CHAPTER 8: COLD PLANING - CONSTRUCTION

8.0 COLD PLANING REHABILITATION

Cold Planing (CP) is the controlled removal of the surface of the existing pavement to the desired depth, with specially designed milling equipment to restore the pavement surface to the specified grade and cross-slope. CP can be used to remove part or all of the existing pavement layers. The amount of material removed can also be varied in order to meet project specific requirements. The resulting textured pavement can be used immediately as a driving surface. CP is more commonly used as a surface preparation for one of the other rehabilitation techniques such as Hot In-Place Recycling (HIR), Cold In-Place Recycling (CIR), Full Depth Reclamation (FDR) or Hot Mix Asphalt (HMA) overlays.

The product of a CP operation is a crushed, somewhat “gap-graded” reclaimed asphalt pavement (RAP) which acts like an asphalt coated granular material. The RAP can be used for hot recycling, Cold Central Plant Recycling (CCPR) or as a granular aggregate.

Pavement distress which can be treated by CP includes:

- raveling
- bleeding
- shoulder drop off
- rutting
- corrugations
- shoving
- removal of deteriorated, stripped or aged asphalt
- poor ride quality caused by swells, bumps, sags, and depressions
- potential bonding problems between existing pavement and new HMA overlay
- diminished curb reveal heights

8.1 CP DETAILED PROJECT ANALYSIS

Through the project evaluation, economic analysis and preliminary selection process outlined in Chapter 3, the potential rehabilitation alternatives were narrowed down to one specific technique. The next step in the rehabilitation design is the detailed project analysis which will lead directly into the final project design, advertising, tendering or letting, and construction.

The HMA overlay, hot recycling, and reconstruction rehabilitation methods will not be addressed since they are routinely used by all agencies. The rehabilitation techniques of HIR, CIR, and FDR are addressed in detail in other chapters.

As CP is primarily used in conjunction with another rehabilitation technique, the detailed project analysis tends to be governed by the subsequent rehabilitation method. The CP detailed project analysis is limited to an assessment of geometric and constructability issues.

Pavements of most widths, shapes, and profiles can be routinely handled due to the wide range in equipment sizes and capabilities. The ability of the cold planer to overlap a previously milled area without adversely affecting the finished product makes most geometric shapes candidates for CP.

Constructability issues primarily concern traffic accommodation and overhead clearance requirements. Traffic interruptions can be kept to a minimum since CP production is relatively high and the roadway can be used by traffic as soon as it has been swept clean of any loose millings. Typically, overhead clearance height, even for the larger milling machines is not a problem, but the project area should be checked for any low overhead obstructions.

When the specifications indicate that significant depths of the existing asphalt pavement are to be removed by CP, the area to be treated should be checked for buried utilities, abandoned rail or streetcar lines, manholes, values, and other castings. These fixtures are usually indicated on existing plans but a field magnetic/metal detector survey should be undertaken.

Some common preparatory measures should be undertaken prior to CP. These include:

- detailed safety or hazard assessment
- development of a detailed traffic control plan

These have become increasingly important as more and more CP is being undertaken at night to reduce the impact on the travelling public.

The equipment used to undertake CP will vary from contractor to contractor but no matter what the CP equipment looks like, it is required to perform the same general steps, including:

- reclaiming and sizing of the existing pavement
- removal of the reclaimed pavement from the roadway
- cleaning of the milled surface
- application of traffic control markings or wearing course

8.2 CP EQUIPMENT

The minimum equipment requirements for CP are:

- modern, self-propelled cold planer
- haul trucks
- water truck
- sweeper or power broom

Development of the cold planer or milling machine began in the late 1970’s when a grade trimmer was upgraded to mill asphalt pavement. Since that time significant advancements in size, horsepower, milling width, milling depth, production, and cost-efficiency have been made. CP has become commonplace in construction and is now the preferred method of removing and/or reclaiming pavement materials.

CP equipment is available in a variety of sizes from mini-milling machines, for localized milling around manholes and valves, etc., as indicated in Figure 8-1, to high capacity machines capable of milling up to 16 feet (4.9 meters) wide and over 12 inches (300 mm) in one pass, as indicated in Figure 8-2.

Figure 8-1: Mini cold planer working around a manhole

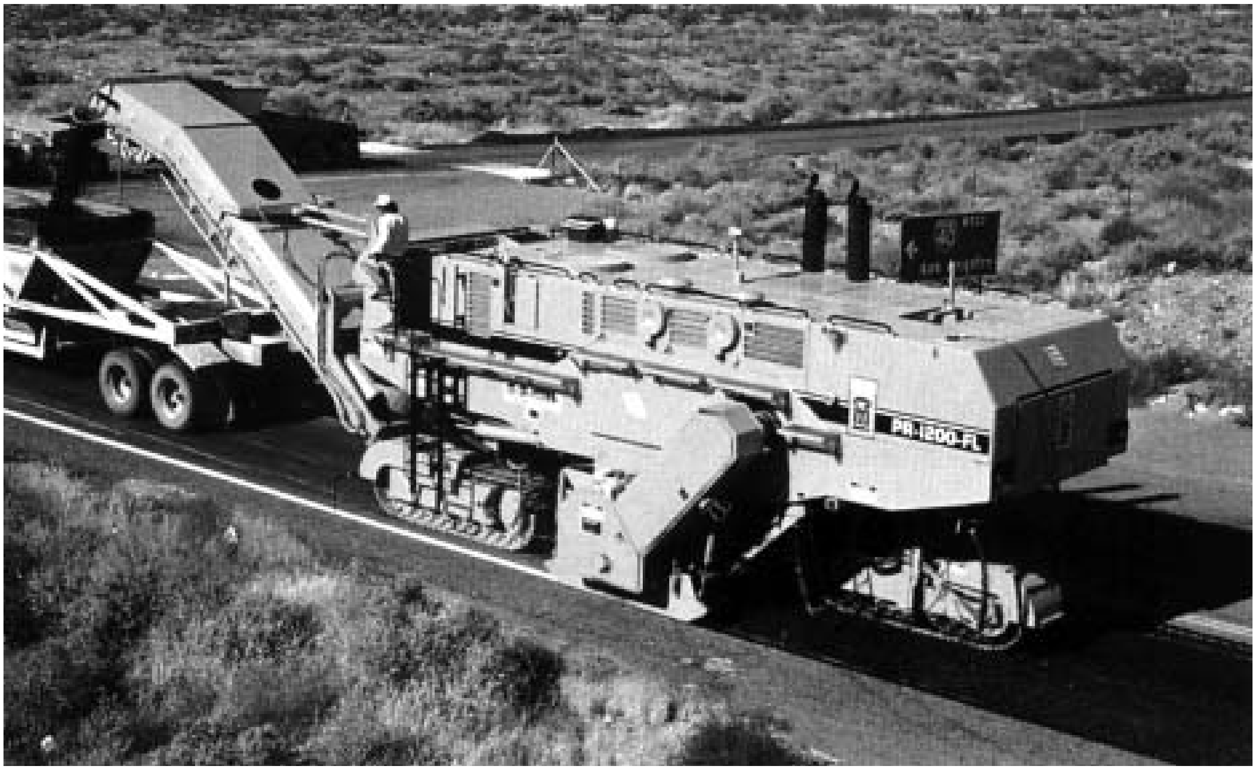


Figure 8-2: High capacity full lane cold planer

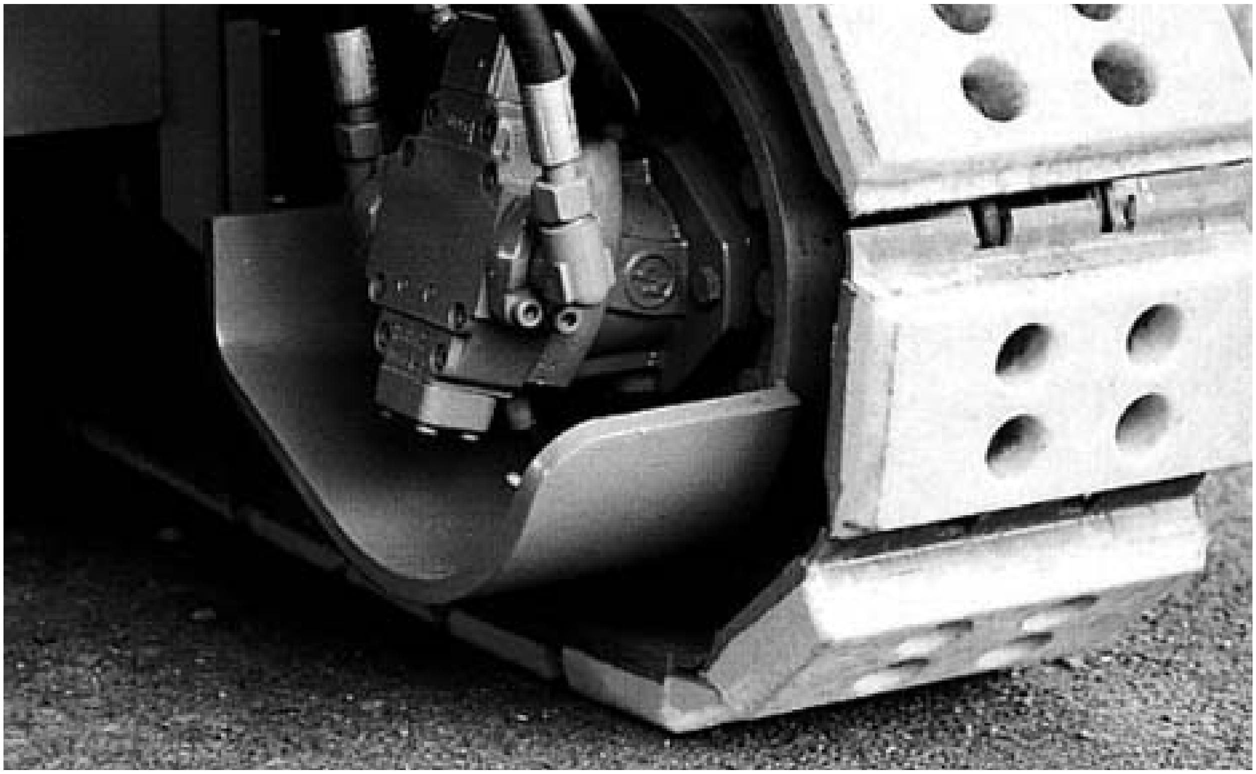


Figure 8-3: Individual track hydraulic drive motor and track pad

The modern cold planer is sized so that the overall weight and available horsepower are related to the milling width and depth in order that traction is always maintained. Cold planers are equipped with either three or four tracks for load distribution, mobility, and traction. Some cold planers are equipped with hard rubber tires for increased maneuverability.

Typically, each track/wheel is driven by a separate hydraulic motor, as indicated in Figure 8-3, which are powered by a common hydraulic pump. Uniform traction is increased on slippery surfaces by various traction locking devices which divert power away from the track that is slipping to the ones that have traction.

The use of rubber/polyurethane track pads, as indicated in Figure 8-3, increases traction and minimizes damage to the roadway surface.

To increase maneuverability, the cold planer can be operated with front steering, rear steering, and/or all track steering. This permits easy maneuvering of the cold planer which allows it to mill around the tight radius turns found on some roadway intersections, as indicated in Figure 8-4. This maneuverability ensures access to most areas, increases production, and reduces costs.

Cutting drums are available in a variety of widths which can be increased with bolt on extensions. The cutting drums can usually be changed relatively quickly depending on the treatment width and surface texture required. Cutting drums generally operate in an "up-cut" direction, i.e., the rotation of the cutting drum is opposite to the direction of the cold planer. Most cold planers have a variable sized shoe which exerts down pressure on the pavement in front of the milling drum. The shoe is used to hold broken pieces of pavement in place so that large pieces or slabs are not

Figure 8-4: Cold planer milling urban intersection

broken loose by the up cutting action of the cutting drum. The shape of the shoe and amount of down pressure used will depend on the condition of the pavement being milled and the size requirements for the RAP being produced. Increasing the cutting drum rotation speed and reducing the forward speed of the cold planer will also help in sizing the RAP.

The cutter drum is equipped with easily replaceable tungsten carbide cutting tools. The development of more robust cutting tools has contributed to the development of larger cold planers. The orientation of the cutting tools is in a helical or spiral pattern that is intended to move the reclaimed material to the center of the cutting drum, as indicated in Figure 8-5. The service life of the cutting tools varies, depending on the material being milled and the depth of milling. Cutting tools may need to be changed from once per hour to once per shift.

The cutting drum drive system is powered by a diesel engine, clutch, power transmission belt/pull, and gearing inside the cutting drum. Automatic power control devices sense the varying load on the cutting drum, due to changes in material condition/hardness and adjusts the forward speed of the cold planer to ensure maximum performance without overloading the drive system.

A heavy-duty scraper blade or “moldboard” is used behind the cutting drum to help collect the reclaimed material and to shave off any high points in the milled surface. The scraper blade usually contains a tungsten carbide wearing surface to enhance durability.

Side plates are used to contain the material within the cutting drum chamber. The side plates can move up and down to accommodate milling adjacent to a concrete curb or area that has been previously milled.

Figure 8-5: Helical pattern of tungsten carbide tools on cutting drum

When milling pavements for utility trench cuts, it is advisable to leave some of the RAP in the trench until the trench is subsequently excavated. The scraper blade at the rear of the cutting drum chamber is raised so that only a portion of the RAP is loaded into the haul trucks with the remainder staying in the trench. In some milling machines, the RAP can be windrowed by leaving an opening in the scraper blade and not using the loading conveyor.

A small amount of water is used during the milling operation, to control the amount of dust generated and to extend the service life of the cutting tools. The water is supplied from the cold planer's onboard storage tank which is refilled by a water truck.

Modern milling machines are of sufficient size to provide the traction and stability needed to remove the pavement surface to the specified profile and cross-slope. Most are equipped with automatic grade controls systems to control the milling process. Typically, one or more automatic leveling systems, operating independently, and a number of different sensors can be used to control the milling machine. Cable sensors can be used for mechanical scanning of the side plates attached to the cutting drum. Non-contact ultrasonic sensors can be used to scan the height of the side plate and also the reference surface beside, in front or behind the cutting drum.

Transducing sensors are used to scan a moving reference line such as a ski or a fixed reference line such as a stringline for grade control, as indicated in Figure 8-7. A slope sensor attached to the milling machine can be used in conjunction with the depth sensor for both grade and cross-slope control. Laser sensors are also being used with a laser transmitter for very tight grade control, usually in specific locations.

Figure 8-6: Front loading milling machine

The RAP generated during the CP operation is usually loaded onto haul trucks by the milling machine and removed from the site. Self-loading milling machines are available in all sizes from the large full lane cold planer, as indicated previously in Figure 8-2, to the smaller partial lane width milling machines, as indicated in Figure 8-8.

Front loading milling machines are now the standard in the industry as they save time and money, since the only lane which needs to be closed to traffic is the lane that is being milled. Front loading also provides a safer work site as all equipment and haul trucks are operating in the same direction as traffic, eliminating the difficult task of backing up the haul trucks. The loading conveyor on the milling machine can be raised or lowered, and in conjunction with an adjustable belt speed, even the longest of haul trucks can be loaded over their full length. The loading conveyors usually can be angled to either side so that the haul truck could be loaded by traveling along side the milling machine. Alternatively, the RAP could be deposited directly onto the adjacent shoulder as a windrow, if desired.

Rear loading of RAP is now typically only used in the smaller class of milling machines particularly for the 3 foot (1 meter) and less utility trench applications in which smaller haul trucks are used, as indicated in Figure 8-8.

The scraper blade and loading conveyor remove most of the RAP, although some smaller particles remain on the milled surface due to its rough grid patterned texture. These fine, loose pieces of RAP are removed from the roadway surface by means of power brooms, vacuum sweepers, and/or power sweepers. The use of power brooms in urban, residential or other sensitive areas may not be allowed due to the potential for dust generation during the cleaning operation.

Figure 8-7: Transducing sensor and stringline for control of the cutting drum

Figure 8-8: Small self loading, partial lane width milling machine

The cleaning/sweeping of the milled surface needs to be completed prior to the roadway being opened to traffic. If not, the fine, loose pieces of RAP will be compacted into the milled surface by the vehicle tires. They will then become extremely difficult to remove.

At the completion of the cleaning operation, the milled roadway can be opened to traffic. Some owners place restrictions on the length of time (days to months) milled roadway surfaces can be left open to traffic prior to placement of a HMA overlay. Many owners specify that all milled surfaces requiring a HMA overlay must be paved prior to any winter shutdown. For some projects, particularly those with high traffic or safety issues, the milled area is paved the same day.

If the underlying pavement structure is adequate, the milled surface can be left indefinitely and needs only traffic control lines to accommodate traffic.

8.3 PREPARATION AND PLANNING

Some preliminary preparation and planning activities are required prior to the start of the CP process. These activities are intended to improve the uniformity of the milled surface. The preliminary activities are also intended to result in better equipment utilization and increased productivity.

The detailed project analysis will have identified many of the preliminary activities. However, field verification immediately prior to construction provides an independent check which reduces the risk that something unexpected will occur.

Identification of buried utilities, abandoned rail or streetcar lines, manholes, valves, and other castings needs to be undertaken prior to the start of CP. If solid, buried obstructions are encountered during the milling operation, damage to the cutting tools, cutting tool holders, cutting drum, and under particularly adverse conditions even to the drive mechanism, can result. The associated down time, inconvenience to the public, and repair costs can be extensive.

In the case of manholes, valves and other roadway castings, these are treated with a mini cold planer as was indicated previously in Figure 8-1. The mini cold planer mills to the required depth in advance of the larger machine so that there is a smooth transition between the two areas, as indicated in Figure 8-9.

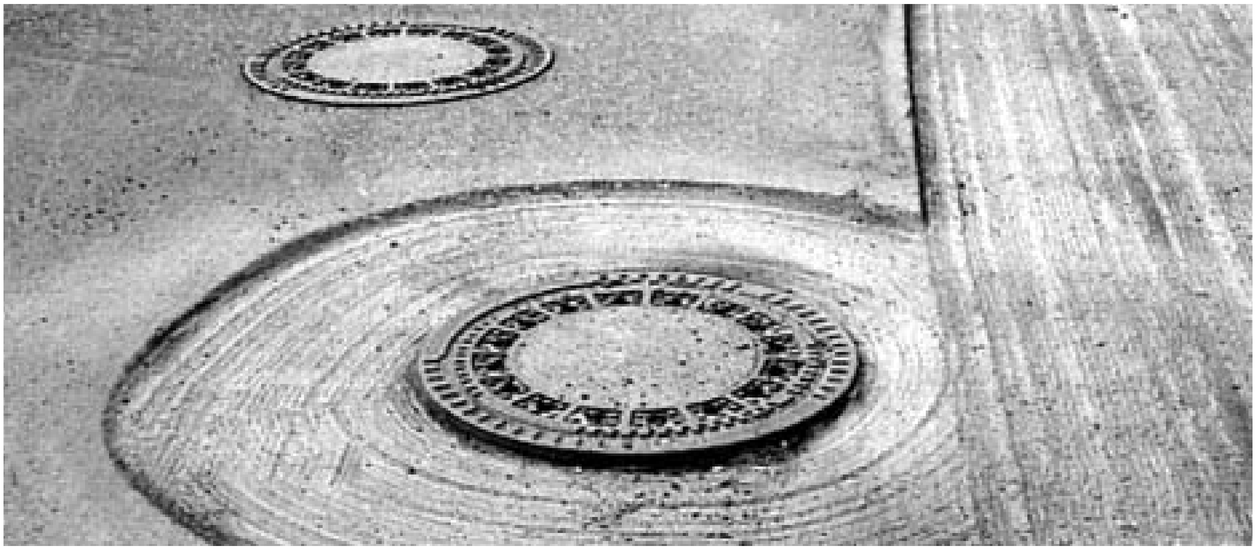


Figure 8-9: Milling around street castings

8.4 CP MICRO MILLING

CP micro milling or “carbide grinding” is a CP process that uses a cutting drum equipped with significantly more cutting teeth in order to produce a much finer textured surface. Micro milling’s primary application is for a milled surface that is to be used as the final riding surface without a HMA overlay. Micro milling can also being used to correct some minor pavement distresses by removing a very thin layer of existing pavement. A surface treatment such as micro-surfacing, chip seal, cape seal, etc., is then placed as the wearing surface at a significantly reduced cost.

Micro milling is also used to remove pavement markings which need to moved due to changing traffic flows or reconstruction activities.

Conventional milling machines are used for micro milling, so only the cutting drum needs to be changed. The conventional drum on a cold planer has cutting tools spaced approximately 5/8 to 3/4 inch (15 to 20 mm) apart. This cutting tool spacing produces a grid patterned textured surface with discontinuous longitudinal striations approximately the same distance apart as the cutting tools, as indicated in Figure 8-10. The micro milling drum has cutting teeth spaced approximately 3/16 inch (5 mm) apart so the grid patterned textured surface with discontinuous longitudinal striations are much close together, as indicated in Figure No. 8-11. Other cutting teeth spacing can existing in the range of 1/4 to 1/2 inch (6 to 12 mm) apart and is commonly referred to as “fine milling.”

