DESIGN AND CONSTRUCTION GUIDELINES
FOR FULL DEPTH RECLAMATION OF
ASPHALT PAVEMENT

GEOTECHNICAL ENGINEERING MANUAL
GEM-27
Revision #1

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1. INTRODUCTION

The recycling of existing pavement to produce new pavement can have results in the savings of material, cost and time. In addition, the act of recycling existing material also helps to solve disposal problems.

As outlined in Kandhal and Mallick (1997), the specific benefits of recycling can be summarized as follows:

- Reduced costs of construction.
- Conservation of aggregate and binders.
- Preservation of the existing pavement geometrics.
- Preservation of the environment.
- Conservation of energy.
- Less user delay.

Full depth reclaimation (FDR) has been defined (Kandhal and Mallick (1997)) as a recycling method where all of the asphalt pavement section and a predetermined amount of underlying subbase material are treated to produce a stabilized base course. It is basically a cold mix recycling process in which different types of additives such as asphalt emulsions and chemical agents (e.g. calcium chloride, portland cement, fly ash, and lime) are added to obtain an improved base. The four main steps in this process are pulverization, introduction of additive, compaction, and application of a surface or a wearing course. If the in-place material is not sufficient to provide the desired depth of the treated base, new materials may be imported and included in the processing. New aggregates can also be added to the in-place material to obtain a particular gradation of material.

Figure 1 provides a schematic of the full depth reclaimation process for a single machine. The single machine, or single-pass equipment, is capable of breaking, pulverizing, and adding recycling agents in a single pass.

This manual provides personnel in design and construction general information on the full depth reclaimation process.
Figure 1 Schematic of Single Machine
(Kandhal and Mallick (1997), from Wirtgen America, Inc.)
2. DEFINITIONS

**Asphalt Emulsion** - A combination of asphalt, water, and small amount of an emulsifying agent processed in a colloid mill. The asphalt is sheared into tiny droplets and the emulsifier (a surface-active agent) keeps the asphalt droplets in a stable suspension and controls the breaking time, resulting in a liquid product.

From Kandhal and Mallick (1997):

**Asphalt Surface Recycling** - Reworking and/or removal of the surface of a pavement by planning or scarifying devices.

**Cold Milling** - An automatic removal method of asphalt pavement by machines having rotating drum lined with variable number of tungsten-carbide tipped teeth.

**Cold-Mix Recycling** - A method in which the existing pavement material is reused without the application of heat. The process can be carried out in-place (cold in-place recycling) or at a central plant.

**Cold Planing** - An automatic removal method of asphalt pavement by shearing off the surface.

**Full Depth Reclamation** - A recycling method in which all of the asphalt pavement section and a predetermined amount of underlying material are treated to produce a stabilized base course.

**Heater Planing** - A process in which a device heats the pavement surface and a stationary or vibratory flat steel blade or plate is used to shear off up to 1 in. (25 mm) of the heated surface.

**Heater Scarification** - A process in which a device heats the pavement surface and stationary steel tines or teeth are used to rake off up to 1 in. (25 mm) of the hot surface.

**Hot In-Place Recycling** - A method in which the existing pavement is heated and softened, and then scarified or hot rotary mixed to a specified depth.

**Hot Mix Asphalt Recycling** - A process in which reclaimed asphalt pavement material are combined with new material, sometimes along with a recycling agent, to produce hot mix asphalt (HMA) mixtures.

**Recycling** - Reuse of existing materials to produce new materials.

**Recycling Agent** - Organic materials with chemical and physical characteristics selected to restore aged asphalt to desired specifications.
**Rehabilitation** - Work undertaken to extend the service life of an existing facility. This includes placement of additional surfacing material and/or other work necessary to return an existing roadway including shoulders, to a condition of structural or functional adequacy.

**Rejuvenator** - A liquid petroleum product, usually containing maltenes, added to asphalt paving material to restore proper viscosity, plasticity, and flexibility to the asphalt cement.

