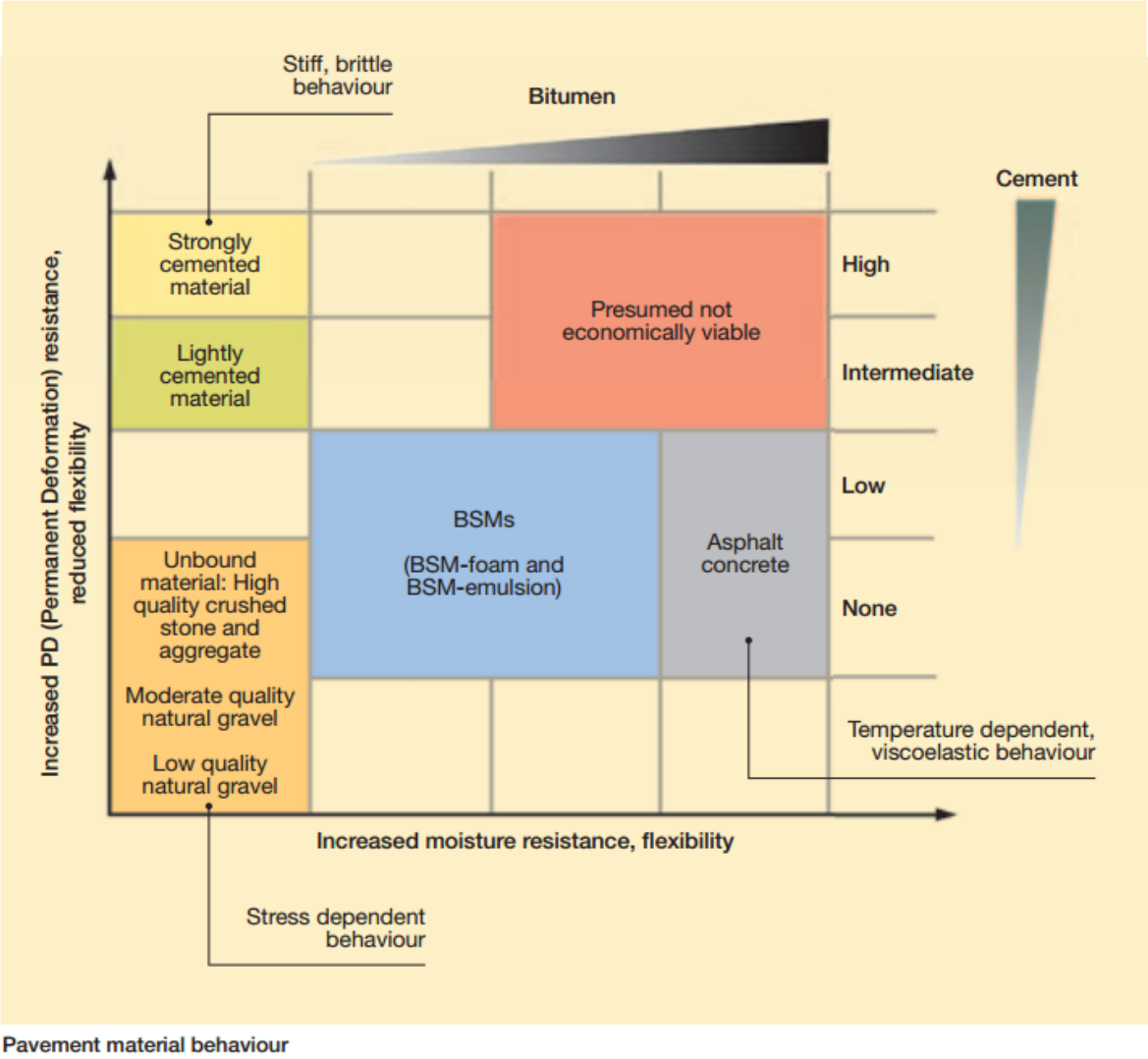


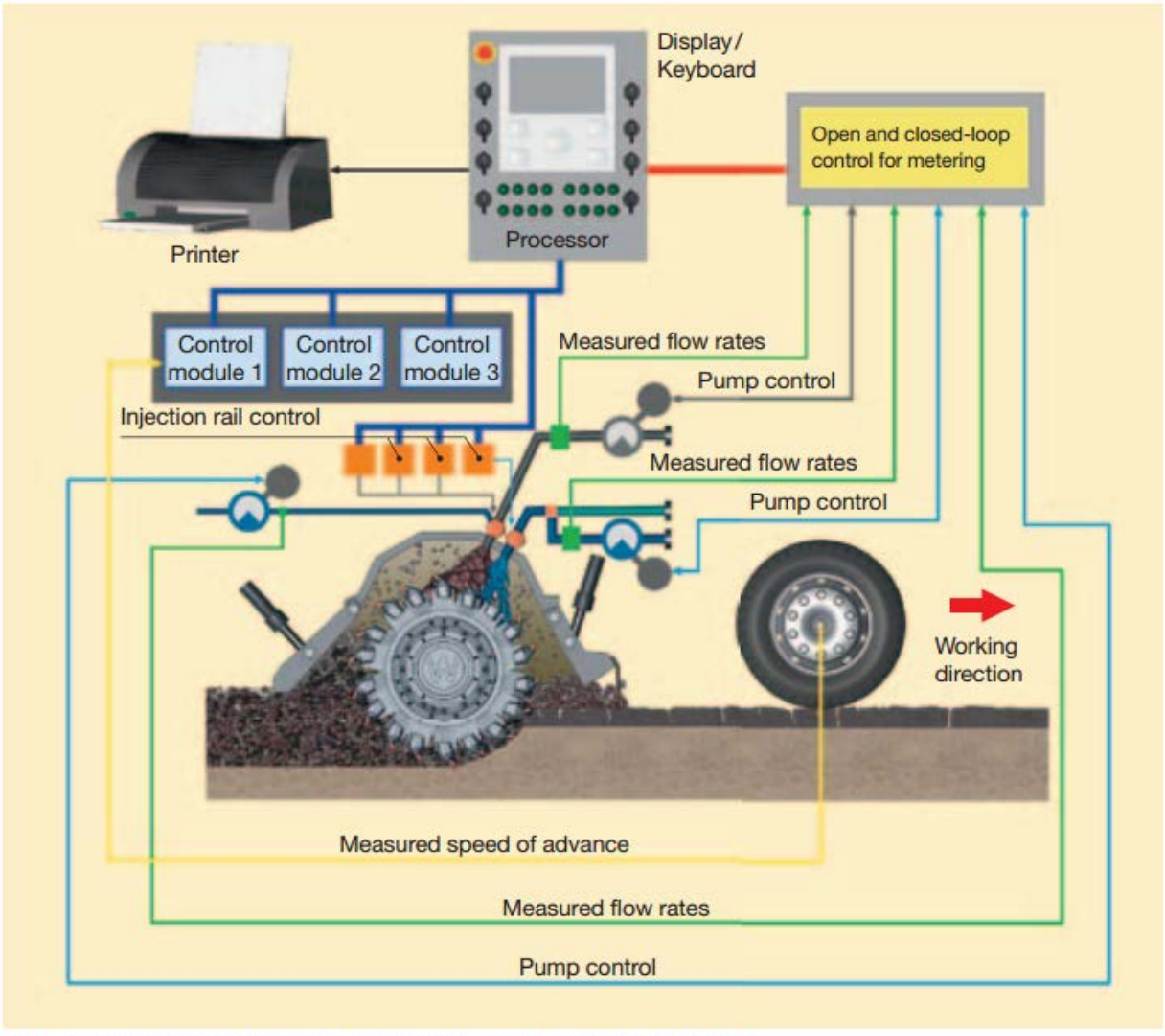
Figure 3: Material properties of cement and asphalt (bitumen) stabilization agents (Wirtgen, 2004)

CONSTRUCTION OVERVIEW

This overview is a brief summary of material presented in ARRA's *Basic Asphalt Recycling Manual* (Dunn and Cross, 2001). The FDR process involves the pulverization and mixing of the existing pavement surface with a predetermined amount of the underlying material.

Mix of pavement and underlying material. Typically, the reclaimed asphalt pavement (RAP – the pulverized existing asphalt pavement) content in the reclaimed material is about 50 percent. A good rule-of-thumb is to use a RAP-to-base ratio of 50:50.