The surface texture, regardless of the type of cutting drum being used, is affected by the condition of the cutting tools, rotational speed of the cutting drum, and the forward speed of the cold planer. The milled surface has a finer texture when the cutting tools are new, the milling drum rotates faster or the forward speed of the cold planer is reduced.

The same grade and slope controls that are on the cold planer for conventional CP are also used during the micro milling process to ensure that the roadway is reprofiled according to the plans and specifications.

A vacuum sweeper usually follows the cold planer equipped with a micro milling drum, to clean the finely milled surface so that the roadway can be opened to traffic.

8.5 CP SAFETY WARNINGS

CP can be used to install safety warnings such as longitudinal “rumble strips”, as indicated in Figure 8-12. Transverse grooves can also be milled into the pavement surface prior to intersections or stop lines, in place of speed bumps.

The rumble strips or transverse grooves are noticeable both physically and audibly to alert the driver to a potential roadway hazard.

Figure 8-10: CP surface texture produced with a conventional milling drum

Figure 8-11: CP surface texture produced with a micro milling drum

Figure 8-12: Installation of longitudinal rumble strips

CHAPTER 9: COLD PLANING – SPECIFICATIONS AND INSPECTION

Although other areas of roadway construction are moving towards end result specifications, this has not yet happened to Cold Planing (CP). Specifications for CP are still in method specification format, for the most part. Some owner agencies are beginning to introduce more end result requirements into the CP specifications, particularly smoothness, when the milled area is to used as the driving surface.

9.1 STANDARD SPECIFICATIONS

Standard specifications for CP projects need to address a number of items, including:

- general description
- material requirements
- equipment requirements
- construction methods
- inspection and Quality Control/Quality Assurance (QC/QA)
- acceptance requirements
- measurement and payment

The general description, usually only one paragraph long, introduces the project, the CP process, and construction methodology in broad terms.

A terms and definition section is not normally included within the CP specifications since it is such a universally used and accepted process. ARRA has defined five classes of CP as follows:

- **Class I: Fix Existing Conditions**

  CP the existing pavement surface, as necessary, to remove surface irregularities. It may include milling for Hot Mix Asphalt (HMA) to fixed elevations. Automatic grade and cross-slope controls are not required.

- **Class II: Grade Control**

  CP the existing pavement surface to a uniform depth, requiring automatic grade but not cross-slope control.

- **Class III: Grade and Slope Control**

  CP the existing pavement surface to a uniform depth and cross-slope, requiring the use of automatic grade and cross-slope controls.

- **Class IV: Full Depth**

  CP the existing pavement structure full depth from the roadway surface to the underlying granular base or subgrade.

- **Class V: Variable Depth**

  CP the existing pavement surface to a variable depth as shown on plans and/or specifications. Automatic grade and cross-slope controls may be required.

The CP specifications may refer to the various ARRA classes of milling which may be required on the project.

The section on materials is included to indicate who will own the reclaimed asphalt pavement (RAP) after it has been milled from the roadway. Ownership of the RAP will be either the contractor or the owner agency. When an owner agency retains ownership of the RAP they usually have subsequent specifications which indicate where the RAP is to be transported, how it is to be stockpiled, and what the maximum size of the largest RAP particle is permitted to be.

The section on equipment requirements contains a fair amount of detail and can be rather lengthy. It can include details for all equipment from the cold planer through to the cleaning/sweeping equipment. The specifications can include requirements for:

- age or operating condition of all equipment
- cold planer size/production capability
- removal of RAP from roadway surface/integral loading system of cold planer
- method for controlling dust generation
- automatic grade and slope controls on the cold planer
- sweeping or roadway cleaning equipment

In addition, requirements for pre-approval or acceptance of the equipment, particularly the cold planer, prior to use are sometimes included. The specifications may include the requirement for the proposed CP equipment to undertake a test or demonstration section in order for the owner agency to evaluate and approve the equipment, construction methodology, contractor, and/or workmanship. This is usually reserved for those projects in which the milled surface will be left as the driving surface.

Construction methods included in the specifications address such issues as:

- production plan indicating number and type of cold planers to be used, width and location of each milling pass, and the number and type of sweepers to be used
- type and location of traffic warning signs
- accommodation of traffic through the work zone
- weather limitations prior to and during CP
- lighting requirements for night work
- preliminary surface preparations
- protection of adjacent infrastructure and/or property from damage
- prevention of RAP from entering underground utilities
- direction of milling
- amount of water used during milling
- gradation requirements of the RAP
- striation pattern and/or surface texture

- changing of cutting tools
- loading of haul trucks and consequences of overloading
- grade and cross-slope requirements including use of independent, moving or fixed reference lines
- ramping requirements for longitudinal edge drop-offs
- ramping requirements for transverse and localized edges, i.e., valves, manholes, etc.
- cleaning of the milled surface
- opening area to traffic

With method specifications, the owner agency is in control of the construction process and therefore needs to have sufficient inspection during the CP operations. The owner agency personnel on the project have to have the experience to evaluate the milled surface and authority to make field adjustments to the CP process.

The specifications sometimes outline the frequency of sampling and the testing methods that will be used, particularly if the owner agency is to use the RAP. Wherever possible, these should be published industry standards, such as American Association of State Highway and Transportation Officials (AASHTO) or American Society for Testing and Materials (ASTM) methods or the owner agency's own adaptation of these procedures. With method specifications, the QC and QA testing are usually one and the same and increased inspection is used to control the CP process.

A section of the specifications outlining the acceptance requirements for the CP work is also included. The acceptance requirements include such things as:

- milling depth and width
- gradation of the RAP
- surface texture
- grade and slope requirements
- surface smoothness

Some of these are obviously end result requirements but are included in the method specifications for CP.

The final section deals with measurement and payment issues. The specifications usually outline how items will be measured such as:

- mobilization/demobilization
- surface preparation prior to CP
- CP of existing pavement
- removal and/or hauling of the RAP
- cleaning of the milled surface
- traffic control

In addition, the specifications indicate what is to be included in each of the payment items.

Mobilization/demobilization is more commonly being included as a specific payment item. Some specifications fix the amount/lump sum or limit it to a percentage of the total contract price.

Other specifications require that mobilization/demobilization be included as part of the other payment items.

Surface preparation, usually by sweeping, prior to the start of the CP process is normally included in the CP compensation. It could be paid for by the square yard (square meter) of surface area on specific projects.

Compensation for CP can be by the cubic yard (cubic meter) or ton (tonne) of RAP milled from the roadway or more commonly by the square yard (square meter) for a specified treatment depth. In all cases, the payment is for the final treatment volume, weight or surface area independent of the number of passes needed to mill a given area, and regardless of the hardness/condition of material being milled.

Removal and/or hauling the RAP is usually included within the compensation for CP. However, when the owner agency retains ownership of the RAP and requires that it be hauled a significant distance to a stockpile site, a hauling/trucking payment item may be used.

Traffic accommodation is also generally included in the CP compensation but can be a separate payment item particularly for higher traffic roadways with specific requirements.

Special Provisions, appended to the CP specifications, are used to indicate specific project requirements such as:

- limits of work
- construction schedule, staging or limitation on hours of work
- trucking requirements
- particular traffic accommodation requirements
- interaction and cooperation with other contractors
- parking and storage of equipment
- any other site-specific requirements

9.2 SPECIFICATION LIMITS

Specifications typically include limits and/or tolerances on a number of physical properties related to CP a pavement surface and could include some or all of the following:

- milling depth
- gradation of the RAP
- surface texture
- grade and cross-slope
- smoothness

Milling depth(s) are typically indicated on the plans or in the specifications. Some variation in milling depth is to be expected, particularly when improvements to grade, cross-slope and smoothness are to be made with CP. Usually the specifications indicate milling is to depths indicated by the owner agency. For specific application such as milling and inlay paving, a tolerance of plus or minus a given amount from the design thickness is allowed. A value such as +/- 3/16 inch (5 mm) could be specified or milling depth tolerance can also be specified as a percentage of the design milling depth such as +/- 10 percent.

Regardless of the method of indicating the tolerance, specifications usually indicate that the milling depth should not be uniformly high or uniformly low.

The gradation or sizing of the RAP can be somewhat controlled by adjusting how the cold planer is being operated. There are physical and economic limits on how fine the existing pavement can be milled with a cold planer.

The surface texture of the milled surface is usually specified in terms of visual appearance. Some agencies are assessing the use of different types of test methods, such as a sand patch test, infrared imagery, or road profiler methods as a way of quantifying the surface texture of the milled surface.

Typically, the milled surface texture is to be a grid-patterned surface with uniform discontinuous longitudinal striations or other similar pattern which has not been torn, gouged or otherwise injured during the milling operation. It is possible to “out run” the cutting drum if the forward speed of the cold planer is to fast compared to the rotational speed of the cutting drum. To maintain an acceptable standard of quality, the ratio of forward speed to cutting drum rotational speed could be specified.

Other specifications attempt to quantify the surface texture by indicating the number of striations produced for each cutting tool for a given longitudinal length, the number of striations in the transverse direction, the maximum dimension between the adjacent striations and/or the maximum depth of the striations. When the dimensions of the striations are used in the specifications, the maximum distance between adjacent striations is usually specified to be a maximum of 3/4 inch (20 mm) and the maximum depth as 3/16 inch (5 mm). The dimensions of the striations may decrease somewhat if micro milling is being specified.

The grade and cross-slope are specified by the owner agency and are checked using precision survey, stringline, and/or straightedge level. Usually the tolerance from grade and cross-slope is around +/- 3/16 inch (5 mm) or if specified as a percentage +/- 10 percent.

Smoothness of the milled surface has traditionally been specified by a straightedge requirement. Typically, this has been +/- 3/16 inch (5 mm) for a 10 foot (3 meter) straightedge. Alternatively, some specifications indicate that a longer stringline be used with maximum variations not exceeding +/- 5/16 inch (8 mm) for a 25 foot (7.5 meter) stringline. If bumps or dips are noted these are usually required to be corrected, so they meet the specified tolerance.

There is a trend towards specifying smoothness in terms of overall ride quality for projects in which CP is being used to prepare the roadway for a thin lift of HMA, a chip seal or similar surface treatment or that will be left as the driving surface. Two approaches are beginning to be used by owner agencies to specify the smoothness of the milled surface. One approach is to determine the roadway smoothness prior to milling, using a conventional measuring device such as a California Profilograph, Mays Ride meter or similar device. After the roadway has been milled, the smoothness is again checked with the same device. The specifications indicate the required percentage improvement in ride quality from before milling to after milling. The other method is to measure the smoothness of the roadway after it has been milled and to specify that it must achieve a maximum value or index for ride quality. A higher percent increase in smoothness or a lower maximum smoothness index is used for interstate roadways and/or for projects in which the milled surface will be left as the driving surface. Incentive payments are usually included for milled surfaces that are smoother than the limits specified.

When choosing the appropriate limits for overall smoothness for both of the approaches noted above, the required texture of the milled surface must be taken into consideration.

9.3 INSPECTION, QUALITY CONTROL AND QUALITY ASSURANCE

The inspection and QC/QA plan used for CP need to be developed based on the CP application and then amended for the specific type of equipment being used on the particular project.

During the CP process the areas of concern that the owner agency/contractor QC/QA plan may need to address include:

- milling depth
- RAP moisture content
- surface texture
- grade and cross-slope
- smoothness

To ensure that the automatic grade controls are working correctly on the cold planer, the milling depth needs to be physically measured. Depth measurements should be performed on a regular basis by measurements at the outside of the cut.

When required the maximum particle size and moisture content of the RAP should be checked periodically. Samples of the RAP are obtained from the discharge conveyor belt and tested. Care must be taken to ensure that representative samples of the RAP are obtained and tested.

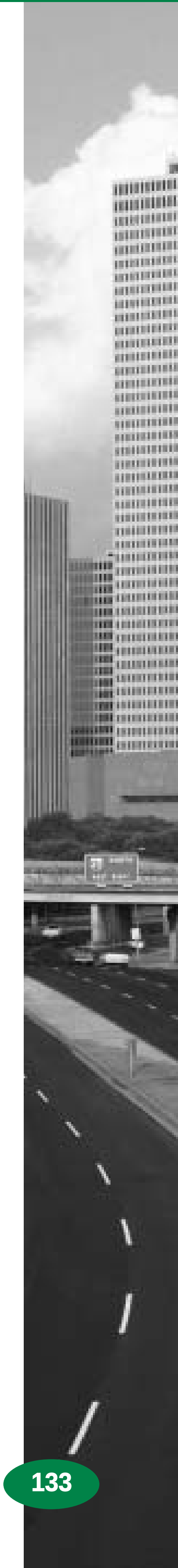
Surface texture is assessed both visually and by taking a number of measurements of the striations and then averaging them to determine whether the specifications are being achieved.

Grade, cross-slope, and smoothness are checked based on what is required in the specifications. A number of locations should be checked and then averaged in order to arrive at a representative result.

CHAPTER 10: FULL DEPTH RECLAMATION – DETAILED PROJECT ANALYSIS

Through the project evaluation, economic analysis and preliminary selection process, outlined in Chapter 3, the potential rehabilitation alternatives were narrowed down to one specific technique. The next step in the rehabilitation design is the detailed project analysis which will lead directly into the final project design, advertising, tendering or letting, and construction.

The Hot Mix Asphalt (HMA) overlay, hot recycling, and reconstruction rehabilitation methods will not be addressed since they are routinely used by all agencies. The rehabilitation techniques of Cold Planing (CP), Hot In-Place Recycling (HIR), and Cold Recycling (CR), are covered in depth in other chapters. It is recognized that many of the steps in the detailed project analysis are common to all the rehabilitation methods but are addressed in each process, for continuity.



10.0 FULL DEPTH RECLAMATION REHABILITATION

FDR is the rehabilitation technique in which the full thickness of the asphalt pavement and a predetermined portion of the underlying materials (base, subbase, and/or subgrade) is uniformly pulverized and blended to provide an upgraded, homogeneous material. Often this blend of material alone, without any additional stabilizing additives, is sufficient to act as the base for a new surface course. However, if after proper project evaluation it is determined that the reclaimed materials need improvement or modification, there are three different types of stabilization that can be used:

- mechanical
- chemical
- bituminous

Mechanical stabilization is achieved with the addition of granular materials such as virgin aggregate or recycled materials such as reclaimed asphalt pavement (RAP) or crushed Portland cement concrete. Chemical stabilization is achieved with the addition of lime, Portland cement, fly ash, lime or cement kiln dust, calcium/magnesium chloride or various proprietary chemical products. Bituminous stabilization is accomplished with the use of liquid asphalt, asphalt emulsion, and/or foamed (expanded) asphalt. For increased stabilization requirements, combinations of all three can also be used.

Pavement distresses which can be treated by FDR include:

- cracking in the form of age, fatigue, edge, slippage, block, longitudinal, reflection, and discontinuity
- reduced ride quality due to swells, bumps, sags, and depressions
- permanent deformations in the form of rutting, corrugations, and shoving
- loss of bonding between pavement layers and stripping
- loss of surface integrity due to raveling, potholes, and bleeding
- excessive shoulder drop off
- inadequate structural capacity

Pavements that have extensive distortion or deterioration due to subgrade or drainage problems are candidates for FDR only when additional work is undertaken to correct the subgrade and drainage deficiencies. To correct subgrade problems the reclaimed material typically is moved to one side, the subgrade is reworked or stabilized with an additive and then the reclaimed material is placed back on the prepared subgrade.

The expected design life, performance requirements during the design life, and acceptable future maintenance requirements are related to the treatment depth of the FDR, the types and amount of stabilizing agents used, and on the type and depth of the subsequent wearing course.

10.1 HISTORIC INFORMATION ASSESSMENT

In the detailed review of historic or existing information the data contained in the Pavement Management Systems (PMS) which needs to be assessed includes:

- age of the roadway including any surface treatments
- past condition surveys in order to assess the rate of pavement deterioration
- type of asphalt binder used in the asphalt pavement layers
- thickness of the existing asphalt pavement and underlying granular materials
- top size of aggregates used in the asphalt pavement layers and underlying granular materials
- presence of any paving fabrics or interlayers within the asphalt pavement. Some paving fabrics are very difficult to recycle with FDR and the presence of an interlayer may need to be assessed further, depending on its characteristic and location
- presence of exotic or specialty mixes, such as Open Graded Drainage Layers, Open Graded Friction Courses, Stone Matrix Asphalt, etc. which may have an effect on the selection of granular materials and on the type and amount of stabilizing agent(s) used

The detailed review of existing information contained in a maintenance database which needs to be assessed includes:

- patching locations and ages
- patching material including HMA, cold mix asphalt, injection spray patching, etc.
- crack sealing activities, product types and ages

The detailed review of the existing Quality Control/Quality Assurance (QC/QA) information, from construction of all asphalt pavement layers, includes:

- asphalt binder content
- aggregate gradation, angularity, flat/elongated particles, and/or petrographic analysis
- field compaction

In addition, existing QC/QA information, from construction of all granular base and sub-base layers, should be reviewed, including:

- aggregate gradation, angularity, flat/elongated particles, and/or petrographic analysis
- field compaction

Figure 10-1: Candidate for FDR Treatment

10.2 PAVEMENT ASSESSMENT

In the detailed pavement assessment, the type, severity, and frequency of the pavement distress which needs to be corrected is determined. The FDR process destroys the existing asphalt pavement cracks and deterioration since the entire asphalt bound layer is pulverized to produce an improved, homogeneous granular material on which a new pavement structure can be placed.

The presence of large or frequent surface patches increases the variability of the existing materials which will have an effect on the consistency of the reclaimed material. Large/deep patches may require their own specific mix design since they are usually newer and of different materials than the original pavement. Patching may also indicate locations of thinner pavement structures, higher groundwater conditions or poor subgrades which may need to be corrected as part of the roadway rehabilitation.

Rutting in the form of wear rutting is easily treated with FDR but it can usually be treated more economically with one of the other recycling methods.

Instability rutting can also be corrected with FDR if the appropriate stabilizing agent(s) and/or granular material are selected and designed into the process. Structural rutting, provided it is not originating in a very weak/wet subgrade, can be addressed with FDR and then selecting the appropriate thickness of HMA as the wearing course. If structural rutting is a result of a very weak or wet subgrade, the pavement structure can be pulverized and moved to one side, the deficient subgrade can then be stabilized or removed and replaced, the pulverized material can be moved back, and the FDR process completed.

10.3 STRUCTURAL CAPACITY ASSESSMENT

Two aspects of the structural capacity assessment need to be addressed. The first aspect is to determine what structural capacity is required for the anticipated traffic during the design life of the rehabilitation using conventional pavement design methods. If a mechanistic-empirical pavement design method is used to determine the required overall pavement structure, the structural layer coefficient of a FDR mix typically ranges from 0.15 to 0.40 with an average value of about 0.20. The range in structural layer coefficient value is related to the amount and types of stabilizing agents used. Each agency will have to determine an appropriate structural layer coefficient typical of the FDR mixes used in their jurisdiction.

Reclaimed mixes which have had lime, Portland cement or Class C fly ash added, in addition to a bituminous stabilizing agent typically have significantly higher initial strength values and slightly higher long-term strengths, compared to reclaimed mixes stabilized with bituminous materials only. These mixes also tend to be stiffer and consequently are less flexible than reclaimed mixes modified with a bituminous stabilizing agent only.

FDR mixes modified with a combination of a bituminous stabilizing agent and either lime, Portland cement or Type C fly ash are significantly more resistant to moisture damage initially, than mixes stabilized with only bitumen. However, mixes with only a bitumen stabilizing agent achieve very similar long-term moisture damage resistance results.

The second aspect is the ability of the underlying subgrade to provide sufficient support so that adequate compaction of the reclaimed mix can take place. The FDR equipment is considerably lighter and smaller than CIR equipment, and generally uses high floatation tires, so that equipment break-through is not usually an issue. However, if the underlying subgrade does not provide enough support, excessive deflection will occur and adequate compaction cannot take place. Weak, wet or deflecting subgrades will require improvement or stabilization in order to ensure that adequate compaction of the reclaimed mix is achieved, otherwise a significant drop in strength and performance will be noted.

The two most useful methods of assessing the load-carrying capacity of the existing subgrade are Dynamic Cone Penetrometer (DCP) and Falling Weight Deflectometer (FWD) testing. With the DCP, the underlying materials can be assessed by coring/drilling through the asphalt pavement layers to expose the granular base/sub-base and subgrade materials. Obviously, if water has been used in the coring operation, the resultant moisture may effect the DCP values of the upper portion of the underlying materials. Assessment of the load-carrying capacity is usually conducted at the same locations that samples of the asphalt pavement, for material property assessment, are obtained. However, for weak and/or thin pavement structures, additional DCP testing should be conducted to more fully assess the load-carrying capacity and/or isolate weak areas. This is critical since the consequence of lower compaction is usually a significant reduction in the performance of the FDR material.

DCP results will change throughout the year in response to changes in base and subgrade moisture conditions. The DCP results should ideally be obtained when the moisture conditions in subgrade will be similar to those at the time of FDR construction. If this is not possible, then an adjustment of the DCP evaluation criteria, to account for the differences in moisture contents from the time of testing to time of construction, will need to be made. Each agency will need to establish its own DCP blow count profile vs. feasibility of FDR construction evaluation criteria, since it will be sensitive to material types, soil and groundwater conditions.