**Remixing** - A process consisting of the following steps: (1) heating of the roadway to a depth of 1½ to 2 in. (37.5 to 50 mm), (2) scarification and collection of the softened material into a windrow, (3) mixing of the material with virgin aggregates and recycling agents in a pugmill, and (4) laying of the recycled mix as a single, homogeneous mix.

**Repaving** - A heater scarification method combined with simultaneous overlay of new hot mix asphalt (HMA).
3. DESIGN

Full depth reclamation (Kandhal and Mallick (1997)) is a method of recycling which allows most pavement distresses to be treated, minimizes hauling costs, allows significant structural improvements to be made (especially in subbase), eliminates material disposal problems, and improves ride-quality.

Full depth reclamation of asphalt pavements has been determined to be a more cost-effective means to rehabilitate low-volume roads, proportionally increasing service life when compared to full depth reconstruction. The full depth reclamation process also conserves natural resources by recycling existing materials. The conservation of natural resources is compounded when you consider the conservation of additional natural resources (natural gas, petroleum products, etc.) necessary to produce, deliver and use new materials required in full depth reconstruction.

The full depth reclamation process utilizes road reclaimers, machines which use milling drums similar to those found on milling machines. However, these milling drums are designed to penetrate the entire pavement section and a predetermined portion of the subbase material, uniformly pulverizing and blending them together, and gauging precise amounts of additives to improve structural characteristics of this newly developed subbase course (Better Roads, 2001).

The full depth reclamation process is applicable to depths up to 12 in. (300 mm), with typical applications in the range of 6 to 9 in. (150 to 230 mm). It removes deep pavement cracks thereby eliminating the potential for reflective cracking. The process allows for cross-slope and profile grade adjustments. If location specific conditions dictate that the final surface treatment will be applied at a later date, the road can be opened to traffic once the compactors complete their pass. Temporary pavement markings are required in accordance with Section 619 of the Standard Specifications. A roadway rehabilitated utilizing the full depth reclamation process is equivalent to a traditionally reconstructed roadway in terms of life expectancy, wear and load-bearing characteristics (Better Roads, 2001). However, the process has less interruption of traffic, is environmentally friendly, and is completed at a fraction of the cost.

3.1 Applicable Pavements

Roadway Volume. The full depth reclamation process is applicable to rehabilitate low-volume roads with less than 1M ESAL’s (18,000 lb. (80-kN) Equivalent Single Axle Loads) over the design life of the pavement.

Roadway Drainage. Groundwater elevation cannot be within 2 ft. (0.6 m) of top of subbase elevation or 1 ft. (0.3 m) below bottom of subgrade elevation (whichever is lower) to provide optimum performance. It is highly recommended that the full depth reclamation process not be considered if groundwater exceeds this constraint.
3.2 Sampling and Pre-Testing

Sampling and pre-testing is critical to provide a satisfactory mix design that will provide a stable and functioning newly developed subbase course as intended.

3.2.1 Drill Work

Drill work will require sampling the pavement (i.e. pavement core) and the subbase/subgrade conditions (i.e. subsurface exploration) to provide sufficient information about the existing roadway materials. The number of samples to be obtained for the project depends on the project size (the project length and the number of lanes in the road section to be reconstructed), the level of subgrade/subbase non-uniformity, and the amount of material needed for laboratory testing (Morian, et al., 2012). Sufficient drill work is required to provide the information necessary to develop the full depth reclamation mix design. A recommended number of cores/subsurface explorations are 4 per lane mile (e.g. 2 lane roadway by 1 mile long = min. 8 drill holes). For FDR projects extending longer than one mile and uniform conditions are observed, sampling can be reduced to 1 per lane mile. Consult with the Regional Materials Engineer for the appropriate sampling quantity.

The Department will provide the following information in the contract documents:
- Pavement Core Report and/or Subsurface Exploration Logs and Laboratory Test Data.
- Total depth of reclamation that is required, including the existing asphalt and underlying material depths and corresponding longitudinal limits.