Equipment. Both tire-mounted and track-mounted reclaimers are commonly used and both employ similar pulverization techniques. Water tankers can be directly coupled to reclaimers to provide the water necessary to achieve the optimum level of density during the compaction process. The reclaimer pulverizes the existing materials using a rotating cutting drum. The drum rotates upwards and as the machine moves forward to pulverize the pavement material. The drum housing is used as a mixing chamber where the materials are mixed together with specified amounts of water. A series of nozzles in the drum housing controlled by a microprocessor injects fluid into the mix. Foamed and emulsified asphalt stabilizing agents can also be injected into the drum housing during this process. If powdered cement is used as a stabilization agent, the cement can be distributed over the existing pavement surface before the reclamation process. The mixed material is pushed to the back of the drum housing where it exits the housing through a rear door. Figure 4 illustrates the inner workings of the reclaimer.



Micro-processor control for the injection systems on the Wirtgen WR 2500 S

Figure 4: Diagram of the Wirtgen WR 2500 S (Wirtgen, 2004)

A roller follows behind the reclaimer to compact the reclaimed material. A grader is then used to shape the compacted roadway to its final elevation. A vibratory roller or a pneumatic tire roller is typically be used to achieve final compaction.

Curing. Cementitious stabilization usually requires a curing period within which minimal or no traffic is allowed on the material and the surface must be prevented from drying out in order to avoid shrinkage cracking. A temporary seal (usually of asphalt emulsion) can applied as a temporary curing membrane.

Overlay. Once complete, the stabilized layer is typically covered with an asphalt pavement overlay or chip seal.

PERFORMANCE AND COST

Most literature on FDR are either (1) how-to informational manuals like ARRA's or Wirtgen's manuals, or (2) case studies of specific construction projects done at or shortly after the time of construction. There are comparatively fewer resources describing expected life or performance over longer periods of time (10-20 years). Available resources generally agree on the following two conclusions:

Properly designed and built FDR pavements can last 10-20 years or more. While long-term performance data is sparse, the few studies that examined long-term performance showed excellent results. Lane and Kazmierowski (2012) reported on the performance of FDR sections using no stabilization and foamed asphalt stabilization and showed that over 10 years both performed well (Pavement Condition Index > 80, International Roughness Index < 80 inches/mile) with the foamed asphalt section showing slightly better performance. Scullion et al. (2003) reported on several TxDOT districts with FDR projects over 10 years old and in good condition. Miller et al. (2011) reported distress surveys conducted 5 years after construction showed FDR sections with and without cement stabilization were performing well (little or no rutting, some thermal cracking). Finally, accelerated testing by Jones et al. (2014) showed excellent performance of a foamed asphalt FDR section after 17.7 million equivalent single axle loads (ESALs) of loading with no cracking, and only about 0.2 inches rut depth. This indicates performance can be much better than 10-20 years because typical low-volume road loading is on the order of 1 million ESALs over 40 years.

FDR shows substantial life-cycle cost savings over full reconstruction. Work by the Nevada DOT (Bemanian et al., 2006) reports a 20-year life-cycle cost for FDR projects of $382,000 per lane-mile compared to over $700,000 per lane-mile for a reconstruction. There are also many examples of single projects where construction costs were estimated as substantially less using FDR over full reconstruction (e.g., Lewis et al., 2006 reported a 42% reduction in initial construction costs using FDR).

SPECIFICATION EXAMPLES

Wisconsin DOT Standard Specification 2015 - Section 325 Pulverized and Re-laid Pavement http://roadwaystandards.dot.wi.gov/standards/stndspec/ss-03-25.pdf#ss325

Maine DOT Standard Specification 2002 – Section 307 Full Depth Recycled Pavement http://maine.gov/mdot/contractors/publications/standardspec/docs/standardspec-complete.pdf

New Hampshire DOT Standard Specification 2010 – Section 306 Reclaimed Stabilized Base http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/documents/2010_Division_300.pdf

Texas DOT Standard Specification 2014 – Section 251 Reworking Base Courses ftp://ftp.dot.state.tx.us/pub/txdot-info/des/spec-book-1114.pdf