The FWD can also be used to assess the load-carrying capacity of the existing subgrade by back-calculating the subgrade resilient modulus. Other parameters such as the base damage index and/or base curvature index can be determined from the deflection bowl measurements produced by the FWD. As with the DCP testing, each agency will have to establish its own evaluation criteria based on their local conditions.

10.4 MATERIAL PROPERTIES ASSESSMENT

Utilizing the results of the existing information review and the pavement assessment, the project is divided into areas/segments of similar materials or performance. A field sampling plan is then established utilizing either fixed interval or random sampling methods to determine the location of the field samples. Samples should be obtained at a frequency of approximately one location per 800 to 1600 feet (250 to 500 meters) or more often, if changing conditions warrant.

Field samples can be obtained by means of either wet or dry coring, usually 6 inches (150 mm) in diameter, and then crushing the cores in the laboratory. Field coring and laboratory crushing of the recovered asphalt pavement produces sample gradations that more closely resemble what is achieved in the field during the FDR process. Block sampling of the asphalt pavement materials by means of sawing and then excavating a test pit to expose, sample and test the underlying materials can also be used, but it is usually more expensive than coring, takes longer and has a significant impact on traffic. Test pits have the benefit that larger, more representative samples, particularly of the granular base materials, can be obtained.

The frequency of field sampling varies with the size of the project, size of the areas of similar materials or performance, and the variability of the existing materials, as determined from the review of existing QC/QA data. Generally, the number of sample locations ranges from 1 to 3 for smaller, consistent areas, to 20 or more for larger, less consistent areas. The number of cores obtained at each field sampling location will depend on the number of field sample locations, the amount of laboratory testing to be performed, whether or not samples will be needed for subsequent FDR mix designs, and what type of mix design method will be used. If a modified Proctor/Marshall mix design method is used the total number of cores will depend on the anticipated FDR treatment depth and core diameter. Typically, approximately 110 pounds (50 kilograms) of the asphalt pavement and underlying granular base material is required for each mix design. If the effects of additional stabilizing agents are to be assessed, then more material will be required.

The core samples should be carefully examined, throughout their full depth, in order to detect the different pavement layers, previous surface treatments, interlayers, geotextile paving fabrics, specialty mixes, evidence of stripping, friable or disintegrating mix, retention of excessive moisture, and any tendency to delaminate. Once the cores have been inspected, the observations recorded, and selected cores photographed, the cores are crushed. Representative samples are then tested to determine:

- moisture content (if dry coring has been used)
- gradation of the crushed RAP
- asphalt binder content, if an asphalt emulsion is to be used as a stabilizing agent

- aggregate properties including gradation, angularity, etc.
- recovered asphalt binder properties including penetration, absolute and/or kinematic viscosity if an asphalt emulsion is to be used as a stabilizing agent

In addition, the granular base or subgrade material will need to be sampled in the field for the depth that will be included in the FDR process. Representative samples are then tested to determine:

- moisture content (if dry coring has been used)
- gradation and angularity
- Plasticity Index
- sand equivalent value

The combined gradation of the RAP and granular base is calculated using the relative proportions of each that will be used in the FDR process.

The above information will assist in the estimation of the type and amount of stabilizing agent(s) to be used, and in determining whether a granular material is needed to improve the RAP characteristics.

10.5 GEOMETRIC ASSESSMENT

In the detailed geometric assessment determine whether the project:

- requires major realignment, widening or drainage corrections
- contains underground utilities/drainage structures
- requires upgrading of any underground utilities
- needs longitudinal/grade corrections
- requires cross-slope/fall corrections.

Major realignment, widening or drainage corrections are easily accommodated in the FDR process since the existing asphalt pavement is totally pulverized and blended with all or part of the underlying granular material. FDR facilitates the reuse of the existing pavement materials within the construction site, with or without the addition of stabilization/modification agent(s).

FDR has been successfully used on projects where existing granular shoulder has been paved in the rehabilitation process. In order to be successful, the existing shoulder area has to: have sufficient granular material; have good subgrade conditions; the appropriate stabilizing agent(s) selected; and have a HMA wearing course of sufficient thickness.

The presence, frequency, and elevation of utility covers (manholes and valves) need to be assessed, particularly in the urban setting. Manholes and valves should be lowered at least 4 inches (100 mm) below the FDR treatment depth and their locations accurately recorded. Manholes should be covered with a sufficiently thick steel plate and the excavation backfilled with RAP or granular base. Treatment of the roadway should take place in an uninterrupted manner so that the FDR depth and material consistency can be maintained. After placement of the subsequent wearing course, the manholes and valves are located, neatly excavated, and raised to the appropriate level of the wearing course to provide a smooth profile. Obviously, if any upgrading of the existing underground utilities is required, it should be undertaken prior to rehabilitating the roadway surface.

The width of the roadway to be treated is of primary importance since it will dictate the number of pulverization passes or “cuts” which will have to be made by the reclaimer in order to cover the full width. Reclaimers are of fixed width, typically between 6 to 12 feet (1.8 to 3.7 meters) wide which can result in different amounts of overlap between cuts, depending on required treatment width. Overlaps between adjacent passes are usually about 4 inches (100 mm). The location of the existing roadway crown will influence the number of passes since crowned roadways should be treated in half-widths, to ensure a uniform treatment depth across the crown. The location of the longitudinal overlays should avoid the outer wheelpath area, if possible. Tapers for turning bays, acceleration and deceleration lanes are usually treated first. Care should be taken to ensure that double application of any stabilizing agent being used does not occur in the overlap areas.

The FDR equipment is very mobile and maneuverable so roadway geometry, even in an urban setting, has little influence upon the types of areas which can be treated. Roadways containing "T" intersections can be treated all the way to the top of the "T." Paved driveways and other entrances, mailbox pullouts, and other short and narrow areas in the roadway can normally be treated, as well.

The FDR process can correct most longitudinal and transverse profile deficiencies prior to placement of the wearing course. However, if the existing pavement profile is severely defective, one of the following corrective operations may be required to ensure uniform treatment depths:

- If the existing asphalt pavement is of sufficient thickness, cold plane the roadway to correct the profile deficiencies prior to FDR or remove excess material after the pulverizing pass.
- Add either virgin aggregate or RAP from an external source prior to the FDR process, particularly for thinner pavement structures,
- Correct as much of the profile deficiencies as possible with the FDR process and then correct the remaining profile deficiencies with additional wearing course material.

10.6 TRAFFIC ASSESSMENT

Originally, FDR was used on low to medium traffic volume roadways because there was no effective way to pulverize the thicker pavements usually found in high-volume roadways. However, with the newer/larger equipment available, FDR is now being used on higher traffic volume roadways, as well. There is no upper limit to roadway traffic volumes provided a pavement structural design is undertaken as part of the rehabilitation process, to ensure that the effects of future traffic is accounted for.

The FDR process minimizes traffic disruptions and user inconvenience due to the short construction time—compared to conventional pavement reconstruction methods and the ability to keep one-half of the roadway open during construction. If possible, it is advantageous to completely detour traffic to other roadways since this will permit the full width of the road to be treated at one time. FDR can be undertaken in off peak hours to further reduce the traffic disruptions but this results in reduced daily productivity and increased costs.

Depending on the width of the existing roadway the FDR operation will usually occupy one-half the width of the roadway at a time. For narrow roadways, accommodation of large/wide truck or oversized loads will need to be addressed.

On two lane roadways, one-way traffic through the construction zone will need to be maintained with appropriate traffic control such as flag people, lane demarcation devices and/or pilot vehicles. Very narrow two lane roadways increase the difficulties for traffic accommodation, particularly if there is little or no paved shoulder.

Traffic control at intersections and at business approaches also needs to be addressed in an urban environment. Due to the speed of the FDR processes the intersections and approaches are not out of service for very long and traffic is usually controlled with flag people and lane demarcation devices.

10.7 CONSTRUCTABILITY ASSESSMENT

As the FDR equipment is relatively light and highly maneuverable, overnight parking or storage of the equipment is usually not a concern. Typically, 4,750 to 9,500 square yards (4,000 to 8,000 square meters) can be completed in a day.

Clear span heights for bridges and underpasses must be checked for not only the FDR equipment but for any haul trucks, as well.

Generally, FDR equipment can process to the edge of a curb and gutter section. For straight-faced concrete sections (with no gutter), a portion of roadway will have to be removed with smaller equipment in order that the area can be fully treated.

The underlying granular materials must be free of oversized rocks and boulders so that damage to the reclaimer does not occur. The maximum aggregate size of the underlying granular materials will need to be less than the maximum particle size permitted in the reclaimed mix.

If granular material is required in the FDR process, then the availability of aggregates of suitable gradation and quality must also be assessed.

10.8 ENVIRONMENTAL IMPLICATIONS

Areas that are extensively shaded receive little or no direct sunlight to assist in the breaking and initial curing of bituminous stabilizing agents, and therefore, take longer to cure and compact. Similar curing conditions/problems can occur if the work is being undertaken in cold, damp conditions typical of early spring, late fall, or winter weather, where there are pavement areas with poor drainage or higher than average moisture content. In these types of conditions, the use of an additional stabilizing agent such as lime, Portland cement or Type C fly ash usually reduces the curing period, and accelerates the strength gain sufficiently to permit the areas to be opened to light traffic within a couple of hours.

FDR should not be undertaken if it is raining or if rain is imminent, since rain dilute the bituminous stabilizing agent and reduce the effectiveness of dry stabilizing agents spread on the surface—resulting in reduced reclaimed mix strength. Similarly, work is usually not undertaken in excessively foggy or humid conditions that can result in longer curing times for the bituminous stabilizing agent.

As with all rehabilitation construction projects, there will be a certain amount of noise associated with the process. Typically, due to the speed of the HIR operation and the transient nature of the process, the noise effects will be short term. This issue will have increased concerns in an urban setting.

10.9 ECONOMIC ASSESSMENT

The expected service lives of the various FDR rehabilitation techniques, when undertaking a life-cycle economic analysis, generally fall within the following ranges:

- FDR with surface treatment . . . . .7 - 10 years
- FDR with HMA overlay . . . . .up to 20* years

Note: * Equivalent to agency's new construction service life.

The effectiveness and performance of the various FDR rehabilitation techniques varies from agency to agency and is dependent on:

- local conditions
- climate
- traffic
- type of technique and quality of materials used
- quality of the workmanship

CHAPTER 11: FULL DEPTH RECLAMATION – MIX DESIGN

Like Hot In-Place Recycling (HIR) and Cold Recycling (CR), there is no nationally accepted method for undertaking a Full Depth Reclamation (FDR) mix design. A number of different FDR mix design methods have been used by various agencies but not many of these mix design methods have been reported in the literature.

When FDR is used as part of the rehabilitation strategy, it is intended to eliminate the existing pavement distresses, to reuse the existing materials, and to create a stronger, higher load-carrying base for the roadway. To increase the reclaimed materials load-carrying capability, stabilizing agent(s) are often added to improve its:

- strength
- durability
- moisture susceptibility

Stabilizing agent(s) can be:

- **mechanical** in the form of particle interlock with the addition of granular materials such as virgin aggregates, Reclaimed Asphalt Pavement (RAP), and/or crushed/reclaimed Portland cement concrete
- **chemical** in the form of calcium chloride, magnesium chloride, lime (hydrated or quicklime), fly ash (type C or F), kiln dust (cement/CKD or lime/LKD), Portland cement (dry or slurry) or other chemical products
- **bituminous** in the form of an asphalt emulsion, emulsified recycling agent or as a foamed/expanded asphalt
- **combination** of two or more of the above

Regardless of the type or number of stabilizing agents used, a laboratory mix design needs to be undertaken in order to optimize the quantity of stabilizing agent and the physical properties of the reclaimed mix. It must also be recognized that the mix design process cannot definitively model what will happen in the field at the time of construction. Therefore, the mix design represents the best possible starting point but field adjustments must be expected. Field adjustments are made based on Quality Control/Quality Assurance (QC/QA) test results and on the workability of the reclaimed mix.

Using the results of the Detailed Project Analysis, as discussed in Chapter 10, the design engineer will determine what type of stabilization mechanism, agent or combination of stabilizing mechanisms and agents, should be assessed.

The results of the historical, structural capacity, and material property assessments will indicate whether pulverization of the existing pavement structure will be adequate. In some cases, additional mechanical stabilization, in the form of additional granular materials, may be required. The amount and gradation of the granular materials will depend on the existing roadway conditions and properties of the reclaimed material. The reclaimed material and any granular materials which have been added will act like an unbound granular base in the rehabilitated pavement structure.

If pulverization or mechanical stabilization alone or if the addition of granular materials cannot be used because of economics or is restricted due to roadway geometry and additional strengthening is required, then chemical or bituminous stabilization may have to be used. There are no hard and fast rules with respect to the selection of a stabilizing mechanism or modification agent(s) but the choice of which stabilizing mechanism and modification agent(s) to use is a function of the:

- thickness of the existing pavement structure
- reclaimed material properties
- amount of strengthening/modification required
- availability of stabilizing agent(s)
- previous experience of the owner agency and local contractors
- economics

A wide range of bituminous and chemical stabilizing agents are currently available and are used to improve the physical properties and/or water resistance of the reclaimed materials. For specific reclaimed materials, some stabilizing agents are more effective and economic than others are but for other reclaimed materials, different stabilizing agents may be more effective and economic. Each type of stabilizing agent has its place in the FDR process or for specific rehabilitation strategies.

The most common chemical stabilization method is with the use of cementitious stabilizing agents including Portland cement, lime, type C fly ash, and/or blends of these materials. The primary function of these stabilizing agents is to increase strength of the reclaimed material by cementing the particles together. In addition, the lime component of Portland cement, fly ash, and calcium oxide (CaO) reacts with the clay particles in the reclaimed materials, reducing its plasticity. Typically, Portland cement is limited to reclaimed materials in which the Plasticity Index is less than 10. If the Plasticity Index of the reclaimed material is in excess of 10, then lime is more often used.

The amount of strength gain is primarily related to the amount of cementitious stabilizing agent added to the reclaimed material. It is noted that more is not necessarily better, since reclaimed materials treated with a cementitious stabilizing agent tend to become a more rigid or brittle material. Increasing the amount of cementitious stabilizing agent increases the rigidity of the reclaimed mix with an associated reduction in fatigue properties and an increase in the amount/severity of the associated shrinkage cracking. The amount of shrinkage cracking associated with cementitious materials can be mitigated by:

- keeping the application content as low as possible, but consistent with the mix design
- compacting the reclaimed mix below the Optimum Moisture Content (OMC) or 75 percent saturation
- reducing or controlling the rate of drying of the reclaimed mix

Therefore, it is important that the physical properties or performance requirements of the chemically stabilized reclaimed mix be linked to the overall pavement design.

The use of bituminous stabilizing agents in the form of asphalt emulsion or foamed (expanded) asphalt has increased due to recent technological advances. Reclaimed materials stabilized with bitumen produces a flexible material with better fatigue properties, compared to those treated with cementitious stabilizing agents. Bituminous stabilized mixes have no shrinkage cracking and can be opened to traffic sooner than cementitious treated mixes. FDR with a bituminous stabilizing agent, creates a bituminous stabilized material not HMA, so it has a higher void content of between 10 and 20 percent. The bituminous stabilized material tends to act partly as a granular material with inter-particle friction and partly as a visco-elastic material capable of handling repeated tensile stresses.

Some bituminous stabilizing agents can be used with marginal reclaimed materials but the stabilized mixes are sometimes susceptible to moisture effects. Moisture sensitivity can be addressed with the addition of small amounts of cementitious materials usually Portland cement, lime or Type C fly ash in combination with the bituminous stabilizing agent. Typically, the addition of 1 to 3 percent by weight of reclaimed material, can significantly increase in retained strength or moisture resistance without adversely affecting the fatigue properties of the reclaimed mix. The addition of small amounts of cementitious materials also acts as a catalyst to increase the strength gain of the stabilized reclaimed mix. This can provide an additional enhancement during construction since the roadway can be opened to traffic sooner. Hence, it is becoming common practice to use Portland cement or lime in conjunction with bituminous stabilizing agents, particularly if the reclaimed materials are of marginal quality.

Asphalt emulsions were developed in order to overcome the difficulties of mixing hot asphalt binders with cold, damp materials. An asphalt emulsion consists of an asphalt binder, water, and emulsifying agent(s). On occasion, the asphalt emulsion may contain other additives such as stabilizing agents, coating improvers, anti-stripping agents, break control agents or polymers. Since asphalt binder and water do not readily mix, the object is to make a dispersion of asphalt binder in water that is stable enough for pumping, prolonged storage, and mixing. The asphalt emulsion should "break" or the asphalt binder should separate from the water within an acceptable period after contact with the recycled materials. Upon curing, the remaining or residual asphalt retains all of the adhesion, durability, and water resistance of the asphalt binder from which the asphalt emulsion was originally produced.

The primary reason for using an asphalt emulsion as a stabilizing agent is to make it possible to mix the asphalt bitumen with the cold, moist, reclaimed material. Mixing of the reclaimed materials with the asphalt emulsion is the first step, since the ultimate goal is to have a bitumen-bounded reclaimed mix. For this to occur, the asphalt binder must break out of suspension in order to act as the stabilizer or "glue" which holds the reclaimed materials together. The chemistry of both the asphalt emulsion and the reclaimed materials has a major influence on the stability and "breaking-time" of the asphalt emulsion. Therefore, it is important to confirm the compatibility of the asphalt emulsion with the reclaimed materials during the mix design.

Foamed asphalt can also be used as the bituminous stabilizing agent but with a more defined type of reclaimed material. For foamed asphalt to be successful, the reclaimed materials need to fall within more controlled gradation and Plasticity Index limits, and may require the addition of fines.

Foaming occurs when a small amount of cold water is introduced into a very hot asphalt binder. The water causes the asphalt binder to expand very rapidly into millions of bubbles resulting in a "froth" or foam. The foamed asphalt is well suited for mixing with cold, moist materials. In the foamed state, the asphalt binder's viscosity is greatly reduced and its surface area is greatly increased, enabling it to be readily dispersed throughout the reclaimed materials.

The potential for using foamed asphalt as a bituminous stabilizing agent was first realized by Professor Ladis Csanyi at the Engineering Experimental Station of Iowa State University in 1956/57, using a steam injection process to make the foam. The technology was subsequently refined and patented by the Mobil Oil Company, which developed the first expansion chamber—where atomized water was mixed with the hot asphalt binder to produce the foam. Since the expiration of the original patent in the early 1990's, additional technological development and a significant increase in use of the foamed asphalt process has occurred worldwide.

Unlike HMA, reclaimed materials stabilized with foamed asphalt are not black in color. This is because the coarser aggregate particles are not coated and are usually free of bitumen. When foamed asphalt comes into contact with the reclaimed materials, the bitumen bubbles burst into millions of tiny "globules" that seek out and adhere to the fine particles, specifically the minus No. 200 (0.075 millimeter) fraction. This preferential attraction to the fine particles creates a bitumen bound filler that acts as a mortar binding the coarse particles together. This results in only a slight darkening of the reclaimed mix.

The main advantages of using foamed asphalt as the bituminous stabilizing agent are:

- reclaimed materials treated with foamed asphalt can be worked in a wider range of weather conditions
- reclaimed materials treated with foamed asphalt remain workable for a sufficient period of time to facilitate placement and compaction
- the road can be opened to traffic immediately after compaction to expedite construction

Similar to stabilization with asphalt emulsion, Portland cement or lime is can be added in small amounts with the foamed asphalt to accelerate the initial strength gain and improve the reclaimed mix's resistance to moisture effects.

When using an asphalt emulsion or a foamed asphalt it is also important to confirm the compatibility of the water used in the process.

11.1 MECHANICAL STABILIZATION MIX DESIGN

When pulverization, mixing, and densification of the reclaimed materials does not produce the required degree of structural support, improvements can be made with the addition of granular materials such as virgin aggregates, reclaimed granular materials or RAP. The amount of granular material that can be added will depend on the:

- gradation and physical properties of the reclaimed materials
- existing roadway geometry
- achievable mixing and compaction depths
- economics

If the reclaimed material is too coarse and clean for adequate compaction, then the granular material will have to be a sandier/finer material in order to produce a more uniformly graded material. Conversely, if the reclaimed material is too fine or has a high Plasticity Index, then a clean, granular material will be required.

Figure 11-1: Mechanical stabilization with RAP as additive

The existing roadway geometry, such as curb reveal heights, clear spans beneath overhead structures, width, and side slopes may limit the amount of granular material that can be added. The granular material will increase the thickness of the reclaimed materials and so must be accounted for in the overall design.

Modern reclaimers used in the FDR process can pulverize and mix existing pavement structures to significantly greater depths than can be readily densified in one lift with current compaction equipment. When the addition of the granular materials results in a layer thickness greater than can be densified in one lift, a portion of the reclaimed material will have to be moved to one side prior to the start of compaction. This impacts the overall costs and affects the economics of the project.

Once the amount and gradation of the granular material (if any) has been determined the mix design can proceed. The mix design consists of determining the appropriate moisture content to maximize the strength properties of the reclaimed mix through adequate densification and particle interlock. To determine the appropriate or OMC and corresponding Maximum Dry Density (MDD), common moisture-density test methods, such as the Standard or Modified Proctor or similar test methods are used.