3.2.2 Pavement Core Classification

The Department will take and analyze 6 in. diameter core samples and provide the following information in the contract documents:
- Core Report which will include the location and depth of the existing asphalt in each core taken.
- Existing asphalt pavement core gradations.
- Percentage of asphalt content in the asphalt pavement cores taken.

3.2.3 Subbase/Subgrade Sample Classification

Samples should be obtained from all layers expected to be reclaimed (asphalt, subbase, and possibly subgrade). The depth of sampling should be 1.5 times the depth of pulverization. The subbase/subgrade samples will be analyzed to define the subsurface characteristics as identified in Table 1 Subbase/Subgrade Sample Testing Methods.
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**Table 1 Subbase/Subgrade Sample Testing Methods**

The Department will provide the following information in the contract documents:

- Subsurface information including Subsurface Exploration Logs and Laboratory Test Data.

3.3 **Pavement Design Overlay**

A 4 in. minimum, two-course asphalt concrete overlay is recommended:

- 2 ½ in. (25 mm) binder,
- 1 ½ in. (9.5mm) top

Consult with the Regional Materials Engineer for the appropriate overlay materials.

It is recommended that, for a hot mix surface, a polymer modified asphalt binder material be applied to the full depth reclamation surface prior to paving to improve the flexibility of the bond response to climatic and traffic loads (Morian, et al., 2012).
4. CONSTRUCTION GUIDELINES

4.1 Additional Drill Work

The Contractor may progress additional drill work (i.e. pavement core and subsurface exploration) through the existing roadway section to determine the full depth reclamation mix design. The Contractor is required to provide a 2-week notice to the Engineer and the Regional Materials Engineer prior to progression of additional drill work.

4.2 Contractor Design

4.2.1 Stabilizing Agents

The reclaimed mixture shall consist of reclaimed materials, new aggregate (if required), chemical or bituminous stabilizing agent(s) and water (if required). The choice of stabilizing agent depends on the composition of the existing structure and the type of subgrade soil. Therefore, the stabilizing agent is dependent on the results of the sampling and pre-testing of the site and will ultimately be determined by the Contractor.

Stabilizing agents include:

- Chemical Stabilizing Agent(s) (Kandhal and Mallick (1997)):
  - Portland cement is used to increase compressive strengths of bases. When cement, soil and water are combined, a cementitious bond between the soil particles is formed immediately, and the mix continues to gain compressive strength over a long period of time. Addition of cement is best effective in granular and low plasticity subbase or subgrade.
  - Lime is used as an additive to mitigate the effect of reactive clay in base materials. Lime reduces the plasticity within days and brings down the swelling potential. It also helps in resisting water damage and increasing tensile and compressive strengths of the recycled mix.
  - Fly ash is used as an additive to form cementitious bond in soil (in presence of water) and increase impermeability and strength of the recycled mix. Fly ash is generally spread by a mechanical spreader and then blended with a reclaiming machine in a second pass.
  - Calcium chloride is used to lower the freezing point of reclaimed base material and thus helps against freeze and thaw problems. Load-bearing capacity of base can also be improved by the addition of calcium chloride. Liquid calcium chloride
can be added in three steps: primary application, blending, and secondary application to seal the shaped and compacted surface. An onboard liquid additive system or a distributor truck can be used for application of calcium chloride.

If water is required in addition to the recycling agent, the liquids may be pre-mixed before delivery to the asphalt storage tank of the travel plant. This system may cause problems if the recycled mix requires variable water contents.

- **Bituminous Stabilizing Agent(s) (Kandhal and Mallick (1997))**: Asphalt emulsion helps to increase cohesion and load bearing capacity of the mix. It also helps in rejuvenating and softening the aged binder in the existing asphalt material. Emulsions are mixtures of asphalt cement, water, and an emulsifying agent. The advantage of using emulsion is that emulsions are low in viscosity and very suitable for application through an on-board liquid additive system in the recycling equipment. After the blending of the subbase material and emulsified asphalt, the emulsion “breaks” and water separates out from the asphalt cement. This water is forced out of the subbase during compaction or will evaporate out during curing period. The resulting residual asphalt cement has high viscosity and, therefore, helps in improving the cohesion of the subbase material.