Pennsylvania DOT Standard Specification 2011 – Section 344 Full Depth Reclamation ftp://ftp.dot.state.pa.us/public/bureaus/design/Pub408/pdf%20for%20printing%202011%209/Pub_408_2011_9.pdf

Minnesota DOT Standard Specification 2014 – Section 2215 Full Depth Reclamation (FDR) http://www.dot.state.mn.us/pre-letting/spec/2014/2014-Std-Spec-for-Construction.pdf

Nevada DOT Standard Specification 2014 – Section 305 Roadbed Modification http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Specifications/2014,%20Standard%20Specifications%20for%20Road%20and%20Bridge%20Construction.pdf

South Carolina DOT Standard Specification 2007 – Section 306 Cement Modified Recycled Base http://www.scdot.org/doing/doingPDFs/2007_full_specbook.pdf

Alberta Transportation Supplemental Specification – Section 3.4 Full Depth Reclamation http://www.transportation.alberta.ca/images/3_04%28FDR%29.pdf

FDR RESOURCES

These resources provide the best information on FDR processes.

Wirtgen GmbH. (2004). *Wirtgen Cold Recycling Manual.* Windhagen, Germany: Wirtgen, 2004. Provides in-depth information regarding project selection, rehabilitation process, stabilization agents, mix deign, and guidelines for recycling different pavement conditions. http://www.wirtgenamerica.com/media/local/1_admin/newsandmeida/download/wirtgen/cold_recyclers_soil_stabilizers/p_manual2010_e.pdf

Stroup-Gardiner, Mary. (2011). *NCHRP Synthesis 421Recycling and Reclamation of Asphalt Pavements Using in-Place Methods,* Transportation Research Board, Washington, D.C. Provides recent state practices of in-place recycling methods assessed through surveys and questionnaires responded by state DOT agencies as well as contractor members of the Asphalt Recycling and Reclaiming Association. Provides benefits and barriers findings and highlights successful in-place recycling experiences. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_421.pdf

Dunn, L. and Cross, S. (2014). *Basic Asphalt Recycling Manual*. Asphalt Recycling and Reclaiming Association (ARRA), Annapolis, MD. Provides an overview on various forms of asphalt recycling and reclamation. Provides details on project selection guidelines, mix design philosophies, construction equipment requirements and methods, quality assurance, and sample specification requirements.

Caltrans. (2013). *Flexible Pavement Rehabilitation Using Pulverization*. California DOT (Caltrans), Sacramento, CA. Good summary reference for FDR. While the guidance is specific for Caltrans, general practices, risks, advantages, etc. are describe well and remain relevant to Washington for the most part. http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/pulv_guide-Jan_2013_update_Final.pdf.

Caltrans. (2013). *Full Depth Reclamation Using Cement*. Caltrans Division of Maintenance, Sacramento, CA. Good overview of FDR with cement stabilization. Procedures are specific to Caltrans and typically of a large DOT. http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/FDR_C_Design_Guide_April_2013.pdf

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Bocci, M., Grilli, A., Cardone, F., Ferrotti, G., 2014. Full-depth reclamation for the rehabilitation of local roads: a case study. International Journal of Pavement Engineering 15, 191–201. doi:10.1080/10298436.2012.657196

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Johanneck, L., Dai, S. (2013). Responses and Performance of Stabilized Full-Depth Reclaimed Pavements at the Minnesota Road Research Facility. Transportation Research Record: Journal of the Transportation Research Board 2368, 114–125.

Johnston, A.G., CET, P.C., Bellamy, M., Eng, P., Alberta, S. (2003). Environmental and Economic Benefits of the Full Depth Reclamation Process in the Urban Context, in: *The Transportation Factor 2003*. Annual Conference and Exhibition of the Transportation Association of Canada., Ottawa, Canada.

Jones, D., Fu, P. (2011). Project Selection Guidelines for Road Rehabilitation Through Full-Depth Reclamation with Foamed Asphalt. *Transportation Research Record: Journal of the Transportation Research Board, No. 2204*, Transportation Research Board of the National Academies, Washington, D.C., pp. 194–205.