If required, further strength testing on the reclaimed mix, compacted at the OMC, can be conducted. Strength testing methods include the California Bearing Ratio (CBR), Resilient Modulus or similar tests. The results of the strength testing are used to confirm the minimum strength properties of the reclaimed mix or used by the design engineer to determine the overall pavement structure required.

Figure 11-2: Chemical stabilization on rural roadway

11.2 CHEMICAL STABILIZATION MIX DESIGN

The same mix design process is used, regardless of the chemical stabilizing agent being considered, and generally consists of:

- determining the suitability of the reclaimed material
- establishing the proportions of reclaimed material, stabilizing agent, and water
- confirmation of the mechanical properties of the stabilized mix

In the first part of the mix design, the suitability of the reclaimed material for use as a chemically stabilized base course is assessed in a manner similar to what was required for mechanical stabilization, listed previously. The physical properties of the reclaimed material, primarily the gradation and Plasticity Index, are used to assess the need for granular material and to select a potential chemical stabilizing agent.

The second part of the mix design is the establishment of the proportions of reclaimed material, chemical stabilizing agent, and moisture content, by means of trial mixes. The initial trial mix proportions are established through trial and error or through experience. Typically, multiple chemical stabilizing agent application rates are assessed during the mix design. Experience with various chemical stabilization agents will help narrow the range of application rates required in the mix design. If a number of application rates are evaluated, the individual application rates are usually varied from each other by at least 1 percent.

For the given chemical stabilizing agent application rate, the OMC and MDD are established by common moisture-density test methods, such as the Standard or Modified Proctor or similar test.

In establishing the OMC and MDD, the mix design should attempt to model what happens in the field. During the mix design, the reclaimed material is brought to a moisture content similar to what will be encountered in the field. The chemical stabilizing agent is then added and preliminarily mixed into the reclaimed material. Additional moisture is added to give a range in total moisture contents and the combination is then thoroughly mixed. Typically, the moisture contents are varied by approximately 1 to 2 percent from each other. When the chemical stabilizing agent is a fluid or if it is being added in the form of a slurry, the moisture content of the chemical stabilizing agent/slurry must be accounted for in the mix design process. If not, the resultant reclaimed mix will be too wet to adequately compact.

Prior to compacting the samples, a laboratory curing period of between 2 to 4 hours is commonly used. This simulates the time during which the last of the field mixing and the initial grading of the reclaimed mix takes place in the field. During the curing period, the laboratory mixed samples are covered to prevent loss of moisture and are periodically mixed with a trowel or spatula.

At the end of the laboratory curing period, the samples are compacted following the moisture-density test method being used. An aliquot sample is used to determine the moisture content of the reclaimed mix at the time of compaction. Utilizing the compacted sample's wet weight, the moisture content, and the volume of the compaction mold, the dry density of the reclaimed mix can be determined. The data is then plotted on normal graph paper and the OMC and MDD are determined using conventional criteria.

The third and final part of the mix design process is to evaluate the strength and durability properties of the reclaimed mix. With chemically stabilized mixes this is usually done by determining the R-Value or unconfined compressive strength, although other strength tests, such as the Indirect Tensile Strength test could be used. To evaluate the strength properties of the reclaimed mix a number of specimens are prepared and compacted at the OMC and then cured under controlled conditions. Typically, the strength specimens are cured for 7 days at a relative humidity of 95 to 100 percent, at a temperature of between 72 to 77°F (22 to 25°C), although other curing times and temperatures can be used.

After compaction the strength specimens are carefully removed from the molds, placed on carrier plates, and then cured for the required time. The moisture content and dry density of the strength samples are usually determined to confirm the results of the moisture content-density test. With some chemical stabilizing agents and reclaimed materials, it may be necessary to leave the strength specimens in the molds for 24 hours in order to develop sufficient strength before removing them from the molds. Spilt molds may facilitate the removal of the specimens.

At the end of the required curing period, the samples are tested for their strength using the selected testing procedures. Typically, three strength specimens are tested at each chemical stabilizing agent application rate and the results averaged.

To determine the required chemical stabilizing agent application rate, the average strength results are plotted on normal graph paper versus application rate. The application rate that produces a strength in excess of the required minimum is selected. In selecting the required application rate of the chemical stabilizing agent, the data is reviewed and any obvious outliers are eliminated or retested.

After selection of the chemical stabilizing agent application rate, some owner agencies may require that the durability and moisture sensitivity of the stabilized reclaimed mix be verified. Established procedures for wet-dry, freeze-thaw or other similar tests are used to evaluate the durability and moisture sensitive of the stabilized reclaimed mix.

11.3 BITUMINOUS STABILIZATION MIX DESIGN

The bituminous stabilization mix design process varies somewhat depending on whether an asphalt emulsion or a foamed asphalt is used as the stabilizing agent. Regardless of which bituminous stabilizing agent is used, the mix design follows the same general outline consisting of:

- determining the suitability of the reclaimed material
- establishing the OMC and Optimum Fluid Content (OFC)
- determining the optimum bitumen content
- confirmation of the mechanical properties of the stabilized mix

For both asphalt emulsion and foamed asphalt, the first part of the mix design determines the suitability of the reclaimed material for use as a bituminous stabilized base course. A procedure similar to what was required for mechanical and/or chemical stabilization listed previously is used. The physical properties of the reclaimed material, primarily the gradation and Plasticity Index, are used to assess the need for granular material and to select a potential bituminous stabilizing agent.

The gradation requirements are more restrictive if foamed asphalt is to be used as the stabilizing agent. Reclaimed materials deficient in fines will not mix well with foamed asphalt. When reclaimed materials have insufficient fines, the foamed asphalt does not disperse properly and tends to form “stringers” or bitumen rich agglomerations of fines. These stringers will vary in size according to the fines deficiency, with a large deficiency of fines resulting in many large stringers. These stringers will tend to act as a lubricant and result in a reduction in strength and stability of the reclaimed mix. The reclaimed material should have between 5 and 15 percent passing the No. 200 (0.075 mm) sieve.

Sieve analysis results may indicate that a reclaimed material may have the appropriate amount of fines, but if the fines have a high Plasticity Index, they will act in a cohesive manner. The field performance of these high plasticity reclaimed materials has generally been poor. The cohesive nature of the fines causes them to bind together, thereby preventing the foamed asphalt from adequately coating and subsequently stabilizing the mix.

When it has been determined that an asphalt emulsion will be used as the bituminous stabilizing agent, the second part of the mix design is to establish the OFC. To do this, the sample of reclaimed material is oven dried to a constant mass and then cooled to room temperature. The OFC of the reclaimed material is determined using common moisture-density testing procedure such as the Standard of Modified Proctor or similar method. The fluid used in the moisture-density test is a combination of 50 percent asphalt emulsion and 50 percent water or a combination which will provide for the minimum amount of water needed for good asphalt emulsion coating. Typically, the fluid content is varied by 1 to 2 percent over a fairly wide range. The dry density of the reclaimed mix is determined for each fluid content, and the results are plotted on normal graph paper. The data should be reviewed for anomalies and any outliers disregarded or retested. The fluid content at which the dry density of the reclaimed mix is a maximum is defined as the OFC.

As noted previously, not all asphalt emulsions and reclaimed materials are compatible. As part of the asphalt emulsion mix design process, the compatibility of the asphalt emulsion and the reclaimed material must be verified. Compatibility is verified by mixing the proposed asphalt emulsion with the reclaimed material and assessing the degree of coating that is achieved. If a high percentage of the reclaimed material cannot be coated, in spite of adjustments in moisture and asphalt emulsion contents and intensive mixing, then an incompatibility exists and a different

Figure 11-3: Asphalt emulsion stabilization in urban setting

asphalt emulsion should be used. If adequate coating or cohesion is achieved in the mixing test, the compatibility of the reclaimed material and asphalt emulsion is further assessed by an adhesion test. In the adhesion test, a sample of the reclaimed mix is cured in a forced air oven. The oven cured mix is then placed in boiling, distilled water for a short period of time. After boiling, the mix is placed on a white absorbent paper and visually assessed for the amount of retained asphalt coating. If the degree of retained asphalt coating is not acceptable, a different asphalt emulsion needs to be used.

It is critical that the sample of asphalt emulsion used in the compatibility and adhesion tests be identical to the one that will be used in the field. Different emulsion suppliers commonly use different emulsifying agents and additives for the same grade of asphalt emulsion which may have an effect on compatibility.

The third step in the asphalt emulsion mix design is determining the optimum bitumen content. The optimum bitumen content is determined by adding a range of asphalt emulsion and water to oven dried samples of reclaimed material so that the previously determined OFC is maintained constant. The various combinations of asphalt emulsion and water are added to the reclaimed material and mixed thoroughly at room temperature. The Marshall, Hveem or other methods modified for cold mixes are used to form and compact the stabilized mix. The dry density of the compacted reclaimed mix is determined for each asphalt emulsion content tested. After compaction, the specimens are allowed to cure in the mold for 24 hours at room temperature. After 24 hours the samples are extruded from the molds and placed on a smooth, flat tray and cured for an additional 72 hours in a forced draft oven at 100°F (40°C), although other curing temperatures and times could also be used.

Figure 11-4: Foamed asphalt operation

When it has been determined that foamed asphalt will be used as the bituminous stabilizing agent, the second part of the mix design is to determine the foaming characteristics of the asphalt binder and to establish the OMC. The objective is to optimize the foaming properties of the asphalt binder by maximizing the expansion ratio and the half-life of the foamed asphalt by determining the percentage of water needed for a given asphalt binder temperature.

Foamed asphalt is characterized in terms of expansion ratio and half-life. The expansion ratio is defined as the ratio between the maximum volume achieved in the foamed state and the volume of the asphalt binder once the foam has completely subsided. The half-life is the time taken, in seconds, for the foamed asphalt to settle to half of the maximum volume attained. The foaming characteristics of a given asphalt binder are influenced by a number of variables, the most important of which are the:

- Temperature of the asphalt binder. The higher the asphalt binder temperature, the higher the foaming characteristics. Typically, the asphalt binder has to be hotter than 320°F (160°C).
- Amount of water added to the hot asphalt binder. Generally, the expansion ratio increases with increasing amounts of water but there is a corresponding decrease in the half-life. The amount of water added is generally 2 percent +/- 1 percent by weight of asphalt binder.
- Pressure under which the hot asphalt binder is injected into the expansion chamber. Low pressure, below 45 pounds per square inch (3 bars), decreases both the expansion and half-life.
- Proportion of asphaltenes in the asphalt binder. Generally, the greater the amount of asphaltenes, the poorer the foam,
- Presence of anti-foaming agents, such as silicone compounds, in the asphalt binder.

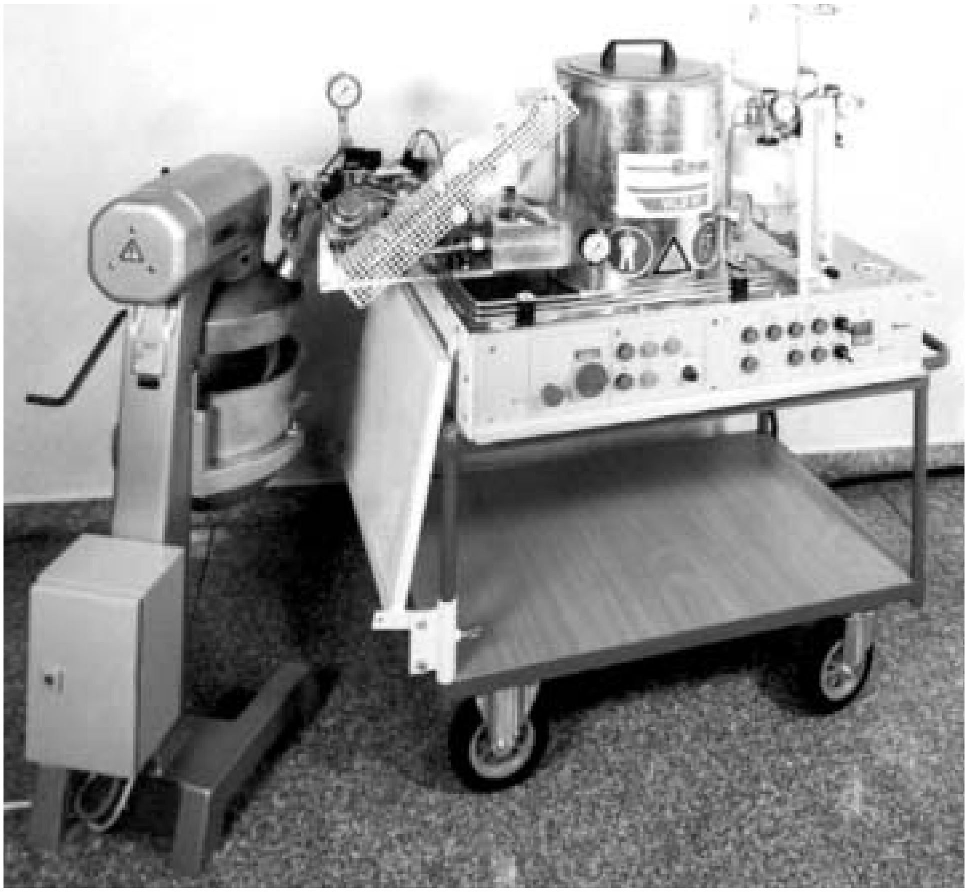


Figure 11-5: Laboratory Asphalt Foaming Plant

The ideal foamed asphalt is one which optimizes both the expansion and the half-life. In general, the better the foaming characteristics of the asphalt binder, the better will be the quality of the resulting mix. There are no absolute limits governing the foaming characteristics since large expansion ratios are obtained at the expense of the half-life and vice versa. Generally, a mix produced with a very high expansion or a very long half-life is of poorer quality than when both the expansion and half-life values are optimized. It is usually difficult to achieve an acceptable mix when the foaming characteristics are extremely poor, i.e., expansion less than 5 and half-life less than 5 seconds. An alternative source of asphalt binder or a foaming agent may be required if the foaming characteristics are not in excess of these minimums.

Softer asphalt binders generally have better foaming characteristics but the selection of asphalt binder grade is primarily related to the in-service temperatures of the bituminous stabilized mix. Harder asphalt binders, with penetrations less than 100, are generally used in hot climates. Use of softer asphalt binders should be verified by conducting comparative strength test on the stabilized mix.

To optimize the foaming characteristics, the expansion and half-life are determined for at least three asphalt binder temperatures and a range of water contents from 1 to 5 percent by weight of asphalt binder. This requires the use of a small laboratory plant as indicated in Figure 11-5, such as the Wirtgen WLB-10 or similar, to produce the foamed asphalt. It is critical that this equipment closely simulates the foamed asphalt used during construction. The results of expansion ratio and the half-life versus the water content for the three asphalt binder temperatures tested are plotted on normal graph paper. From this plot, the combination of asphalt binder temperature and water content which maximizes the expansion ratio at the longest possible half-life time, is selected for use.

The OMC for the reclaimed material is established, as indicated previously, with water as the compaction fluid.

The third step in the foamed asphalt mix design, is determining the optimum bitumen content. Samples of the reclaimed material are oven dried and cooled to room temperature and then re-wetted to 90 percent of the previously determined OMC. A range of foamed asphalt is then added to the reclaimed material and mixed thoroughly at room temperature. The Marshall, Hveem or other methods modified for cold mixes are subsequently used to form and compact the stabilized mixes. The dry density of the compacted mix is determined for each foamed asphalt content tested. After compaction, the specimens are allowed to cure in the mold for 24 hours at room temperature. The samples are then extruded from the molds and placed on a smooth, flat tray and cured for an additional 72 hours in a forced draft oven at 100°F (40°C), although other curing temperatures and times could also be used.

The fourth and final part of both the asphalt emulsion and foamed asphalt mix design process is to evaluate the strength and moisture sensitivity properties of the stabilized mix. With bituminous stabilized materials, this is usually done by determining the Marshall Stability, Hveem Stability or Indirect Tensile Strength, although other strength tests could be used. The samples, previously prepared and cured, are tested at 77°F (25°C). To assess the moisture sensitivity of the bituminous stabilized mix, companion samples to those tested in the dry state are soaked in water prior to testing. The traditional method is to soak the samples in 77°F (25°C) water for 24 hours prior to testing although vacuum saturation for shorter soaking times can also be used. At the completion of the water-soaking period, the specimens are surface dried and tested for strength using the same procedure as for the dry samples. A comparison of the strength after water soaking to the dry strength is made which determines the moisture sensitivity of the bituminous stabilized reclaimed mix.

The test results are plotted on normal graph paper with the test result on the ordinate axis and the bitumen content on the abscissa. The bitumen content at which the soaked strength is a maximum is defined as the Design Bitumen Content (DBC) provided the minimum moisture sensitivity value is exceeded. Where required, additional tests such as the resilient modulus, dynamic creep, etc., are performed on the cured stabilized reclaimed mix, at the DBC. The results of these tests can be used in empirical-mechanistic design methods to determine the required bituminous stabilized base thickness and overall pavement structure.

11.4 COMBINED STABILIZATION MIX DESIGN

Combined stabilization mix designs will usually consist of a combination of the chemical and bituminous mix design methods. Mechanical stabilization is incorporated into both the chemical and bituminous mix design methods when the decision whether or not to use a granular material is made. The most common combined stabilization method is to use a cementitious stabilizing agent such as lime or Portland cement with a bituminous stabilizing agent. As indicated previously, the cementitious stabilizing agent, when added in small quantities, accelerates the strength gain and enhances the moisture resistance of the bituminous stabilized mix.

Figure 11-6: Bituminous stabilization operation with cement slurry (combination stabilization)

The same mix design process is used, regardless of the cementitious stabilizing agent being considered, and generally consists of:

- determining the suitability of the reclaimed material
- selecting the percentage of cementitious stabilizing agent to be added
- determining the OMC and/or OFC
- establishing the optimum bitumen content
- confirmation of the mechanical properties of the stabilized reclaimed mix

In the first part of the combined stabilization mix design, the suitability of the reclaimed material follows the procedures outlined previously in the bituminous stabilization mix design method.

If an asphalt emulsion is to be used as the bituminous stabilizing agent the cementitious stabilizing agent is added and mixed into the reclaimed material immediately prior to the introduction of the blend of asphalt emulsion and water. The method for determining the OFC and the optimum bitumen content, as given previously, are then followed.

If a foamed asphalt is to be used, then the cementitious stabilizing agent is added to the reclaimed material during the determination of the OMC. The cementitious stabilizing agent is also added and mixed into the moist reclaimed material immediately prior to the introduction of the foamed asphalt in the determination of the optimum bitumen content procedures given previously.

The combined stabilized mix must also be checked for stiffness or fatigue properties since the addition of the cementitious stabilizing agent increases the rigidity of the reclaimed mix.

The cementitious stabilizing agent content should be high enough to improve the durability/moisture sensitivity of the reclaimed mix, but not so high as to cause the reclaimed mix to lose the visco-elastic properties of a bituminous stabilized mix. The Marshall flow or other similar property is used to assess the cementitious stabilizing agent content. There is a minimum amount of cementitious stabilizing agent that can be practically added in the field. This minimum amount varies depending on whether it is being added as a dry powder or as a slurry. The addition of the cementitious stabilizing agent increases the cost of the FDR, so there is an economic benefit to using only the minimum necessary.

CHAPTER 12: FULL DEPTH RECLAMATION – CONSTRUCTION

Reclamation of paved roadways has historically been undertaken by scarifying the existing asphalt bound layers with rippers attached to motor graders or crawler tractors. The ripping process produced large blocks of asphalt pavement which were subsequently reduced to smaller, more manageable sizes by travelling hammer mills, grid rollers or similar equipment.

The development of rotary mixers in the 1950's enhanced sizing of the previously ripped asphalt pavement and increased productivity. The mixing equipment increased steadily in size over the years, but generally, the asphalt pavement had to be ripped since the rotary mixers could not effectively or efficiently pulverize an un-ripped pavement.

The development and widespread use of cold planing machines and the ease in which they removed and sized asphalt pavements, led to the production of large, self-propelled, high horse-powered reclaimers, as indicated in Figure 12-1.

These reclaimers were equipped with specialty designed cutting drums equipped with replaceable tungsten carbide tipped cutting tools which allowed the reclaimers to pulverize and mix the asphalt pavement without it first being ripped into large chunks. This development significantly increased production and facilitated sizing and mixing of the existing asphalt pavement and resulted in FDR, as it is known today.

Figure 12-1: Modern FDR reclaimer

In FDR, all of the asphalt bound layers are pulverized and mixed with some or all of the underlying granular base, subbase or subgrade materials. The decision on how much of the underlying granular base to mix with the pulverized asphalt layers depends on the:

- thickness of the asphalt layers relative to the granular base, subbase or subgrade thickness
- gradation/physical properties of the pulverized asphalt layers
- gradation/physical properties of the granular material
- type and condition of the underlying subgrade soils
- whether or not a stabilizing agent(s) will be used
- desired end result of the FDR process

In any event, some portion of the underlying material must be incorporated during the pulverization of the asphalt layers. This is to prevent:

- excessive wear of the cutting tools
- significant reduction in productivity
- corresponding increase in costs

During pulverization, the cutting drum rotates in an "up-cut" or opposite to the forward direction of travel of the reclaimer, as indicated in Figure 12-2. The up-cut rotation is required so that the cutting tools are cooled as they move through the underlying, moist materials, to enhance pulverization, and to assist in sizing of the reclaimed materials. Incorporating a minimum of 1 inch (25 mm) of underlying granular material is a good rule of thumb. When there is unsuitable material directly below the asphalt layer, the specifications may require that the pulverization depth be kept even with the bottom of the asphalt layer. If the asphalt layer is not penetrated by the cutting drum, the drum is prone to bouncing. This results in a variable depth of pulverization, decreased productivity, increased cutting tool wear, and increased reclaimer maintenance.