The results of these characterization methods should be used in conjunction with Table 2 to select the appropriate stabilization approach based on soil classification type, and also based on the percent of material passing the No. 200 sieve, plasticity index, and liquid limit (Morian, et al., 2012).

Enter Table 2 with the percent of material passing the No. 200 sieve and the plasticity index. The Stabilizer identified in that row is appropriate for the color-shaded column cell relating to the soil classification type. If more than one possible solution is available (the first row has a narrower magnitude (12%) on the material passing the No. 200 sieve as compared to the first subset of the second row (25%) with respect to a plasticity index of less than 6), other factors such as the desirability of individual processes for the project and potential cost/benefit of the entire roadway treatment (including surfacing) should be considered.
Table 2 Correlation of Stabilization Agent as a Function of Soil Type, Percent Passing No. 200 Sieve, and Plastic Index  
(Morian, et al., 2012)
The Contractor’s methods and FDR mix design submittal shall specify all the equipment and materials necessary to do the work, which will include the proposed stabilizing agent. The submittal will also include the schedule to complete the work, which is to address the required curing time of the proposed stabilizing agent.

The final mixture shall conform to the strength parameters as outlined in Quality Assurance section. The reclaimed mix’s moisture content may be determined by the Contractor and may be adjusted to account for actual field conditions.

4.2.2 Water Content for Mix Design

The reclaimed mixture shall consist of reclaimed materials, new aggregate (if required), chemical or bituminous stabilizing agent(s) and water (if required). The reclaimed mix’s moisture content is determined by the Contractor and may be adjusted to account for actual field conditions.

To establish a moisture content, a Contractor will determine the moisture – density relationship utilizing the Standard Proctor Density Test in accordance with AASHTO T-99. From the compaction control curve, the optimum moisture content (OMC) at peak dry density may be obtained.

If a material contains a significant amount of RAP or coarse material and does not produce a well defined moisture – density curve, then the moisture content is typically fixed at 3%. If a material contains less than 4% passing No. 200, or if no peak develops with the OMC curve, then the moisture content is typically fixed between 2% and 3%.

4.3 Submittal Process

Prior to beginning the work, the Contractor is required to submit the following to the Engineer:

- Proposed methods to satisfactorily complete the specified full depth reclamation – The submittal shall specify all the equipment and materials necessary to do the work which will include, but is not limited to, the in-place single or multiple step full depth reclamation sequence; the type, brand name and model number of all equipment being used (including rollers); the Work Zone Traffic Control Plan appropriate for the selected method to complete the full depth reclamation; and the schedule to complete the work, which includes curing time based on the respective stabilizing agent.

  The Contractor is required to use approved in-place full depth reclamation equipment. A self-propelled reclaimer is required, to be equipped with a liquid additive system specifically manufactured for full depth reclamation type of work. The machine is to have automatic depth controls and the cutting drum is to be variable speed with the capability to up-cut and down-cut, pulverize, and mix the existing asphalt pavement and underlying subbase material(s).
Mixing equipment is required to be calibrated prior to the start of work.

- The full depth reclamation mix design – The full depth reclamation mix design shall specify the name and producer/manufacturer of the all the materials. All materials are required to be State-approved.

4.4 Preconstruction Meeting

A preconstruction meeting will be held prior to the start of any work. Representatives from the Geotechnical Engineering and the Materials Bureaus shall be present.

4.5 Full Depth Reclamation Process

The full depth reclamation process includes the in-place pulverization and uniform blending of existing roadway surface materials, and a predetermined thickness of underlying material, creating a homogenous mixture of reclaimed base material. The process also consists of shaping, finishing, fine grading, and compaction of the reclaimed base material.

Compaction. The Contractor shall achieve thorough and uniform compaction of the reclaimed material using a combination of the following equipment:
- Initial (breakdown) rolling performed with a vibratory pad foot roller.
- Intermediate rolling performed with a pneumatic-tired roller.
- Finish (final) rolling performed with a tandem vibratory–steel drum roller.