Jones, D.; Wu, R. and Louw, S. (2014). Comparison of Full-Depth Reclamation with Foamed Asphalt and Full-Depth Reclamation with No Stabilizer in Accelerated Loading Test, *Transportation Research Record: Journal of the Transportation Research Board, No. 2462*, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 126–135.

Lane, B.; Kazmierowski, T. (2012). Ten-Year Performance of Full-Depth Reclamation with Expanded Asphalt Stabilization on Trans-Canada Highway, Ontario, Canada. *Transportation Research Record: Journal of the Transportation Research Board, No. 2306*, Transportation Research Board of the National Academies, Washington, D.C., pp. 45–51.

Lewis, D.E.; Jared, D.M.; Torres, H. and Mathews, M. (2006). *Transportation Research Record: Journal of the Transportation Research Board, No. 1952*, Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 125–133.

Maurer, G., Bemanian, S., Polish, P. (2007). Alternative Strategies for Rehabilitation of Low-Volume Roads in Nevada. *Transportation Research Record: Journal of the Transportation Research Board, No. 1989*, Transportation Research Board of the National Academies, Washington, D.C., pp. 309–320.

Miller, H.J.; Kestler, M.A.; Eaton, R. and Hall, A. (2011). *Transportation Research Record: Journal of the Transportation Research Board, No. 2204*, Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 206–214.

Portland Cement Association (PCA). (1992). *Soil-Cement Laboratory Handbook*. PCA, Skokie, IL.

Scullion, T. Guthrie, S. and Sebesta, S. (2003). *Field Performance and Design Recommendations for Full Depth Recycling in Texas*. Report 4182-1, TxDOT, Austin, TX.

Stroup-Gardiner, Mary. (2011). *NCHRP Synthesis 421Recycling and Reclamation of Asphalt Pavements Using in-Place Methods,* Transportation Research Board, Washington, D.C.

Stroup-Gardiner, M. (2012). Selection Guidelines for In-Place Recycling Projects. *Transportation Research Record: Journal of the Transportation Research Board, No. 2306*, Transportation Research Board of the National Academies, Washington, D.C., pp. 3–10.

Wirtgen GmbH (2004). *Wirtgen cold recycling manual*. Wirtgen, Windhagen, Germany.

ANALYSIS OF EXISTING TIB FDR PROJECTS

A data analysis was performed on the four TIB FDR projects to date (completed 2012 to 2014).

DATA

The TIB FDR dataset includes four projects from FY 2012 through FY 2014. Six projects were initially investigated but after examining the bid tabulations, project plans, and specifications, it was unclear on whether two of these projects reused the reclaimed pavement layer.

Of the four projects analyzed, three stabilized the reclaimed layer using cement, while the other project did not stabilize the reclaimed layer. The following projects used cement to stabilize the reclaimed layer:

- Town of Malden 6-E-914(001)-1
- City of Westport 2-W-960(003)-1
- Spokane County 8-3-032(065)-1

The City of Mattawa 2-E-862(005)-1 project appears to have not used any stabilization agent in the reclaimed layer.

All four projects paved a 2-3 inch overlay on top of the reclaimed base layer.

METHOD

Bid tabulations, plans, and specifications were obtained for the projects. The bid tabs were broken apart to determine the quantities and cost of work associated with FDR work only. The following bid items were considered to be a part of the FDR process:

- Pulverization of asphalt pavement
- Cement Treated Base/Soil
- Portland Cement
- Crushed surface top course
- Crushed surface repair
- FDR
- Shaping, grading and compacting

We considered adjusting these bid items to a baseline value based on the WSDOT Construction Cost Index however we ultimately did not because: (1) the 2012 index was quite close to the 2013 index, and (2) the 2014 and 2015 indexes were abnormally large for unknown reasons (over 1.30 times the 2013 index), which would have overwhelmed the results.

The cost per square yard was determined by dividing the total cost associated with FDR work by the area of the roadway. The area of the work associated with FDR was determined from the bid tabulation and checked against the dimensions shown in the roadway typical section plans.

RESULTS

Table 1: Cost Analysis Summary for Four FDR Projects.