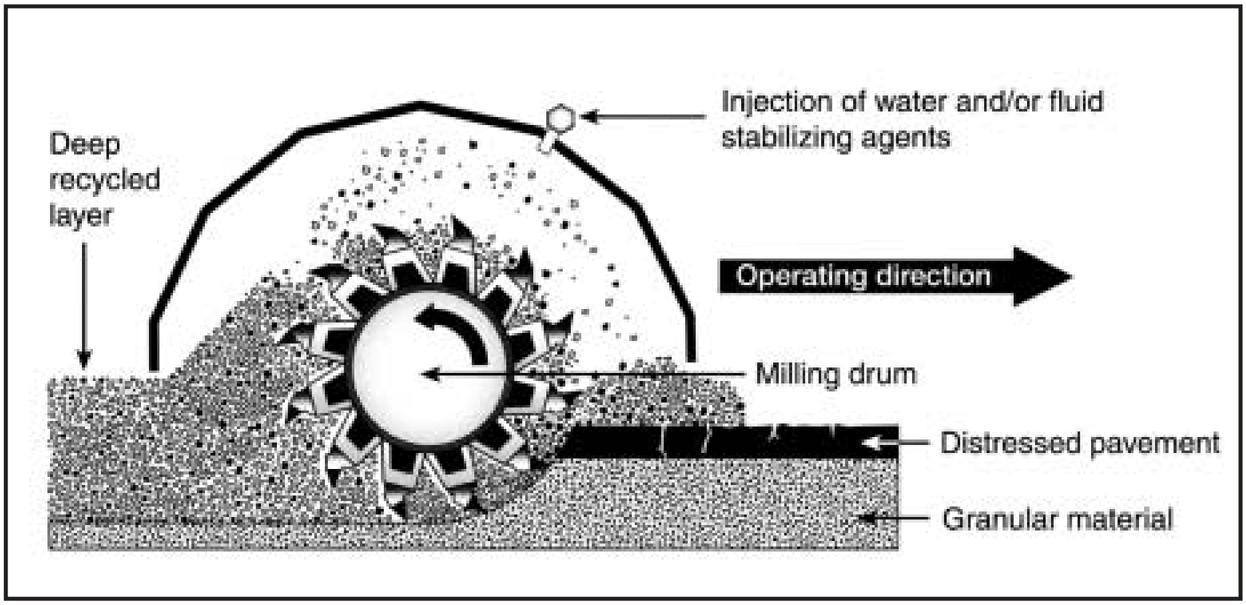


Figure 12-2: Cutting drum operating in up-cutting direction

Some common preparatory measures should be undertaken prior to FDR. These include:

- detailed safety or hazard assessment
- development of a detailed traffic control plan
- repair of any areas with drainage problems
- repair of any subgrade failure area unless chemical stabilization has been specified
- detailed project analysis, as outlined in Chapter 12
- preparation of a mix design, as outlined in Chapter 13

The equipment used to undertake FDR will vary from contractor to contractor but no matter what the FDR train looks like, it is required to perform the same general steps, including:

- pulverization and sizing of the existing asphalt bound layers
- incorporation and mixing of the underlying granular base, subbase or subgrade soil
- application of mechanical, chemical, bituminous or combination stabilizing agent(s), if required
- mixing of the reclaimed materials and stabilizing agent(s)
- initial or breakdown compaction
- rough grading or initial shaping
- intermediate compaction
- intermediate shaping
- final compaction
- final trimming or “tight blading”
- removal of all loose material
- curing
- application of seal or wearing course

12.1 FDR EQUIPMENT

The FDR process does not require a large amount of equipment, most of which is normally used in roadway construction. The minimum equipment required in the FDR process is a:

- modern, self-propelled reclaimer
- motor grader
- one or more compactors

For more complex FDR projects including the application of stabilizing agent(s), the additional construction equipment could include some or all of the following:

- end or bottom dump haul trucks
- windrow sizer or calibrated aggregate spreader
- water truck complete with spray bar
- calibrated bulk spreader for dry stabilizing agents
- mixer and tankers for slurry application of stabilizing agents

Figure 12-3: Reclaiming Operation

- asphalt emulsion tanker(s) and distributor truck
- computerized liquid or foamed asphalt additive system on the reclaimer
- front end loader

A variety of different reclaimers are available to pulverize and mix the reclaimed materials and it is the essential piece of equipment in the FDR process. Most reclaimers have an 8 foot (2.4 meter) wide cutting drum, while extensions can be added to some models of reclaimers to increase the cutting drum width to 12 feet (3.7 meters). The reclaimer should have the capability to pulverize and mix a minimum of 12 inches (300 mm) of asphalt pavement and underlying materials. The cutter drum should be equipped with replaceable tungsten carbide tipped cutting tools and have both manual and automatic depth control capabilities. The cutting drum should be capable of being rotated at a number of different speeds for pulverizing and mixing a variety of material thicknesses and types. The orientation of the cutting tools is typically in a chevron pattern which promotes mixing as opposed to a helical pattern found on cold planing machines which is intended to move the material to the center of the cutting drum. The chevron pattern of the cutting tools minimizes lateral movement of the reclaimed material, leaving it ready to be struck off by the bottom edge of the rear door on the mixing chamber. The propulsion system should have a load sensing mechanism to automatically control the forward speed of the reclaimer.

Some reclaimers have four-wheel drive and/or four-wheel steering to improve traction and maneuverability. Others have the ability to operate in both directions. This feature means that the cutter drum can be operated in the up-cut direction for pulverization and in both the up-cut and

Figure 12-4: Dry stabilizing agent being spread prior to FDR

the opposite down-cut direction for subsequent mixing. In reality, the cutter drum always rotates in the same direction, it is the reclaimer which operates in a reverse direction.

Haul trucks will be required to provide any granular material required to:

- increase the thickness of the layer to be processed
- modify the gradation of the reclaimed material
- provide additional mechanical stabilization

Some means of accurately controlling the addition rate of the granular material is required. Haul trucks may also be required to move any excess reclaimed mix after the final tight blading and compaction has been completed.

Typically, the reclaimed material is not at the optimum moisture content (OMC) for compaction. Either aeration will be required to dry the reclaimed material or, more often, moisture will have to be added. A water truck can act as a supply truck to the reclaimer’s onboard liquid additive system or it can be equipped with a spray bar to add moisture directly to the reclaimed material. Additional moisture can be added during pulverization by the reclaimer or after pulverization in order to better assess the amount which needs to be added. The water truck should be equipped with a pump/metering system and a spray bar with nozzles if it is to be used to add moisture directly to the reclaimed material. A water distributor truck may also be required to periodically add a fine spray of moisture for curing, particularly if cementitious stabilizing agent(s) are used.

Figure 12-5: Motor grader blading FDR mix

When the stabilizing agent is added in dry powder form, a calibrated bulk spreader will be needed, as indicated in Figure 12-4. Dry stabilizing agents can be added prior to pulverization of the asphalt layers or they can be added after pulverization and prior to the mixing pass of the reclaimer. Dry stabilizing agents are more susceptible to environmental effects such as wind and rain showers. Care must be taken in order not to create an excessive dust cloud during placement and mixing of dry stabilizing agents.

When the stabilizing agent is a liquid or is being added as a slurry, supply tankers will be required. A "nurse" truck or means of connecting the tanker to the reclaimer is required if the liquid is being added by the reclaimer, as was indicated previously in Figure 1-16. If stabilizing agents in liquid or slurry form are to be added by the reclaimer, it needs to have a computerized onboard liquid addition system. The on-board additive system should be equipped with a meter capable of recording the rate of flow and total amount of each liquid being added to the reclaimed material. It should also have a positive interlock system linked to the forward speed of the reclaimer so that the amount of liquid stabilizing agent being added will change according to the operational speed of the reclaimer.

When foamed asphalt is being used as the stabilizing agent, the reclaimer will need to be equipped with a computerized on-board foam generating system. It must also have a heated asphalt binder surge tank, a storage tank for the water used in the foaming process, and some means of producing and injecting the foamed asphalt into the reclaimed material. The computerized system should be able to adjust the amount of foamed asphalt being added relative to the forward speed of the reclaimer and to the volume of reclaimed material being processed.

A motor grader is used to spread and shape the reclaimed mix after the reclaimer has completed all the mixing passes, as indicated in Figure 12-5.

Figure 12-6: Compaction of FDR mix

If the reclaimed material is above the OMC, the motor grader will be used to help aerate the material. When the depth of reclaimed mix is too thick to be adequately compacted, the motor grader will move a portion of the reclaimed mix to one side to permit compaction of the lower lifts.

The number and type of compactors used on a FDR project will depend on:

- specified degree of compaction required
- material properties of the reclaimed mix
- thickness of the reclaimed mix
- support characteristics of the underlying subgrade
- type of wearing surface to be used
- productivity required

Vibratory padfoot, vibratory smooth drum, pneumatic, and static steel rollers can be used for compaction, as indicated in Figure 12-6.

Due to the thickness and material properties of the reclaimed mix, the rollers used are typically large and heavy. Large pneumatic, vibratory smooth drum or padfoot rollers may be used for initial compaction. Intermediate compaction is typically undertaken with a pneumatic roller, while finishing rolling is performed with a vibrating smooth drum or static steel roller.

The large pneumatic roller can also be used to proof roll the reclaimed area to identify weak areas in the subgrade which need replacement.

A skid steer or small rubber tire loader is used to remove any excess material after tight blading. Excess material can be used to fill in low areas in the roadway ahead of the reclaimer.

12.2 PREPARATION AND PLANNING

Some preliminary preparation and planning activities are required prior to the start of the FDR process. These activities are intended to improve the uniformity of the reclaimed mix since stopping the FDR train results in discontinuities in the finished product. Discontinuities in the reclaimed mix, similar to discontinuities in other construction operations like Hot Mix Asphalt (HMA) paving can create areas of potential weakness and should be avoided whenever possible. The preliminary activities are also intended to result in better equipment utilization and increased productivity.

The Detailed Project Analysis, as indicated in Chapter 10, will have identified many of the preliminary activities. However, field verification immediately prior to construction provides an independent check which reduces the risk that something unexpected will occur.

Identification of buried utilities, abandoned rail or streetcar lines, manholes, valves and other castings should be undertaken prior to the start of FDR. These fixtures are usually identified from existing plans but a field magnetic/metal detector or Ground Penetrating Radar (GPR) survey should be undertaken. If solid, buried obstructions are encountered during the pulverization or mixing passes of the reclaimer, damage to the cutting tools, cutting tool holders, cutting drum, and under particularly adverse conditions even to the drive mechanism, can result. The associated down time, inconvenience to the public, and repair costs can be extensive. In addition, shallow buried utilities have a habit of moving from where they are located on the plans. A serious safety hazard can be created if the buried utility is not correctly located, including depth, particularly if the buried utility happens to be a high-pressure gas line or something similar.

In the case of manholes, valves and other roadway castings, these are lowered to at least 4 inches (100 mm) below the anticipated FDR treatment depth a day or more in advance. They are reinstated to the proper grade after completion of the FDR process, prior to or after the wearing surface has been placed. Other buried items are removed, relocated or buried below the FDR treatment depth, depending on the specifics of the project.

When the FDR process is undertaken in an urban setting it is sometimes necessary to cold plane some of the existing asphalt material prior to pulverizing the roadway. Cold planing is usually undertaken in order to maintain existing roadway surface elevations, thereby eliminating the costs associated with adjusting concrete curbs, drainage, and other facilities. The existing roadway has to be checked, particularly at the curb lines, to ensure that the upper portion of asphalt pavement can be removed without compromising the overall strength of the pavement structure. It is also wise to check the condition of the underlying granular base materials in the areas to be cold planed, to ensure they are of sufficient thickness, as well. Obviously, if an area is cold planed the reduction in asphalt bound material will have to be accounted for in the mix design process, particularly if a stabilizing agent is being used.

Roadways that are very distorted or out of shape, both longitudinally and transversely, should be corrected (if possible) prior to the start of the FDR process. This is to ensure that the thickness of the reclaimed mix is consistent both laterally and longitudinally after tight blading has been performed by the motor grader. Shape corrections include adjustments to cross-slope, superelevation, elimination of localized bumps and dips, and gradeline adjustments for heaves or settlements. Pre-shaping is intended to establish the final surface shape of the roadway, thereby ensuring the geometric integrity of the reclaimed area.

Prior to the start of the FDR process, it is important to develop a plan that encompasses the various steps, operations, and issues which need to be undertaken or addressed. The plan should consider the:

- specification requirements
- roadway geometrics
- traffic accommodation during construction
- condition/properties of existing materials
- behavior of reclaimed mix
- restrictions on opening roadway to traffic
- production rates

A review of the project specifications needs to be undertaken in order to determine:

- treatment depth, widths, and project limits
- type and amount, if any, of granular material and/or stabilizing agent(s) to be added
- degree of compaction
- disposal of surplus materials
- curing requirements
- surface texture, smoothness, and tolerances

Roadway geometrics, particularly width, will influence the number of passes of the reclaimer required to treat the full width of the road. In addition, the existing surface shape, i.e., crowned or cross-slope, will influence the positioning of the longitudinal joints between adjacent passes. The longitudinal joint, for roadways with a pronounced crown, is at or slightly offset from the crown. If the crown of the existing roadway has flattened, the need to have adjacent passes near the crown is reduced. Tapered sections for acceleration/deceleration lanes, turning bays or passing lanes must also be considered when setting out the location of the various passes. Typically, these areas are processed first, and double processing in the transition areas is inevitable. Care must be taken to ensure that any stabilizing agent(s) are added only once and, usually, when the main area is being processed.

Existing traffic, in terms of total volume and amount of heavy vehicles and how it will be handled during construction, will also influence the way work is laid out. Limitations on working hours and access requirements to adjacent properties will also impact the work. Compared to other reconstruction methods, FDR has significantly less impact on public traffic due to the high production rates and the ability to keep one-half of the roadway open during construction. If possible, it is advantageous to completely detour traffic to other roadways since this will permit the full width of the road to be treated at one time. If traffic must be maintained, one-half of the width can be treated while maintaining one-way traffic on the other half of the road. Obviously, if traffic is to be maintained the work zone must be adequately identified with temporary warning signs, delineators, flag people, and/or pilot vehicles. Poor signage and traffic control can lead to unsafe conditions and major disruptions on the site.

The condition or properties of the existing roadway materials have an influence on project planning. The consistency of the asphalt bound materials, in terms of thickness and intactness, significantly influences the production of the reclaimer. The moisture condition of the underlying materials will also influence production if aeration or additional moisture is required. The variability of the materials will have an influence on the application rates of any stabilizing agent(s), degree of compaction, and properties of the reclaimed mix.

The properties of the reclaimed mix influence how it should be placed, compacted and finished. The reclaimed mix properties dictate the type and length of curing required before the roadway can be opened to traffic and will also influence the type and timing of the wearing course placement.

Restrictions which dictate when traffic can use a section of reclaimed roadway will differ depending on the stabilizing agent(s) used and owner agencies' policies with respect to surface condition of the reclaimed mix or placement of the wearing course.

Typically, cementitious stabilizing agents require a period of moist curing so that they do not dry out and develop excessive shrinkage cracks. Moist curing could consist of periodic applications of moisture or placement of a temporary seal coat. If proper placement, compaction, and curing procedures are followed, light traffic can be allowed on the reclaimed mix without adversely effecting it.

For asphalt emulsion stabilization, the curing time will depend on the:

- type and quality of the asphalt emulsion
- moisture content of the reclaimed mix during compaction
- degree of compaction achieved or voids content of the reclaimed mix
- aggregate type including gradation and absorption properties
- amount of cement or lime added
- ambient conditions

The curing time could be as short as a few days or as long as a few months. Light traffic can be allowed on asphalt emulsion stabilized mixes shortly after final compaction has taken place.

Foamed asphalt stabilized mix can be opened to light traffic immediately after the completion of the compaction process. Foamed asphalt stabilized mix can be reworked without adversely affecting its ultimate strength, provided the moisture content is maintained at the same level as at the time of compaction. However, if the reclaimed mix is allowed to dry, reworking will significantly reduce its ultimate strength.

During the curing period, no matter what stabilizing agent has been used, heavy truck traffic should be restricted or at least limited, since the reclaimed mix is still developing strength. Excessive early heavy truck traffic may induce flexural or fatigue cracking which can lead to premature failure of the reclaimed mix.

Production rates, in order to meet construction schedules, will influence both the project planning and the type of equipment used on the project. In order to maximize the effectiveness of the construction equipment, the project is usually undertaken in sections. Ideally, these sections should be the full roadway width which can be processed in one working day. If required, a section could be the half the roadway width that can be processed in one working day, although this is less desirable. Processing half roadway widths can create problems for overnight traffic due to the differences in surface textures and in matching the joints when the second half of the roadway is processed. With the section approach, the total distance which can be processed in one day is divided into approximately 1/4 mile (400 meter) segments. The first pulverization pass of the reclaimer is along the outer edge of the roadway for the segment distance. The second pulverization pass is back to the starting point along the opposite outer edge of the roadway segment. The third and subsequent pulverization passes are inside the previous passes until the complete roadway width is pulverized. If no mixing passes of the reclaimer are required, it then moves to the next segment to begin the first pulverization pass. As soon as the reclaimer starts work on the next segment, the rollers begin the compaction process and the motor grader begins shaping the reclaimed material in the first segment. In this way, the equipment advances from one segment to the next, in two to three hour increments, until the daily section length has been completed.

The working speed of the reclaimer has the greatest influence in determining the length of section which can be processed in one day, and consequently the length of each segment. The working speed of the reclaimer is affected by:

- thickness of the asphalt layer
- hardness of the asphalt layer
- thickness of the underlying materials being incorporated into the reclaimed material
- top size, gradation, and density of the underlying materials
- gradation requirements of the reclaimed material
- production capabilities of the reclaimer

If stabilizing agent(s) are being added to the reclaimed material, more than one pass of the reclaimer is usually required. It may be possible to add the stabilizing agent(s) during the pulverization pass. However, on some projects may require the stabilizing agent(s) to be added during a second pass of the reclaimer in order to maintain a more consistent working speed obtaining a more accurate and uniform application of the stabilizing agent(s). On larger projects, utilizing more than one reclaimer, one for pulverization and a second for adding the stabilizing agent(s) and mixing, will significantly increase the overall production rates.

Since FDR is a high production, fast-track process, logistics need to be addressed in the planning process. To ensure that the reclaimed mix is uniform and productivity remains high, the project has to be continuously supplied with the necessary materials such as stabilizing agent(s), granular materials, and compaction water. Daily requirements for these materials need to be determined in advance and procedures need to be in place to see that they are supplied without interruption. On large projects or when supply lines are long, temporary storage facilities near the project are established to protect against supply delays and to increase production.

12.3 PULVERIZATION

The preferred way to start the very first pulverization pass of an asphalt surfaced roadway is to have the reclaimer make a preliminary cut from the roadway shoulder perpendicular to the direction of the succeeding passes. The cutting drum is lowered into the softer shoulder material, reducing cutting tool wear, and provides a vertical butt-joint in the pavement to work and compact against. Where this is not possible, the alternative is to line the reclaimer along one edge of the first segment and slowly grind through the asphalt surface and into the underlying materials. This method causes accelerated cutting tool wear, and some bouncing of the cutting drum can be experienced when the asphalt layer is thick and/or hard. If the reclaimer is allowed to creep forward very slowly while cutting through the asphalt pavement a reduction in the bouncing of the cutting drum may be noticed.

Figure 12-7: Reclaiming operation

To align the reclaimer longitudinally and to prevent strips of unpulverized materials being left between adjacent passes, a clear guide for the operator should be given. Typically, this entails painting guide marks on the existing pavement or by stringing a line which is easy to follow. With an experienced operator, only the first pass needs to be marked out since the previous pass is followed on subsequent passes.

Roadway and reclaimer widths do not normally match, and several passes are required to pulverize the roadway treatment width. This results in a series of longitudinal joints and some overlap between passes is usually required. Therefore, only the first pass will be the full width of the reclaimer, with the width of subsequent passes being reduced by the amount of the overlap. The minimum overlap width is normally 4 inches (100 mm) but this is sometimes increased to take into account:

- treatment depths in excess of 12 inches (300 mm)
- coarseness of the reclaimed materials
- type of stabilizing agent(s) being used
- time lapse between adjacent passes

The width of the overlap generally is increased with: increasing layer thickness; reclaimed material coarseness; when working with cementitious stabilizing agent(s) and; where the first pass was made more than twelve hours before the adjacent pass, particularly when using stabilizing agent(s).