The moisture content is very critical to compaction of the mix. Sufficient moisture lubricates the particles and helps in compaction, whereas excess moisture causes low density and moisture retention in the sealed layers (Kandhal and Mallick (1997)).

Tolerance. The reclaimed surface shall be constructed within the tolerances provided in the specification.

Curing. The Contractor is required to proof roll the compacted material. The reclaimed mixture should be allowed to cure for the specified time as in the approved full depth reclamation mix design. Curing is the Contractors responsibility, who should consider all factors, including the weather limitations and restrictions, and the project Work Zone Traffic Control plan.

Weather & Seasonal Limitations. This work will not be permitted when the existing pavement or reclaimed material contains frost, or when the air and/or surface temperature is below 45º F (7º C). The minimum air temperature must be 60º F (15º C) and the relative humidity must be less than 80% when bituminous stabilizing agents are used. Working in the rain or when rain is imminent is not allowed. No work under this item will be permitted from September 30 to May 15. The reclaimed base shall be paved before winter.
5. QUALITY ASSURANCE

5.1 Component Quality Assurance

Aggregates – All new aggregate must be stockpiled. A minimum of two Quality Control (QC) aggregate gradation samples, weighing a minimum of 45 lbs. (20 kg) each in accordance with AASHTO T311, will be obtained from each stockpile and tested by the Contractor. All QC test results will be provided to the Engineer prior to the start of work and all test results shall meet the gradation as specified in the approved mix design.

Portland Cement – When Portland Cement is used, a 1 gal. (3.8 L) sample from each delivery vehicle will be obtained in accordance with §701-01 and submitted to the Regional Materials Engineer for testing.

Fly Ash – When Fly Ash, Class C is used, a 1 qt. (0.9 L) sample from each delivery vehicle will be obtained in accordance with §701-01 and submitted to the Regional Materials Engineer for testing.

Bituminous Stabilizing Agent – When Bituminous Stabilizing Agents are used, a sample from each delivery vehicle will be obtained in accordance with Materials Method 702-2 and submitted to the Regional Materials Engineer for testing.

5.2 Mix Design Quality Assurance

The approved mix design shall conform to the following strength parameters and test procedures based on the stabilizing agent used:

- Chemical Stabilizing Agent(s): Use Unconfined Compressive Strength Test parameters in conformance with ASTM D1633 Method A. Minimum strength shall be 350 psi (2413 kPa) but less than 800 psi (516 kPa).

- Bituminous Stabilizing Agent(s): Use Modified Proctor Density, ASTM D1557 and /or Marshall Method, ASTM D6927.

On the first day of production, the Contractor will take the appropriate QC samples of the reclaimed mix in accordance with ASTM D1633 and or/ASTM D1557/ASTM D6927. Four additional samples will also be tested by the Contractor’s laboratory for aggregate gradation and percent stabilizer content. Test results will be submitted to the Engineer before the end of the next workday.

For each subsequent day of production, a minimum of one sample of the reclaimed mix will be taken from each ½ mile (805 m) of production, or fraction thereof. These samples will be tested...
as noted for the first day of production. The Engineer will receive these test results within two workdays to be verified for compliance with the approved mix design.

If a second reclamation train is introduced at the contract site, QC sampling will follow the requirements needed for the first day of production.
6. METHOD OF PAYMENT

Full depth reclamation process is divided into three pay items:

- Full depth reclamation of asphalt pavement – Addresses the payment for work including cleaning the existing pavement free of all debris and material that may interfere with the reclamation’s milling process; milling; pulverizing and mixing the existing asphalt pavement; adding new aggregate and chemical or bituminous stabilizing agent(s) as required; then remixing; grading; compacting; and curing in conformity with the lines, grades, depths and typical sections as shown in the contract documents.

- Stabilizing Agent – Addresses the payment for the stabilizing agent (chemical or bituminous).

- Aggregate – Addresses the payment for adding aggregate.
REFERENCES


Portland Cement Association, *Full-Depth Reclamation with Cement*,
http://www.cement.org/pavements/pv_sc_fdr.asp