Project Name	TIB Project Number	Total Contract Cost	Approximate FDR Area (SY)	FDR Cost	FDR Cost/SY
Town of Malden Moreland and Broadway Avenues Reconstruction Project	6-E-914(001)-1	$599,420.10	15495	$186,556.95	$12.04
City of Mattawa Boundary Ave & Portage Ave Improvements	2-E-862(005)-1	$189,760.00	9250	$34,550.00	$3.74
Westport - Newell Street Reconstruction Forest Street to Montesano Street	2-W-960(003)-1	$198,492.62	5250	$47,305.00	$9.01
Spokane County - Wall ST/Waikiki RD/Mill RD	8-3-032(065)-1	$1,781,949.64	44400	$158,609.46	$3.57

Descriptive Statistics

FDR

Statistic	FDR ($/SY)
Observations	4
Minimum	3.57
Maximum	12.04
Range	8.47
Median	6.37
Mean	7.09
St. dev. (n-1)	4.16

FINDINGS

- **The median cost for all 4 TIB FDR projects is $6.37/yd^2.** Since there are only 4 projects this is a tentative median cost at best.
- **The variability in FDR costs can be largely attributed to the amount of aggregate imported to the project and/or the use of any stabilizing agents.** If the addition of aggregate and stabilizing agents are removed from the analysis, the cost of FDR is about $3-4/yd^2.
- **Thin overlay surfacing costs an additional $11-15/yd^2 for FDR projects. T**his is a bit higher than the $9-12/yd^2 reported in Part 2 of this report. The unit price of CL ½" PG 64-28 range from $80-105/ton
- **FDR may cost between 30 and 60% less than an equivalent reconstruction design**. A median FDR cost with a thin overlay would cost about $17-21/yd^2. An equivalent reconstruction design (5 inches of HMA over 6 inches of crushed aggregate) would cost $24-53/yd^2 based on information in Part 2 of this report.

STAKEHOLDER INTERVIEWS

Stakeholders from various TIB FDR projects were interviewed to understand their role in the project, their recommendations for best practices, and their impression on the success of the project. The following stakeholders were interviewed for this report:

- Randy Lewis, City of Westport – **Public Works Director**
- John Duval, Pavement Services, Inc. – **Pavement designer**
- Dave Mariano, Mariano & Associates Design, Inc. – **Construction Manager**

Interview methods used include questionnaires and unstructured phone interviews. Randy Lewis responded using the questionnaire while John Duval and Dave Mariano responded via phone interviews. Below are the questions and findings from each respondent.

RANDY LEWIS, CITY OF WESTPORT PUBLIC WORKS DIRECTOR

Questionnaire response dated 3/15/2015

Background

1) How many Full Depth Reclamation (FDR) roadway projects have you been involved in?

One.

2) How many years have you been involved in FDR projects?

Our project was constructed in July 2014.

3) What was your role in the project?

I am the Public Works Director for the City. I contracted with the engineers and contractors, and participated in the pre-construction, project update, and acceptance inspections and meetings.

Overall Impression of the FDR projects

4) On average, how long does the construction of FDR projects take?

The project involved approximately 1/3 of a mile and only took five working days to pulverize the existing roadway, shape, and apply the concrete to prepare for paving.

5) What was your impression of the timing of construction for the FDR projects? Do they tend to take longer than the scheduled duration?

The weather really cooperated so there weren't any delays from that end and the project moved actually quicker than projected. The one potential problem would be weather related delays on the west side of the state so the timing of the project is important. Also, it did not take any longer to complete the FDR than similar projects that we have completed that did not involve FDR.

6) What was your impression of the quality of the completed FDR roadway?

We are very satisfied. One of the advantages was that we were able to shape over and provide better coverage for an existing shallow culvert much easier and with less time than using a traditional method.

7) Are you satisfied with the results of the FDR projects? Are there any complaints from the community regarding the outcome of the pro method?

We are very satisfied and there weren't any complaints at all. We obviously don't have a lot of time with this project to observe wear but we haven't had any initial indications of any problems.

8) What was the level of TIB participation for these projects? What role did TIB play?

TIB provided the geotechnical engineer to coordinate with our design engineer to make sure we had the right proportions and that it would work. This was definitely worth the effort and I strongly recommend that it be part of every FDR project to get it right the first time.

9) What are some lessons learned or things you would do differently on future FDR projects?