With the size and horsepower of modern reclaimers, the need to rip the asphalt pavement in front of the reclaimer has been eliminated in all but very isolated instances. These could include very thick asphalt layers or very stiff asphalt pavements due to excessive oxidation hardening or low ambient temperatures. There is no standard or rule of thumb for the optimum size of the chunks that should be left after ripping.

The treatment depth or “depth of cut” is determined by the specifications in accordance with the desired finished product of the reclaimed mix. When the specified depth of cut requires the cutting drum to be kept at the bottom of the asphalt layer due to unsuitable material below, the condition of the cutting tools needs to be checked more often. This is due to the accelerated wear that may occur since the cutting tools are not cooled by the underlying granular material. The depth of cut can be controlled manually or automatically through the reclaimers on-board sensing systems. On most reclaimers, the depth of cut can also be controlled on each side of the cutting drum.

Depending on the opening of the rear door of the reclaimer’s pulverization/mix chamber and the materials being pulverized, the reclaimed material will be “bulked” or “fluffed” up and will be higher than the original pavement surface. As the rear tires of the reclaimer ride up on this fluffed up material the cutting drum may rise and the processing depth should be verified at this point. In addition, if the reclaimer is making subsequent mixing passes of the pulverized material, the mixing depth will be influenced by the amount of bulking that has taken place.

The gradation of the reclaimed material should be checked after pulverization to ensure it corresponds to the gradation used in the mix design. It is neither necessary, practical, nor economical to pulverize the existing asphalt layer to the maximum aggregate size used in the original HMA or underlying materials. Reclaimers are not crushers and will not reduce the pavement layers to sizes smaller than the original aggregates.

The gradation of the reclaimed material can be controlled by the operation of the reclaimer. The gradation of the reclaimed material is influenced by the:

- front and/or rear door opening on the pulverization/mixing chamber
- position and/or breaker bar setting of the pulverization/mixing chamber
- rotation speed of the cutting drum
- forward speed of the reclaimer
- condition of the existing pavement
- ambient temperature

The more the rear door is closed, the longer the pulverized material is retained inside the pulverization/mixing chamber. This increases the number of contacts with the cutting tools and the breaker bar under the hood of the pulverization/mixing chamber. This allows the larger chunks of asphalt pavement and underlying agglomerates to be broken down. The maximum size of the reclaimed material will be larger than the maximum aggregate size of the existing aggregates but it will be the smallest when the rear door is opened very little. It is important to remember that the existing material fluffs after being pulverized due to the increase in void content, and so the rear door cannot be completely closed.

The closer the breaker bar is to the cutting drum, the finer will be the gradation of the reclaimed material.

A lower cutting drum rotation speed, the one with the most torque, is typically used when pulverizing thick lifts of asphalt layers or when mixing dense granular base materials with the pulverized asphalt layers. A faster rotation speed is used when working with light or medium pavement thicknesses. The fastest cutting drum rotation speed is used when pulverizing very thin asphalt layers or for mixing passes.

A slow forward speed of the reclaimer means that as each cutting tool hits the existing material it dislodges or pulverizes a small piece of material. Generally, the slower the forward speed of the reclaimer, the finer the gradation of the reclaimed material.

When the existing asphalt layers are cracked and/or alligator cracking is present, sizing of the reclaimed material is more difficult. The cutting drum, operating in an up cut direction, tends to lift or flip up the asphalt layer in large chunks instead of being ground off or pulverized by the cutting drum. These large chunks of pavement are harder to size than if they had remained in place. Several operational techniques can be used in order to maintain the required size of the reclaimed material, including:

- reducing the forward operating speed
- increasing the cutter drum rotation speed
- reducing the rear door opening
- raising the cutting drum to the bottom of the asphalt layer

Reducing forward speed, increasing cutting drum rotation and closing the rear door will increase the number of impacts within the pulverization/mixing chamber, so the material has a greater chance of being broken down to the correct size. Raising the cutting drum reduces the angle of approach for the cutting tools to a more horizontal impact and there will be less of a tendency to flip up or dislodge chunks of asphalt. This will require that a second mixing pass be undertaken to ensure the full treatment depth has been achieved.

The physical properties of the asphalt layer are affected by the ambient temperature. If the pavement is cool, the asphalt layer is very stiff but also very brittle, and can be pulverized into small pieces. As the temperature of the asphalt layer increases, it becomes more plastic, and the risk of “slabbing” increases. Slabbing occurs when the asphalt layer lifts or breaks off in large chunks in front of the cutting drum and must be handled as noted previously. Typically, the most efficient temperature for sizing of the reclaimed material is between 50 and 90°F (10 and 30°C).

The reclaimed material tends to migrate down-slope when the reclaimer is operating on a cross-slope or superelevation. This phenomenon becomes more apparent, the greater the cross-slope and the thinner the treatment depth becomes. A motor grader is used to blade the reclaimed material back into place before the adjacent pass is made with the reclaimer thereby maintaining the roadway shape and ensuring an adequate longitudinal joint.

The up-cut rotation of the cutting drum tends to bury the larger pieces of reclaimed material at the bottom of the treatment depth. Likewise, a down cutting rotation of the cutting drum, as can occur during a mixing pass, tends to lift the larger pieces of reclaimed material to the top of the treated area. This must also be accounted for when adjusting the operation of the reclaimer for the proper sizing of the reclaimed material.

The occasional oversized chunk of asphalt pavement can elude pulverization. It is more economical to have these picked up and placed in front of the reclaimer for further reduction, than to make an additional pulverization pass with the reclaimer.

Figure 12-8: Reclamation of commercial/industrial site

12.4 MIXING AND PLACEMENT

When additional pulverization or mixing passes are required to obtain the required gradation or to increase uniformity, the reclaimed material should be lightly compacted and reshaped. This is required to more accurately control the mixing depth, since the rear wheels of the reclaimer compact or reduce the thickness of the fluffed up reclaimed material during the pulverization pass. With light compaction and then reshaping, the reclaimed material will be uniform in thickness allowing the treatment depth to be better controlled. On most FDR projects, the most frequent error made during the mixing passes is incorporation of subgrade soil into the reclaimed mix by operating the cutting drum at too great of a depth. Care should be taken to ensure that the depth of the pulverization pass is between 1 and 2 inches (25 and 50 mm) less than the final mixing pass. This will reduce the risk of a thin layer of untreated reclaimed material being left beneath the stabilized layer.

Light compaction and reshaping also should be undertaken when stabilizing agent(s) are being added. The light compaction will provide a solid working platform for the reclaimer, water truck, and/or stabilizing agent tankers, allowing for a more consistent working speed. Reshaping will permit more accurate control of the treatment depth and application of the stabilizing agent(s).

Various types of modern reclaimers will place the pulverized and mixed reclaimed material in different ways. Most often, the cutting tools on the reclaimer's cutting drum are arranged in a chevron pattern to promote mixing. Lateral movement of the reclaimed material is minimal. The reclaimed material exits from the pulverization/mixing chamber rear door, spread across the width of the pass being struck off and smoothed out by the bottom edge of the rear door. The shape of this initial placement of the reclaimed material is dictated by the reclaimer since the rear door is attached to the pulverization/mixing chamber.

Reclaimed materials that do not require aeration to adjust moisture content may be spread to the required thickness immediately after mixing. Reclaimed materials that require aeration are generally formed into a windrow after mixing. As there is a tendency to leave a hump in the roadway when blade spreading from a centerline windrow, and to improve traffic accommodation, it is better to move the windrow to one side.

The motor grader is used to move and place the reclaimed material to the desired longitudinal grade and cross-slope. The amount of motor grader work required to place the reclaimed material will depend on the original shape of the roadway, the specified final shape of the roadway, and on the type of wearing surface which will be used. If a thick layer of HMA is to be used as the wearing course, the final or surface smoothness tolerance is usually larger than if a single surface treatment is to be used.

The motor grader should be used judiciously and be carefully supervised. Some reclaimed materials have coarse gradations, particularly for projects in which the asphalt layers were very thick and these materials can be easily segregated.

Some highway or airport projects with very tight surface tolerances may require the use of sonic or laser controls on the motor grader. For even tighter grade control, a grade trimmer or cold planer, equipped with automatic grade and slope controls, and using a mobile reference point/ski or fixed reference point/stringline, may be required.

At the end of the tight blading or trimming of the reclaimed surface, any excess material should be removed. Extreme care must be taken to ensure that shallow depressions are not filled with thin lenses of uncompacted reclaimed materials which are not bonded to the underlying mix.

12.5 STABILIZING AGENT ADDITION

If stabilizing agent(s) are required to improve the physical properties of the reclaimed mix, they can be added in a number of ways and locations. How and when the stabilizing agent(s) are added depend primarily on the:

- type of stabilizing agent(s) being used
- form of the stabilizing agent(s), i.e., dry, liquid or slurry
- availability of equipment
- desired end result

There are no hard and fast rules on how and where to add the stabilizing agent(s), since each project has its own set of unique requirements.

Addition of the stabilizing agent(s) during the pulverization pass, using the reclaimer's onboard additive system, eliminates some or all of the subsequent mixing passes. This has a corresponding reduction in production costs and works well if the existing roadway is uniform in surface condition, material thickness, material composition, and no undetected buried utilities/castings are encountered.

Figure 12-9: Stabilizing Agent Addition

In order to maintain a uniform application of the stabilizing agent(s) the following three variables must be held as constant as possible:

- operating speed of the reclaimer
- volume or depth of the layer being treated
- amount of stabilizing agent(s) being added

If one or more of these variables changes, an adjustment to the others has to be made in order to achieve uniformity or consistency in the reclaimed mix. Notwithstanding the computerized interlock between the forward operating speed and the amount of stabilizing agent being added, separate pulverization and mixing passes are being used more often. Although more costly, this has the effect of increased, more consistent working speeds as undetected buried utilities/castings are exposed and dealt with prior to the addition of the stabilizing agent. Variation in material thickness and composition can be assessed and corrected, resulting in a more uniform application of the stabilizing agent.

Stabilizing agent(s) that traditionally have been added in a dry state are now more frequently being added in the form of a slurry. The dry stabilizing agent is premixed with water to form a slurry which has a water content at or slightly below the amount which would be required to bring the reclaimed material to the OMC or 75 percent saturation whichever is less. The slurry is then controlled and injected into the pulverization/mixing chamber by the reclaimer's onboard liquid additive system. Application of the dry stabilizing agent as a slurry eliminates the environmental effects, particularly wind and rain, and can be a more accurate application method.

12.6 COMPACTION

The degree of compaction achieved is one of the primary determinants of the future performance of the reclaimed mix. Reclaimed mixes which are poorly compacted:

- can densify under traffic which may result in rutting
- will not achieve early strength gain which may result in surface raveling
- will not achieve the ultimate strength gain which may result in premature failures

Hence, it is imperative that adequate compaction be achieved at the time of construction.

Typically, one or more compactors are needed to adequately densify the reclaimed mix. As with compaction of other construction materials, the size, type, and number of compactors used will depend on the material properties, lift thickness, percent compaction required, smoothness of the compacted area, and production requirements.

The characteristics of the reclaimed mix will determine whether padfoot, smooth drum, and/or pneumatic compactors should be used. The depth of the reclaimed mix being compacted and the desired degree of compaction will influence the weight and amplitude/frequency of vibration for vibratory compactors and the static weight and tire pressure of pneumatic compactors. A field test strip can be used to establish the best combination of amplitude and frequency or combination of rollers.

As with other construction materials, it is also possible to over-compact a reclaimed mix, particularly if stabilizing agent(s) have been used. This reduction in compaction is more prevalent when vibratory compactors are being used. Generally, it is not necessary to loosen or remix the over-compacted area, but a smaller pneumatic compactor or vehicle traffic is used to seal the transverse check-cracking associated with over compaction.

Obviously, the correct moisture or fluid content is critical in achieving adequate compaction with the minimum of effort. Due to the time delay between initial compaction, placement, shaping, and final compaction, a light application of water is usually applied to the surface of the reclaimed mix before final compaction takes place.

Uniform compaction needs to be achieved in order to ensure consistent performance of the reclaimed mix. Compaction must be uniform in not only the longitudinal and transverse directions but also throughout the depth of the reclaimed mix. The rear wheels of the reclaimer ride on the surface of the reclaimed mix, partially compacting the material in the wheelpaths, while leaving the remaining material uncompacted. Prior to initial blading, the uncompacted material needs to compacted to the same level as the material in the wheelpaths. If this is not done, the compactors, particularly if steel drum rollers are used, will tend to ride on the lightly compacted material in the wheelpath and bridge over the uncompacted area. This can lead to differential or non-uniform compaction.

If the reclaimed mix exhibits instability in the form of rutting, shoving or cracking under the action of the rollers, the compaction process should be suspended immediately. When the instability is due to an excessive moisture or fluid content in the reclaimed mix, it needs to be aerated prior to further compaction. If the excessive moisture is not released, the area will not achieve the required degree of compaction, will not have the same strength as the surrounding area, will be sensitive to disturbance by traffic, and will most likely lead to a failure.

Often the instability of the reclaimed material is not due to excessive moisture but to an underlying subgrade problem. If proof rolling or an excavation reveals a subgrade problem, it needs to repaired. The repair method will vary, depending on the type and severity of the subgrade problem, but whichever method is used it is important to ensure that the area will drain at the end of the repair process.

Experience has indicated that compaction of reclaimed mixes stabilized with asphalt emulsion should be complete at or just after the emulsion starts to break, or when the reclaimed mix starts to change from a brown to a blacker color. The moisture content of the reclaimed mix prior to the asphalt emulsion breaking is sufficient to act as a lubricant between aggregate particles, but does not fill the void space between the aggregate particles and prevent densification from occurring. In addition, after the asphalt emulsion breaks, the viscosity increases significantly, requiring additional effort to achieve the required compaction.

Compaction of reclaimed mixes stabilized with foamed asphalt can take place immediately after mixing, assuming it is at or near the optimum fluid content for compaction. Reclaimed mixes stabilized with foamed asphalt will remain workable, providing the moisture content stays at or above the moisture content at the time of the foamed asphalt injection and mixing. Ideally, the compaction process should be completed before the foamed asphalt stabilized mix starts to dry out.

Cementitious stabilized mixes need to be compacted in as short a period of time as possible since the hydration process begins as soon as there is moisture available. Specifications traditionally indicate that the total time for mixing, placing, compacting, and finishing the cementitious stabilized mix be less than a specific time period, usually between two to four hours. The two to four hours is usually measured from the time the stabilizing agent first is exposed to moisture to the time compaction is complete. With a modern reclaimer this time limit is usually not difficult to achieve, provided the length of the segment being treated is appropriate for the available equipment.

Depending on the characteristics of the reclaimed mix and the type of finished surface required, the initial or breakdown rolling is completed with a vibratory padfoot or single or tandem smooth drum vibratory roller. Intermediate rolling is then performed with a heavy pneumatic roller and final rolling is undertaken with a tandem static or vibratory steel drum roller. Depending on project specifics, other combinations of rollers can and are used.

12.7 CURING

Reclaimed materials that have been stabilized by chemical, bituminous or a combination of these stabilizing agents need to be properly cured to:

- achieve the ultimate strengths
- prevent raveling under vehicle traffic
- facilitate placement of the wearing course

Curing can be divided into three categories: initial; intermediate; and final. Initial curing is relatively short and permits the stabilized mix to gain sufficient cohesion to be less susceptible to surface disturbance. Time for initial curing can be shorter than half an hour for foamed asphalt stabilized mixes and an hour or more for asphalt emulsion stabilized mixes. Initial curing times for cementitious and combination stabilizing agents usually fall between these two limits. Initial curing times depend almost entirely on the amount and type of stabilizing agent(s) used and very little on the ambient conditions.

Generally, the surface of the reclaimed mix is dampened with a light application of moisture, and the surface tightened with a pneumatic roller, as the last stage of compaction and the first stage of initial curing. During the initial curing period, all vehicle traffic is kept off the area or it is severely restricted, depending on the characteristics of the reclaimed mix. At the end of the initial curing period, the roadway can be opened to light vehicle traffic.

Intermediate curing is more extensive in length, and depends almost equally on the amount and type of stabilizing agent used and ambient conditions. Intermediate curing is required, to allow the reclaimed mix to build up sufficient strength and/or to allow sufficient moisture or volatiles to escape to permit the wearing course to be successfully applied.

In the case of asphalt emulsion stabilizing agents, intermediate curing allows the excess moisture required for compaction to escape. Entrapment of excess moisture by placement of a chip seal or other type of seal coat may cause the seal to strip or be removed under traffic, and numerous spot patches will be required. If the excess moisture is trapped by a relatively thin HMA overlay, the surface of the overlay may begin to shove under traffic due to bonding problems.

A criteria for determining when adequate intermediate curing has taken place has not been established due to the wide variety of reclaimed materials and stabilization agents. A minimum moisture content of bituminous stabilized mixes has been used as a means of establishing the intermediate curing period. With the increased use of lime or Portland cement to accelerate initial curing and strength gain, it may no longer be an adequate measure, as field strength does not correlate well with moisture content. As a rule of thumb, whenever a core can be extracted from the reclaimed mix relatively easily, it usually has developed enough strength and lost sufficient moisture to be covered by the wearing course.

In the case of cementitious stabilizing agents, intermediate curing allows hydration to take place and strengths to increase. With cementitious stabilizing agents, proper intermediate curing is also critical, in order to prevent excessive shrinkage cracking. Typically, the two types of intermediate curing are moist curing and asphalt sealing. Moist curing consists of keeping the surface of the reclaimed mix damp by regular applications of a very light misting of moisture, using a water truck. In hot and/or windy conditions, moist curing will be difficult since the surface will dry quickly and the potential for excessive shrinkage cracking increases dramatically. When intermediate curing is with an asphalt seal, it typically consists of a slow setting asphalt emulsion, applied relatively thick with an asphalt distributor. In some instances, the asphalt emulsion may be slightly diluted. On some projects, the asphalt seal may be a low viscosity, medium curing cutback asphalt.

The criteria for determining when adequate intermediate curing has taken place with cementitious stabilized mixes, typically depends on the attainment of a specified strength or waiting a fixed period of time. Typically, the intermediate curing period for cementitious stabilized mixes is seven days.

Raveling can occur with reclaimed mixes. The amount of raveling will depend on the gradation of the material, tightness of the surface, the type and speed of traffic permitted, and amount of initial curing which has taken place. Some reclaimed mixes may need to have a very light fog coat of slow setting asphalt emulsion, diluted one to one with water, to prevent excessive raveling prior

Figure 12-10: Bituminous stabilization mat prior to placement of wearing surface.

to placement of the wearing surface. When the area is opened to traffic before the fog coat has completely cured, a sanding will be required to prevent pickup of the asphalt emulsion.

Adequate intermediate curing has a direct effect on both the long-term performance of the reclaimed mix, the wearing surface, and the pavement structure. Heavy truck traffic should not be allowed or at least limited, during the intermediate curing period. Early heavy truck traffic can produce severe flexural or fatigue cracking of the reclaimed material which can lead to structural failure.

Final curing is the time it takes the stabilized mix to reach its ultimate strength, and can be a very long period. Final curing takes place after the wearing course has been applied and is dependent on the amount and type of stabilizing agent and ambient conditions. For some stabilizing agent(s) it can be measured in months or years.

12.8 WEARING SURFACE

After the reclaimed mix has been adequately cured, it can be surfaced with a variety of different wearing materials. The selection of what type of wearing surface to use depends primarily on the anticipated traffic, structural requirements, local climatic conditions, type of stabilizing agent(s) used, and economics. Since reclaimed mixes can have significantly higher load-carrying capabilities, particularly if stabilizing agent(s) have been used, it may be possible to use a thinner layer of HMA or even a more economical surface treatment such as a double chip seal. No matter which wearing surface is selected, it is critical that it bond properly to the reclaimed mix.

In preparation for surfacing, the reclaimed mix is usually swept with a power broom to remove all loose material. The type of wearing surface to be used will dictate what happens next. For HMA or cold mix overlays on bituminous or combination stabilized mixes, a tack coat of asphalt emulsion is typically used to assist with bonding. The application rate of the asphalt emulsion will depend on the surface condition of the reclaimed mix. For chemically stabilized mixes which have been cured with a seal coat, a tack coat may not be necessary. A prime/tack coat is usually required if the chemically stabilized mix has been moist cured.

For surface treatments such as chip seals, micro-surfacing, etc., the surface preparation of the reclaimed mix will vary to suit the particulars of the surface treatment.

CHAPTER 13: FULL DEPTH RECLAMATION – PROJECT SPECIFICATIONS AND INSPECTION

As with all roadway construction processes, two key steps are required to ensure the satisfactory construction and performance of a Full Depth Reclamation (FDR) project. First, is the development of an adequate and equitable set of specifications, and second is inspection during construction to ensure that the intent of the specifications has been achieved.

Although there is a trend in the Hot Mix Asphalt (HMA) industry towards greater reliance on end result specifications, with some owner agencies introducing performance warranties in conjunction with end result specifications, this has not yet been implemented with FDR. The number of unknowns associated with the existing pavement structure, the difficulties in specifying the end result requirements, and the recent development of the process, have all resulted in most FDR projects being undertaken using method specifications. This is not to say that end results are not used for FDR projects but that they are contained within the framework of the method/standard specifications.