The one potential problem would be weather related delays on the west side of the state so the timing of the project is important. Also, it did not take any longer to complete the FDR than similar projects that we have completed that did not involve FDR.
A second issue is to make sure the contractor provides a lot of informational signage that informs the public of the use of concrete and the need to stay out during the day(s) when the concrete product is being applied. We had a couple of cars that got into the area and the contractor had to track them down to get them to wash their vehicles. The public does not realize the difference between this process and others where there is dust and gravel on a road under construction. It isn't possible to keep everyone out of the project at all times in most instances so coordination and warnings about concrete dust would help.

JOHN DUVAL, PAVEMENT SERVICES, INC.

Phone Interview Conducted on 3/19/2015; 1:30 pm

How John Duval Gets Involved in TIB Projects

John Duval is a pavement designer and has worked on three FDR projects in collaboration with TIB. John has been working with TIB for quite a while now and is asked to consult on a case-by-case basis. The process involves TIB calling John when they have found a FDR suitable project.

From 2012 to 2013, John was hired as an on-call consultant for TIB. He was involved in the early scoping process with the intent of saving design costs. The consulting work typically involves a 1-day field assessment trip.

The FDR project located in the town of Malden was John's first FDR project with TIB. The second project was in the city of Westport and the third one was in Raymond.

The FDR project in the town of Raymond was somewhat unique. TIB hired a roadway engineer which subbed out the pavement design to a geotech. TIB didn't like the design so John got involved and came up with a mix design for the FDR layer.

TIB Project Selection Process

Visual surveys are critical in establishing the roadway condition. Visual inspection of structural distress are particularly important to investigate the condition of the supporting base materials.

Core sampling or test pits are conducted to retrieve existing subbase and subgrade samples. It is also done to establish the existing pavement structure and depths.

As-builts may be a good reference, especially to identify the depth of any drainage, gas, or other utility structures. In the Westport FDR project, the reclaimer hit a shallow lateral water line. The City came in to fix it right away but the response to these types of incidents can vary and impact construction.

If the rehabilitation options are narrowed down to either FDR or full reconstruction, the nature of the existing subgrade, use of geotextiles and other fabrics in the existing pavement layer, and the existence of shallow utilities may help decide between the two methods. Extremely soft subgrade soils can be difficult to address by stabilizing the base layer. In addition to stabilizing the reclaimed layer, corrective aggregate may be needed to adequately support the existing and future traffic loads. The cost between the two options can help determine the rehabilitation method.

If there are any geotextile fabrics in the existing pavement layer or shallow utility lines, full reconstruction may be a better method. Geotextiles and other fabrics used to control reflective

cracking in the existing pavement can cause problems in the pulverization process. Similarly, shallow utilities can also cause problems in the pulverization process. It may be more cost effective for a conventional full reconstruction of the pavement.

Design Process

Material samples are obtained from core samples or from test pits. The base and subgrade is lab tested to determine its material classification, gradation, moisture content, and other properties deemed necessary depending on the existing cite conditions.

When considering what stabilizing agent to use, John looks at what type of stabilizer will be effective with what is in place in the existing subgrade. With sandy soils, asphalt emulsion can be used to increase the density of the soil and aids in providing a flexible base. However, asphalt emulsion is scarce in Washington and contractors typically pay a premium. Using cement to stabilize the reclaimed layer is common in Washington and is the most cost effective. For bidding purposes, cement content is generally specified at 8%. The final cement content can be determined using the PCA's *Soil-Cement Laboratory Handbook* (1992) for selecting cement content for FDR projects. Unconfined compressive strength is a key parameter that is used to determine the final cement content. A seven-day unconfined compressive strength ranging from 200 and 300 psi is recommended. Using values higher than this range may cause reflective cracking. Other parameters from the lab testing include the determination of the maximum dry density and the optimum moisture content.

John's Advice on Future FDR Projects

TIB hires an on-call contractor/roadway engineer. On TIB projects, the prime contractor may decide to hire a geotechnical subcontractor to come up with an acceptable pavement mix design to address existing roadway distresses. Being a geotechnical engineer does not necessarily mean that they are a competent pavement designer. Geotechnical engineers may perform field tests such as borings and penetration tests. These tests aren't very helpful in pavement design, especially if the visual distress survey identifies structural distresses. John recommends involving a competent pavement engineer for roadway rehabilitation projects. Hiring a pavement engineer helps ensure that the best decision on stabilization type and content are made.