13.1 STANDARD SPECIFICATIONS

Standard specifications for FDR projects need to address a number of items, including:

- general description
- definitions and terminology
- material requirements
- equipment requirements
- construction methods
- inspection and Quality Control/Quality Assurance (QC/QA)
- acceptance requirements
- measurement and payment

The general description, usually one or two short paragraphs long, introduces the project, the FDR process, and construction methodology in broad terms. It may or may not identify other sections of the owner agency’s existing specifications that are related to the FDR specifications and the various documents that need to be submitted by the contractor.

Some method specifications include a section outlining the terminology and definitions used within the specifications. The terminology and definition section is more often included when FDR is being used for the first time and not everyone is familiar or comfortable with the terms used.

The section on materials includes requirements for the granular materials, chemical and/or bituminous stabilizing agents, and water. The granular materials are added when the gradation of the reclaimed material requires alteration for increased mechanical stabilization or to increase the amount of reclaimed material for shape or thickness corrections. The chemical and/or bituminous stabilizing agent(s) that are required are usually indicated by a specific product, an equivalent product, existing owner agency specifications or other published specifications such as those contained in the American Society for Testing and Materials (ASTM).

In a method specification, the owner agency, as part of the mix design process, selects the:

- granular material gradation and source
- stabilizing agent(s) type and source
- application rate of stabilizing agent(s)

The stabilizing agent(s) could be mechanical, chemical, bituminous, or a combination of one or more of these. The stabilizing agent(s) could be supplied and used in liquid or dry powder form. Water used to aid compaction must be compatible with the stabilizing agent(s). The materials section is therefore primarily to indicate to the contractor the types of materials that will be used on the project, as opposed to requiring the contractor to select the particular materials to be used.

The section on equipment requirements contains a fair amount of detail, and can be rather lengthy. It includes details for all equipment from the reclaimer through to the placement and compaction equipment. The specifications can include requirements for:

- age or operating condition of all equipment
- reclaimer output/treatment depth capability
- treatment depth controls on the reclaimer
- rotational direction of the reclaimer’s cutting drum
- mechanisms for controlling the reclaimed material gradation via breaker bar and/or door opening on the reclaimer
- water truck/distributor capacity and ability to control application rates
- liquid additive system, complete with microprocessor to control addition of water and/or liquid stabilizing agent(s), linked to forward operating speed of reclaimer
- a system on the reclaimer to accurately produce and sample foamed asphalt when it is being used as the stabilizing agent
- liquid stabilizing agent tanker and/or distributor
- bulk spreaders to accurately add granular materials and/or dry stabilizing agents
- placement control methods on the reclaimer or on the motor grader
- type, size, and number of rollers required for compaction
- asphalt emulsion distributor and application controls for fog/seal coats

In addition, requirements for pre-approval or acceptance of the equipment, particularly the reclaimer, prior to use are often included. In some instances, the specifications include the requirement for the proposed FDR equipment to undertake a test or demonstration section in order for the owner agency to evaluate and approve the equipment, construction methodology, contractor, and/or workmanship.

Construction methods included in the specifications address such issues as:

- weather limitations prior to and during construction
- production plan indicating: sequence and length of each treatment segment; estimated

pulverization, mixing, placement, and compaction times for each segment; layout of transverse and longitudinal joints; stabilizing agent addition rates per segment; and other pertinent information

- accommodation of traffic through the work zone
- determination of in-situ moisture content of the materials to be reclaimed
- preliminary surface preparations required
- surface shape and grade requirements
- addition of stabilizing agent(s)
- time limitations between addition of the stabilizing agent(s) and completion of the compaction process
- method of controlling moisture content of the reclaimed mix
- method of addressing materials with excessive moisture contents
- gradation requirements of the reclaimed material
- continuity of stabilized materials
- methods of dealing with subgrade instability problems
- placement requirements for cross-section shape and grade control
- compaction procedures
- curing requirements and methods
- opening roadway to traffic
- protection and maintenance of the reclaimed mix prior to application of the wearing surface

With method specifications, the owner agency is in control of the construction process, and therefore needs to have full time inspection and testing. The owner agency personnel on the project need to have the experience to evaluate the test results and authority to make field adjustments to the FDR process.

The specifications usually outline the frequency of sampling and the testing methods that will be used. Wherever possible, these should be published industry standards, such as American Association of State Highway and Transportation Officials (AASHTO) or ASTM methods or the owner agency's own adaptation of these procedures. Since the owner agency is essentially in control of the construction process, the QC and QA testing are usually one and the same and increased inspection is used to control the FDR process.

A section of the specifications outlining the acceptance requirements for the FDR work is also included. The acceptance requirements include such things as:

- treatment depth/layer thickness
- gradation of the reclaimed materials
- stabilization content or physical properties of the reclaimed mix
- moisture content of reclaimed mix
- reclaimed mix uniformity
- degree of compaction.
- surface level/grade

- surface texture
- surface smoothness

Some of these are obviously end result requirements, but are included in the method specifications for FDR.

The final section deals with measurement and payment issues for the FDR project. The specifications usually outline how items will be measured such as:

- mobilization/demobilization
- surface preparation prior to FDR
- FDR of existing pavement structure
- stabilizing agent(s) supply and addition
- subgrade instability repair

In addition, the specifications indicate what is to be included in each of the payment items.

Mobilization/demobilization is more commonly being included as a specific payment item. Some specifications fix the amount/lump sum or limit it to a percentage of the total contract price. Other specifications require that mobilization/demobilization be included as part of the other payment items.

Surface preparation prior to the start of the FDR process is usually paid for by the square yard (square meter) of surface area. It includes full compensation for all work necessary to clean the roadway, usually by sweeping. Removal of edge vegetation is particularly important for projects in which the roadway is to be widened by blending shoulder material into the reclaimed mix.

Surface preparation does not include any preliminary leveling or removal of high spots by cold planing or similar activities. When these are required, they are paid for as separate items using the standard units of measurement.

Compensation for FDR can be by the cubic yard (cubic meter) of reclaimed mix or by the square yard (square meter) for a specified treatment depth. In both cases, the payment is for the final treatment volume or surface area, independent of the number of passes to process a given area, regardless of the overlap widths required, and regardless of the hardness or type of material reclaimed.

Individual pay items for areas with identifiable differences in asphalt pavement layers, granular base thickness, and/or required treatment depths should be used with the pay-by-area method.

The FDR unit rate usually includes full compensation for:

- setting out of the work
- pulverizing
- sizing
- supply and addition of water
- mixing
- overlap areas
- placing
- compaction

- curing
- protection/maintenance of the reclaimed mix
- all labor, tools, and equipment

Traffic accommodation is also generally included but can be a separate payment item, particularly for higher traffic roadways with specific requirements.

The supply and addition of stabilizing agent(s) are usually by separate payment items. Granular materials are paid by the ton (tonne) although they could also be by the cubic yard (cubic meter). Liquid stabilizing agent(s) are paid by the gallon (litre), and chemical stabilizing agent(s) are paid by the tonne (ton) for dry materials and by the gallon (litre) for slurried materials.

The rates include full compensation for supply, and addition of the stabilizing agent(s), including all transportation, handling, storage, spreading or fluidizing into a slurry, and application in the FDR process, disposal of all packaging, for all wastage, and safety measures required during handing and application.

Compensation for subgrade instability repairs is made as an individual payment item, using standard measurement units.

Special Provisions, appended to the FDR specifications, are used to indicate specific project requirements such as:

- limits of work
- construction schedule, staging or limitation on hours of work
- trucking requirements
- particular traffic accommodation requirements
- interaction and cooperation with other contractors
- parking and storage of equipment
- mix design information
- any other site-specific requirements

The condition of the existing or in-situ materials, as determined from the investigations carried out, together with the results of testing conducted on representative samples are usually included in the special provisions. Typically, information included from the detailed project analysis consists of:

- existing pavement structure, including individual layer thickness
- type of asphalt binder used in asphalt layers
- gradation of aggregates used in asphalt layers
- presence of any paving fabrics or specialty mixes
- moisture content, gradation, and asphalt content of Reclaimed Asphalt Pavement (RAP) samples
- location of all utilities and roadway castings, both exposed and buried
- moisture content, gradation, and plasticity of underlying materials
- results of any preliminary mix designs
- condition of subgrade, including soil type, moisture content, and strength

Any information included is usually accompanied by a caveat which indicates there is no guarantee that conditions other than those indicated will be encountered.

The degree to which the various issues are addressed within the specification and the special provisions will depend on the owner agency's experience with FDR.

13.2 SPECIFICATION LIMITS

Specifications typically include limits and/or tolerances on a number of physical properties of the reclaimed mix and could include some or all of the following:

- treatment depth/layer thickness
- gradation of the reclaimed materials
- addition of stabilizing agent
- moisture content of reclaimed mix
- reclaimed mix uniformity
- degree of compaction
- surface level/grade
- surface smoothness

Treatment depth or layer thickness is typically indicated on the plans or in the specifications. Thickness of the treated layer is one of two critical variables that affect the long term performance of the reclaimed mix. Some variation in treatment depth is to be expected, depending on the thickness variability of the existing pavement structure. The specified treatment depth is usually somewhat shallower than the existing pavement thickness, in order to prevent contamination of the reclaimed material with subgrade soils.

Typically, a tolerance of plus or minus a given amount from the design thickness is allowed. A value such as +/- 3/4 inch (20 mm) for a design treatment depth of 10 inches (250 mm) could be specified for pavement with uniform thickness. Treatment depth tolerance can also be specified as a percentage of the design thickness, such as +/- 5 percent for a uniform pavement thickness.

Regardless of the method of indicating the tolerance value, the treatment depth should not to be uniformly high or uniformly low. When existing pavement thickness is highly variable, an increase in the treatment depth tolerance should be made.

As indicated in Chapter 12, the gradation or sizing of the reclaimed material can be somewhat controlled by adjusting how the reclaimer is being operated. Recognizing that there are physical and economic limits on how fine the existing pavement can be pulverized by the reclaimer, most specifications indicate the amount passing a preferred maximum particle size, the amount passing the next smaller sieve size, and an upper limit on the amount passing the No. 200 (0.075 mm) sieve.

In the FDR process, 100 percent of the existing asphalt pavement is used along with a predetermined percentage of the underlying materials. Therefore, the variation or consistency of the existing asphalt pavement and underlying materials will have the greatest influence on the variation or consistency of the reclaimed mix. Typically, there are no specified gradation requirements for the intermediate sieve sizes, since these are determined by the gradation of the existing materials.

Adjustment in the overall gradation is normally addressed by the incorporation of granular material, as determined in the mix design.

The maximum size that 100 percent of the particles must pass is normally listed as either 2 inches (50 mm) or 1 1/2 inches (40 mm). The decision to use one over the other will depend on characteristics of the existing materials and desired properties of the reclaimed mix. The smaller the maximum particle size, the finer the overall gradation, but this is achieved at an increased cost.

The amount passing the next smaller sieve size in the standard sieve series is usually 90 or 95 percent. If the maximum particle size were listed as 2 inches (50 mm), the specifications would indicate that 90 or 95 percent of the reclaimed material was to pass the 1 1/2 inch (40 mm) sieve size. The decision on the maximum amount specified to pass the next smaller sieve size also depends on the characteristics of the existing pavements and the required characteristics of the reclaimed mix.

The amount passing the No. 200 (0.075 mm) sieve is typically listed as a maximum value and is used to ensure that the subgrade soil is not being excessively incorporated into the reclaimed materials. Typically, a value of 20 or 25 percent is used depending on the gradation of the underlying materials.

As was noted in Chapter 11, when foamed asphalt is used as the stabilizing agent, the reclaimed materials must meet higher gradation and Plasticity requirements. The mix design will determine whether the reclaimed materials can be stabilized with foamed asphalt in a cost effective manner.

The types of stabilizing agent(s) and required application rates expressed as a percentage of the dry mass of the reclaimed material should be indicated in the specifications, typically the special provisions. The tolerance limits of the stabilizing agent addition rate will depend on the type of stabilizing agent and the form in which it is being used.

When mechanical stabilization by the addition of granular materials is used, the application rate is usually required to be controlled to within +/- 5 percent of that specified. Other tolerance values for the application rate can be used, depending on the maximum aggregate size, gradation, and quantity of granular materials being used.

Tighter control of the addition rate is required when chemical or bituminous stabilizing agent(s) are being used. Specifications typically require that the stabilizing agent be controlled to within +/- 0.5 percent or less of the application rate indicated by the mix design/specification.

The tolerance for moisture content of the reclaimed mix will vary, depending on the type of stabilizing agent(s) being used. For mechanical and/or bituminous stabilizing agents, the field moisture content is usually required to be controlled so that it does not exceed the Optimum Moisture Content (OMC) or Optimum Fluid Content (OFC) nor be more than 2 percent less than the OMC/OFC. For cementitious stabilizing agents the field moisture content is usually required to be controlled so that it does not exceed the OMC or 75 percent saturation whichever is lower. If specialized chemical stabilizing agents are used, the field moisture contents will need to be controlled to the stabilizing agent supplier requirements.

Uniformity of the reclaimed mix is generally assessed visually and by specification requirements, with respect to longitudinal and transverse joints. Specifications usually indicate that between adjacent longitudinal passes of the reclaimer there can be no gaps of unprocessed material. Some specifications address this issue by requiring a minimum overlap of 2 to 4 inches (50 to 100 mm) for adjacent passes.

To ensure the continuity of the reclaimed mix, specifications may also require that the exact location of the end of each processing pass be marked. Processing of subsequent segments is required to start a minimum of 1.5 to 3 feet (0.5 to 1.0 meter) behind the transverse mark of the previous pass.

To be uniform, the recycled mix must be free of segregation and surface defects. Conventional methods of assessing segregation and surface defects of granular base materials could also be used for reclaimed mixes.

The degree of compaction is the second of the two critical variables that affect the long term performance of the reclaimed mix. Degree of compaction influences both the rate of strength gain and the ultimate strength achieved. These in turn will determine the reclaimed mix's response to repeated loading and load-carrying capabilities and by inference, the long term performance. The degree of compaction is usually specified as a percentage of a corresponding reference density.

The reference density for reclaimed mixes stabilized by mechanical or chemical stabilizing agents is usually the Maximum Dry Density (MDD), as determined by the Standard or Modified Proctor test or other compaction method used during the mix design. The MDD is not a fundamental property of the reclaimed mix, as it is dependent on the compaction effort and moisture content.

The degree of compaction for reclaimed mixes that have been stabilized with a bituminous agent is usually calculated using the MDD, as determined by the Marshall, Hveem or other compaction method used during the mix design.

The degree of compaction is typically specified to be an average of 95 percent of whichever reference density is being used, with no individual areas less than 92 percent. The specified degree of compaction can range from a low of 92 or 93 percent to a high of 97 or 98 percent.

In addition, if the lift thickness being compacted is relatively thick, the specifications sometimes include a compaction tolerance limit for depth. Generally, the specifications indicate that the percent compaction of the bottom third of the lift be not less than 2 percent lower than the average percent compaction for the total lift thickness. This is to ensure that compaction is uniform not only horizontally but also vertically.

Specifications usually indicate that the reclaimed mix has to be placed and compacted to the design grade and cross-slope with a tolerance. The tolerance is related to the maximum particle size of the reclaimed mix and the type of wearing surface that will be used. Typically, the tolerance is +/- one half of the maximum particle size specified, with no areas being uniformly high or uniformly low.

Specifications usually indicate that the smoothness of the reclaimed mix surface is to be checked with a straightedge. Individual irregularities must be less than 3/8 inch (10 mm) when checked against a 10 foot (3 meter) straightedge placed on the reclaimed mix surface in any direction. Some specifications also indicate that if the irregularities are caused by factors that are outside the control of the contractor, the specification can be relaxed.

13.3 INSPECTION, QUALITY CONTROL AND QUALITY ASSURANCE

A generic inspection, Quality Control (QC) or Quality Assurance (QA) plan cannot be presented herein due to the wide range of projects in which FDR is used and to the wide variety of equipment. The inspection and QC/QA plan needs to be developed based on the FDR application, and then amended for the specific type of equipment and stabilizing agent(s) being used on the particular project.

During the FDR process the areas of concern that the owner agency/contractor QC/QA plan needs to address include:

- treatment depth
- gradation
- stabilizing agent application rate
- moisture content
- uniformity
- compaction
- smoothness

To ensure that the automatic treatment depth controls are working correctly on the reclaimer, the treatment depth needs to be physically measured. Depth measurements should be performed on a regular basis by removing the reclaimed material on each side of the reclaimer. Pulverizing the pavement structure fluffs up the material and this needs to be accounted for when determining the treatment depths of subsequent mixing passes. A good ground man is indispensable in controlling treatment depth, particularly if the thickness of the existing pavement structure is variable.

The gradation of the reclaimed material should be checked periodically. This is to verify the gradation assumptions used in the mix design process and to ensure that the existing asphalt layers are being pulverized to the required maximum particle size. Maximum particle size checks are usually made more often than determination of the overall gradation of the reclaimed material. Sampling of the reclaimed material needs to be undertaken with special care to ensure that only the pulverized/mixed materials are sampled. The sample must also be taken from the full treatment depth since a reclaimer operating with the cutting drum in a down cutting mode will bring more of the large sized particles to the surface. If the full treatment depth is not completely sampled, the gradation results will not be representative.

The application of the stabilizing agent(s) must be checked on a regular basis since variations in application rates result in variations in the material properties and ultimate strength. The application rates should be checked not only randomly throughout the day but also for average application rates, using daily bulk quantities and daily treatment area.

Liquid stabilizing agents added through the reclaimer can be checked by using the on-board metering system. The metering system should be equipped with a means of determining the liquid flow and displaying the amount being added per minute. It should also have a totalizer to keep track of the quantity of liquid stabilizing agent that has been used. Using these two readings, the stabilizing agent application rate can be checked for a known area and for the day's production. The application of liquid stabilizing agents by distributor truck should be checked with standard methods used to verify application rates. The application rate of dry stabilizing agents is usually checked by using a tarp of known area and weighing the material retained by the tarp.

To ensure that the moisture content of the reclaimed materials is within the range appropriate for compaction, periodic checks on the moisture content of the reclaimed materials need to be made. Moisture content checks need to be made during the pulverization and mixing passes and even more frequently during the compaction process. For adequate compaction and long term performance, it is important that the field moisture be controlled at or slightly less than the OMC or OFC.

The water used in the FDR process needs to be clean and free of detrimental concentrations of acids, alkalis, salts, sugars and other chemical and organic compounds. If the water is not from a potable supply, it will need to be tested to ensure it is suitable, particularly when stabilizing agent(s) are being used.

Uniformity of the reclaimed mix is initially checked visually for any segregated areas. Segregated areas can be remixed with the reclaimer or motor grader on an as-required basis. Uniformity is also checked by ensuring that a sufficient overlap between adjacent passes, both longitudinally and transversely, is being used. Uniformity can also be checked by a comparison of the reclaimed mix gradation in a suspected segregated area with the gradation in a typical area.

Compaction is one of the critical variables that influences the long term performance of the reclaimed mix and so must be continually checked. It is important to confirm the average degree of compaction for the total treatment thickness but also for individual layers. The importance of determining the variation in compaction between the upper and lower layers of the treated thickness increases with increasing layer depths.

Nuclear density gauges are commonly used to determine the moisture content and density of many construction materials. Use of the nuclear gauge to determine moisture content of reclaimed mixes must be undertaken with extreme caution, since the nuclear gauge typically overstates the moisture content which, in turn, understates the field dry density/compaction. Nuclear gauges use the difference between the number of fast moving neutrons to the number of slow moving neutrons to determine measured moisture of a material. Fast moving neutrons emitted from the radioactive source in the nuclear gauge are turned into slow moving neutrons when they encounter hydrogen atoms which are assumed to be the hydrogen atoms of water. The reclaimed mix contains pulverized pavements that contain asphalt binder. Asphalt binders also contain a significant number of hydrogen atoms and so a direct correlation between the neutron/hydrogen count and moisture content is not possible. Calibration of nuclear gauges to account for the hydrogen in the asphalt binder is possible but not practical, as the amount of pulverized pavement and associated asphalt binder varies in a reclaimed mix. To overcome this problem a sample of the reclaimed mix at each test location for compaction has to be obtained and tested for moisture content in the laboratory. Alternatively, the field moisture and density can be determined with volumetric measurement tests such as the sand cone or rubber balloon method.

Figure 13-1: Completed FDR with Hot Mix Overlay

Existing pavements vary in composition not only longitudinally but also transversely and consequently, so do the material properties of the reclaimed mix. Care must be used when selecting the appropriate reference MDD to calculate the percent compaction achieved in the field. On projects with a significant amount of variability in the reclaimed mix, a sample may be needed to determine the appropriate MDD at each density test location.

During tight blading or immediately afterwards, the surface of the reclaimed mix should be checked for smoothness with the 10 foot (3 meter) straightedge. A number of locations should be checked, with the straightedge placed parallel and perpendicular to the longitudinal direction of the roadway.

CHAPTER 14: COLD RECYCLING – DETAILED PROJECT ANALYSIS

Through the project evaluation, economic analysis, and preliminary selection process outlined in Chapter 3, the potential rehabilitation alternatives were narrowed down to one specific technique. The next step in the rehabilitation design is the detailed project analysis which will lead directly into the final project design, advertising, tendering or letting, and construction.