DAVE MARIANO, MARIANO & ASSOCIATES DESIGN, INC.

Phone Interview Conducted on 3/31/2015; 2:30 pm

How Dave Mariano Gets Involved in TIB Projects

The following information is specific to the Westport FDR project:
The City of Westport wanted to pursue a TIB grant to rehabilitate a local roadway. They contacted Dave Mariano and help with the grant process. Initially, the City of Westport was qualified for a grant involving a 3" overlay to improve this particular local roadway. Dave worked with John Duval (Pavement Systems, Inc.) to develop recommendations for a rehabilitation method. They ultimately decided on using FDR with 2" HMA overlay. This was approximately the same cost as the overlay only option (+/- $10,000). Based on the pavement design, the FDR with cement stabilization has a design life of 20 years.

Advantages of Implementing an FDR Process

Dave mentioned that one of the biggest advantage of FDR compared to the 3" overlay is the duration of the work. The FDR with cement stabilization took 2 weeks – from mobe to demobe. The reclamation process took 2 days. Dave states that a conventional rebuild can take anywhere from 20 to 30 working days. Implementing FDRs for correctly scoped projects can reduce the construction time significantly.

Issues Brought Up

TIB provides funding through a grant based program. Small cities or towns can find it difficult to write grants to preserve their roadways. Dave thinks that it would be helpful if TIB can step in and define preservation needs for these small cities. TIB can help communities prioritize to fix roads. If TIB owned the contracts, they can help setup a pooled preservation program and realize cost savings from economies of scale.

NEED FOR A PAVEMENT ENGINEER

Correct design (and construction) are critical to the long-term success of a FDR project. While preliminary project scoping for an FDR project can be done without pavement expertise, the actual verification of these scoping efforts, as well as structural design and mix design require an engineer with specific expertise in pavement engineering. This section describes what a pavement engineer would typically do once a project is preliminarily scoped for FDR. A "pavement engineer" is defined as a registered engineer with specific experience in designing pavement structures and mixes. While no P.E. license exists for such a specialty, verifiable experience in pavement design will ensure that recommendations and designs are done correctly. The pavement engineer may need to be on-site for at least the start of construction in case structural or mix designs need adjusting based on field conditions.

PAVEMENT ENGINEER SITE INVESTIGATION

The pavement engineer would conduct a site investigation to verify the depths of the existing pavement layers and to collect field samples of the existing materials. This can be accomplished by excavating a series of test pits to identify the individual pavement layer thickness. The pavement engineer may collect bulk samples from each pavement layer for laboratory testing used to determine moisture content, density, and general condition of the material. Laboratory test results should also indicate whether stabilization is required and the type of stabilization agent that is suitable for the in-place material. The pavement engineer may be able to identify sections of pavement within the project that require full reconstruction due to some pre-existing condition or identify project sections subject to subgrade water saturation issues that should be corrected before FDR work. If resources permit the pavement engineer may collect deflection data (using a falling weight deflectometer or similar device), which can help the FDR and pavement design.

STRUCTURAL DESIGN

The pavement engineer can accomplish structural design using a number of procedures. In general, the *SHRP2 R23 Scoping Methodology Including Advanced Renewal Systems* recommends using a conservative value of 100,000 psi as the resilient modulus for a FDR layer (values of 200,000 psi or more can be common) and then using the standard 1993 *AASHTO Guide for Design of Pavement Structures* design process for pavement thickness. As an example, a standard design using this process with a 100,000 psi FDR layer, 50% reliability, Δ PSI of 2.2, and typical HMA properties for 1 million ESALs (rather heavy loading for a small city even over 40 years) results in a 2.5-inch HMA surfacing over a 6-inch FDR layer. This design can be assumed for preliminary estimating purposes unless the pavement is known to have excessive heavy vehicle loading.

LABORATORY MIX DESIGN

A laboratory mix design process is typically used to determine (1) the suitability of various stabilizing agents, (2) the appropriate amount of stabilizing agent to use, and (3) parameters needed to come up with new layer thicknesses using a standard pavement design method.