The Hot Mix Asphalt (HMA) overlay, hot recycling, and reconstruction rehabilitation methods will not be addressed, since they are routinely used by all agencies. The rehabilitation techniques of Cold Planing (CP), Hot In-Place Recycling (HIR), and Full Depth Reclamation (FDR) are covered in depth, in other chapters. It is recognized that many of the steps in the detailed project analysis are common to all the rehabilitation methods but are addressed in each process, for continuity.

14.0 COLD RECYCLING REHABILITATION

Cold Recycling (CR) is the rehabilitation of asphalt pavements without the application of heat during the recycling process. The two sub-categories of CR, based on the process used, are Cold Central Plant Recycling (CCPR) and Cold In-Place Recycling (CIR).

CCPR is the process in which Reclaimed Asphalt Pavement (RAP) is processed in a central location to produce a recycled mix which can be used immediately or stockpiled for later use. CCPR is most frequently used as part of a total reconstruction of an existing roadway or in new construction where an existing source of RAP is available. The project issues associated with CCPR are similar to any centrally produced material used on a new or reconstruction project.

The CIR process consists of the on-site rehabilitation of the asphalt pavement with a recycling train which can range in size from a single unit to a multi-unit train.

Pavement distresses which can be treated by CIR, include:

- raveling
- potholes
- bleeding
- skid resistance
- rutting
- corrugations
- shoving
- fatigue, edge, and block cracking
- slippage, longitudinal, and transverse thermal cracking
- reflection and discontinuity cracking
- poor ride quality caused by swells, bumps, sags, and depressions

It is noted that unless the cause or causes of the pavement distress are addressed during the rehabilitation process, the distresses will be mitigated but they will not be eliminated.

The expected design life, performance during the design life and future maintenance requirements, are related to the treatment depth of the CIR, and on the type and depth of the subsequent wearing course. Hence, the detailed project analysis will further refine the CIR treatment depth and subsequent wearing course requirements.

14.1 HISTORIC INFORMATION ASSESSMENT

In the detailed review of historic or existing information, the data which needs to be assessed includes:

- age of the roadway, including any surface treatments. Surface treatments tend to be high in asphalt binder content which must be accounted for in the mix design process
- past condition surveys, in order to assess the rate of pavement deterioration
- thickness of the existing pavement structure and HMA layers. A minimum of 2 inches (50 mm) of asphalt pavement is generally required for CIR but 3 to 4 inches (75 to 100 mm) is preferred. If the CIR treatment depth is 2 inches (50 mm) and the total asphalt pavement layer is also 2 inches (50 mm), there is an increased risk that portions of the underlying granular base may be incorporated into the CIR mix

  Incorporation of untreated granular materials has been successfully undertaken, but there is an upper limit that can be incorporated into the CIR mix. The upper limit must be established during the mix design process but should generally be less than 25 percent by weight of RAP. If the untreated granular base content is in excess of 25 percent, the overall costs increase due to the higher recycling additive demand. In addition, the risk of segregation increases during construction, particularly if the granular base has a large maximum aggregate size and/or a coarse gradation. Segregation has an impact on overall strength, since segregated mixes tend to have reduced strength
- thickness of the HMA lifts within the anticipated CIR treatment depth. Moisture in HMA, delamination and/or poor bonding of HMA lifts and stripped aggregates could be encountered. Pavements with moderate stripping problems have been successfully treated by adding lime, either dry or as a slurry
- type of asphalt binder used in surface lift. Softer asphalt binders tend to have reduced stability values which may need to be improved with the use of additional recycling modifiers such as Portland cement, lime or coarse aggregate. Chemical recycling additives such as type C fly ash have been successfully used as well
- top size of aggregates used in surface lift. Depending on the top size of the aggregate, large stone mixes may influence the CIR treatment depth
- presence of any paving fabrics or interlayers in the anticipated treatment depth plus 25 percent. Paving fabrics are difficult to recycle with CIR and the presence of an interlayer may need to be assessed further, depending on its characteristic and location
- presence of exotic or specialty mixes, such as Open Graded Drainage Layers, Open Graded Friction Courses, Stone Matrix Asphalt, etc., will have an effect on the mix design and construction due to their coarser gradations

The detailed review of existing information contained in the maintenance records which needs to be assessed includes:

- patching locations and ages. Weak pavement structures/failing subgrades can lead to the CIR equipment "breaking-through" the pavement structure. Weak pavement structure can also lead to reduced compaction of the CIR mix, due to the pavement deflecting under the compaction equipment which in turn can lead to raveling during the curing period or rutting after the wearing course has been placed
- patching material including HMA, cold mix asphalt, injection spray patching, etc. (if these areas are significant)
- crack sealing activities, product types and ages

The detailed review of the existing Quality Control/Quality Assurance (QC/QA) information, from construction of all pavement layers within the anticipated CIR treatment depth, includes:

- asphalt binder content
- aggregate gradation, angularity, flat/elongated particles, and/or petrographic analysis
- voids total mix (VTM), voids in mineral aggregates (VMA), and voids filled with asphalt (VFA) properties
- field compaction
- recovered asphalt binder properties

In order to delineate or isolate areas of substantial difference and/or uniformity within the project limits, a comparison of the QC/QA test results should be undertaken. Two times the standard deviation of the QC/QA test results, compared to the construction production tolerances, will give a quick indication of whether or not the mix variability is high or low. High mix variability is less desirable, since 100 percent of existing materials within the treatment depth will be recycled in the CIR process. The construction specifications may have to be modified to account for projects with high mix variability, if other factors have indicated that CIR is a viable option.

14.2 PAVEMENT ASSESSMENT

In the detailed pavement assessment, the type, severity, and frequency of the pavement distress which needs to be corrected is determined. Although CIR can rehabilitate most types of pavement distresses, cracked pavements which are structurally sound and have well-drained bases are the best candidates. The CIR process destroys the existing crack pattern and produces a crack-free layer for the new wearing course such as a HMA or an asphalt surface treatment. For CIR to be effective in mitigating the cracking, as much of the existing asphalt pavement layer should be treated as possible. Typically, at least 70 percent of the existing asphalt pavement thickness needs to be treated in order to mitigate the reflection cracking. The treatment depth is also affected by the maximum depth that can be treated at one time. Generally, the treatment depth is 2 to 4 inches (50 to 100 mm) for mixes modified with liquid recycling additives such as asphalt emulsions and emulsified recycling agents. Using additional recycling modifiers such as lime or Portland cement or a chemical recycling additive such as type C fly ash, increases treatment depths to 5 to 6 inches (100 to 150 mm). Obviously, the thicker the untreated portion of the existing asphalt pavement relative to the CIR treatment depth, the higher the probability of reflection cracking eventually occurring. Wherever possible, paved shoulders should also be treated in order to

Figure 14-1: CIR Candidate Road

prevent propagation of shoulder cracks into the adjacent treated driving lane.

An unusual surface texture may indicate the presence of a specialty HMA mix in the upper layer of the pavement which will need to be assessed further during the material properties assessment.

The presence of large or frequent surface patches increases the variability or decreased homogeneity of the existing materials which will have an effect on the consistency of the CIR mix. Large patches may require their own specific mix design, since they are usually newer and contain materials different from the original roadway.

Rutting in the form of wear rutting is easily treated with CIR and the appropriate high quality HMA wearing course, to ensure that wear rutting does not return. Instability rutting can be corrected with CIR if the appropriate recycling additives, modifiers and/or granular materials are selected. The addition of recycling modifiers such as lime and Portland cement, with asphalt emulsions or emulsified recycling agents, have been used to correct rutting problems. The selection of the type and amount of asphalt emulsion or emulsified recycling agent is also critical to correcting rutting problems. The use of High Float emulsions with harder base asphalt cements and/or the addition of polymers is becoming more prevalent. A chemical recycling additive, such as type C fly ash, can address instability rutting, as well. If granular materials are used they should be coarse, crushed material with addition rates usually less than 25 percent by weight of the RAP. Structural rutting, provided it is not originating in a very weak/wet subgrade, can be addressed with CIR and the subsequent placement of the appropriate thickness of HMA.

14.3 STRUCTURAL CAPACITY ASSESSMENT

There are two aspects of the structural capacity assessment which need to be addressed. The first is the structural capacity required for the anticipated traffic during the design life of the rehabilitation. The second is the ability of the existing pavement structure to support the CIR equipment during construction.

The first step is to reassess the structural capacity of the existing pavement and determine what is required for the anticipated traffic during design life of the rehabilitation. If the existing structural capacity needs improving, a determination of the required strengthening thickness must be undertaken using the agency's normal overlay thickness design methods.

If a mechanistic-empirical design method is used to determine the required overlay thickness for structural strengthening, the structural layer coefficient of a CIR mix typically ranges from 0.20 to 0.44 with an average value of about 0.30. The range in structural layer coefficient values is related to the amount and types of stabilizing additives which are used. CIR mixes that have had lime or Portland cement added as a modifier to liquid recycling additives, and chemical additives such as type C fly ash, typically have higher values. In addition, CIR mixes usually have measurable increases in strength after construction, due to curing of the recycling additive and/or modifier, and a reduction in the field VTM with traffic. The rate of strength increase is greatest during the first few months after construction but may continue at reduced rates for up to 2 years. Comparison of CIR mixes with standard HMA mixes, at similar VTM contents, has indicated that the CIR mixes have slightly higher modulus values and significantly greater fatigue life, indicating that the CIR mix may behave more like an open graded material than a dense graded material. Each agency will have to determine an appropriate structural layer coefficient typical of the CIR mixes used in their jurisdiction.

When the existing structural capacity is sufficient to handle the anticipated design traffic, then the CIR processes can be assessed further. Since no increase in strength is required, a thin HMA overlay or a single or double asphalt surface treatment could be used as the surface course.

Even when the strengthening thickness required is high, or if poor or marginal base and subgrade conditions exist, CIR has been successfully undertaken. In these instances asphalt emulsions, emulsified recycling agents with the addition of modifiers such as Portland cement or lime or chemical additives such as type C fly ash are commonly used. The combination of liquid recycling additives and either the Portland cement, lime or type C fly ash, produces higher earlier mix strengths that may be capable of bridging over the weak underlying areas.

When the existing structural capacity requires significant strengthening, due primarily to the anticipated traffic and the existing roadway does not contain structural or base failures, then CIR could still be used to treat the existing pavement distress, such as cracking, etc. The overall structural capacity deficiency could then be addressed by a thicker HMA overlay.

Pavements with major or extensive structural and/or base failures will not be good candidates for CIR and other rehabilitation methods should be assessed. If the structural/base failures are less than 10 percent of the project area, it may be economically feasible to remove and repair the failed areas by deep patching prior to undertaking the CIR. Care must be taken to ensure that water is not trapped within the repair area by creating a "bath tub" condition within the subgrade. If the excavation in the failed area needs to be below the surrounding subgrade elevation, the excavation must have a drainage outlet provided or be filled with non-permeable stabilized material.

Whichever rehabilitation technique is chosen, the source/cause of any isolated structural problems within the pavement must be identified and corrected or they will likely reappear with time.

For the second case of structural assessment, a determination of the load-carrying capacity of the granular base and pavement remaining after cold planning is required and becomes more important for thinner overall pavement structures. The CIR equipment wheel loads are generally high and after the cold planing machine removes the existing pavement for treatment, the rear drive track of the cold planer and the subsequent equipment is only supported by the remaining pavement structure. If the remaining pavement structure is thin or weak, the vertical load and shearing force of the rear track of the cold planer, as it pulls the recycling train along, can punch/shear into the underlying materials, lose traction stopping the CIR train.

The two most useful methods of assessing the load-carrying capacity of the pavement structure are Dynamic Cone Penetrometer (DCP) and Falling Weight Deflectometer (FWD) testing. With the DCP, the underlying materials can be assessed by coring or drilling through the asphalt pavement layers to expose the granular base, subbase, and/or subgrade materials. Obviously, if water has been used in the coring operation, the resultant moisture may affect the DCP values of the upper portion of the underlying materials. Assessment of the load-carrying capacity is usually conducted at the same locations that samples of the asphalt pavement for material property assessment are obtained. However, for weak and/or thin pavement structures, additional DCP testing should be conducted to more fully assess the load-carrying capacity and/or isolate weak areas. This is critical since reduced compaction may lead to a reduction in the performance of the CIR material.

Each agency will need to establish its own DCP blow count profile versus feasibility of CIR construction evaluation criteria, since it will be sensitive to material types, soil, and groundwater conditions. In general, if there is a minimum of 2 inches (50 mm) of asphalt pavement remaining below the CIR treatment depth and 6 inches (150 mm) of granular base, the risk of equipment break-through is low even if relatively low DCP blow counts are noted. As the remaining asphalt pavement thickness and/or the thickness of the granular base is reduced, higher DCP blow counts will be required to ensure equipment break-through does not occur.

DCP results will change throughout the year in response to changes in base and subgrade moisture conditions. The DCP results should ideally be obtained when the moisture conditions in the base, subbase, and subgrade will be similar to those at the time of CIR construction. If this is not possible, then an adjustment of the DCP evaluation criteria, to account for the differences in moisture contents from the time of testing to time of construction, will need to be made.

The FWD can also be used to assess the load-carrying capacity of the existing pavement structure, including the base, subbase, and subgrade by back-calculating the subgrade resilient modulus and the effective pavement modulus. Other parameters such as the surface curvature index, base damage index and/or base curvature index can be determined from the deflection bowl measurements produced by the FWD. As with the DCP testing, each agency will have to establish its own evaluation criteria based on their local conditions.

14.4 MATERIAL PROPERTIES ASSESSMENT

Utilizing the results of the existing information reviewed and the pavement assessment, the project is divided into areas/segments of similar materials or performance. A field sampling plan is then established utilizing either fixed interval or random sampling methods to determine the location of the field samples.

Field sampling has traditionally been obtained by coring/sawing or small milling machines. The popularity of using small milling machines to obtain field samples is declining since the consistency of the samples between different types of small milling machines is highly variable and it is relatively expensive. The gradation of the samples obtained by small milling machines is not as coarse with smaller maximum particle size and more fines, i.e., passing No. 200 (0.075 mm) sieve size than what is produced by the large milling machines during the CIR process. The current trend is to obtain samples by means of coring, usually 6 inches (150 mm) in diameter, and then subsequently crushing the cores in the laboratory. With field coring and laboratory crushing, the sample gradation more closely resembles what is achieved in the field during the CIR process. Block sampling, by means of sawing, can also be used, but it is usually more expensive than coring. It is important that the full depth of the asphalt bound layers be cored in order to assess its condition. However, only the upper portions of the core, equivalent to the anticipated CIR treatment depth, are used for subsequent analysis.

The frequency of field sampling varies with the size of the project, size of the areas of similar materials or performance, and the variability of the existing materials, as determined from the review of existing QC/QA data. Generally, the number of sample locations ranges from 3 to 5 for smaller, consistent areas to 20or more for larger, less consistent areas. Samples are obtained at a frequency of approximately one location per 5/8 mile (kilometer) per lane direction. The number of cores obtained at each field sampling location will depend on the number of field sample locations, the amount of laboratory testing to be performed, whether or not samples will be needed for subsequent CIR mix designs, and what type of mix design method will be used. If a modified Marshall or Hveem mix design is planned, the total number of cores will depend on the anticipated CIR treatment depth and core diameter. Approximately 110 pounds (50 kilograms) of material is usually required for each mix design. If the effect of an additional modifier or chemical additive other than traditional liquid recycling additives is to be assessed, then more material will be required.

The core samples should be carefully examined in order to detect the different pavement layers, previous surface treatments, interlayers, geotextile paving fabrics, specialty mixes, evidence of stripping, friable or disintegrating mix, retention of excessive moisture, and any tendency to delaminate. Once the cores have been inspected, the observations recorded and selected cores photographed, the cores are trimmed to the depth of the anticipated CIR treatment and crushed. Representative samples are then tested to determine:

- moisture content (if dry coring has been used)
- gradation of the crushed RAP
- asphalt binder content
- aggregate properties including gradation, angularity, etc.
- recovered asphalt binder properties including penetration, absolute and/or kinematic viscosity, and perhaps Superpave PG grading

This information will assist in the selection of the type and amount of liquid recycling additive and with determining whether or not new granular materials are needed to improve the characteristics of the RAP or are needed to address a deficiency in the original asphalt pavement such as flushing, etc.

14.5 GEOMETRIC ASSESSMENT

In the detailed geometric assessment, determine whether the project:

- requires major realignment, widening or drainage corrections
- contains underground utilities/drainage structures
- requires upgrading of any underground utilities
- contains bridges/overpasses
- needs longitudinal/grade corrections
- requires cross-slope/fall corrections

If major realignments, drainage corrections or frost heave mitigation repairs are required, reconstruction may be the preferred rehabilitation alternative. The use of CIR could be included as a stage in the overall rehabilitation process or CCPR could be used, particularly if extensive base, subbase, and/or subgrade problems are present. The existing pavement can be cold planed off and stockpiled for future use. The underlying materials are either removed and replaced or improved by stabilization. The stockpiled RAP could then be processed by CCPR and placed as a stabilized base course material.

CIR has been successfully used on projects where existing granular shoulders have been paved in the rehabilitation process. In order to be successful, the existing shoulder area has to: have sufficient granular material; be of sufficient strength; incorporation of the existing uncoated granular material is limited to 25 percent by weight of RAP; the appropriate stabilizing additive(s) are used; and the wearing course is a HMA of sufficient thickness.

The presence, frequency, and elevation of utility covers (manholes and valves) needs to be assessed, particularly in the urban setting. Manholes and valves should be lowered to 2 to 4 inches (50 to 100 mm) below the CIR treatment depth and their locations accurately recorded. Manholes should be covered with a strong steel plate and the excavation backfilled with RAP. Treatment of the roadway can take place in an uninterrupted manner so that the CIR depth and material consistency can be maintained. After placement of the subsequent wearing course, the manholes and valves are located, neatly excavated, and raised to the appropriate level of the wearing course to provide a smooth profile. Obviously, if any upgrading of the existing underground utilities is required, it should be undertaken prior to rehabilitating the roadway surface. CIR will also help mitigate the cracking at the edges of the underground excavations.

Existing pavements on bridges and overpass decks are traditionally not treated with the CIR process. All bridges and overpasses must be checked for structural capacity to determine whether they can support the CIR equipment.

The cold planers used as part of the recycling train have cutting head widths of 10 to 12 feet (3.0 to 3.7 meters) with extension widths of 1, 2 and 4 feet (0.3, 0.6 and 1.2 meters) being available. Hence, a variety of CIR treatment widths is available from 10 to 16 feet (3.0 to 4.9 meters).

If existing paved shoulders are to be treated, the width of the shoulder will influence how and when it is treated. Paved shoulder widths up to 4 feet (1.2 meters) can be treated at the same time as the adjacent driving lane by using the appropriate width of cold planer in the recycling train. Paved shoulder widths greater than 4 feet (1.2 meters) and less than 10 feet (3 meters) are difficult to treat, but two methods are available, both of which increase the project costs. The first method would be to use a smaller cold planer to mill the shoulder material to the desired depth and cross-slope, and windrow the RAP on the adjacent driving lane in front of the recycling train. The recycling train would then process the shoulder and driving lane material but at reduced production rates due to the volume of materials being handled. This method may not be viable if the CIR treatment depth is over 3 inches (75 mm) due to the material handling capabilities of the recycling train. The second alternative would be to use the smaller cold planer to remove the shoulder material, have the RAP treated using a CCPR facility and then placed on the shoulder prior to treating the adjacent driving lanes.

Pavements that are not whole multiples of the treatment width of the CIR equipment will require some overlap to ensure full CIR coverage. Ideally, an overlap between adjacent CIR passes of 4 to 6 inches (100 to 150 mm) is desired. If the overlaps become significantly larger, there are potentially both economic and performance implications, particularly if significant amounts of new granular material, liquid recycling additive and/or an additional modifier or chemical additive is being used in the process.

The CIR equipment is very long due to the number of pieces in the train. Therefore, roadway geometry, particularly in an urban setting, will influence the types of areas which can be treated. The CIR equipment can handle moderate radius turns such as acceleration/deceleration lanes, turning bays, etc., provided there is sufficient room for the equipment to exit the area. Roadways containing “T” intersections cannot be treated all the way to the top of the “T.” However, small milling machines are effective in working in conjunction with CIR trains to facilitate recycling the entire roadway in urban settings. Paved driveway and other entrances, mailbox pullouts, and other short and narrow areas in the roadway cannot normally be treated. Varying the CIR treatment width for short sections along the length of the project is not practical or recommended.

The CIR process can correct most longitudinal and transverse profile deficiencies prior to placement of the wearing course. However, if the existing pavement profile is severely defective, one of the following corrective operations may be required:

- if the existing asphalt pavement is of sufficient thickness, cold plane the roadway to correct the profile deficiencies prior to CIR
- add either new granular material or RAP from an external source in the CIR process
- correct as much of the profile deficiencies as possible with the CIR process and then correct the remaining profile deficiencies with additional leveling and/or wearing course material

14.6 TRAFFIC ASSESSMENT

Originally, CIR was used on low to medium traffic volume roadways, but it is now routinely being used on higher traffic volume roadways. There is no upper limit to roadway traffic volumes if a proper pavement structural design is undertaken as part of the rehabilitation process to ensure that the effects of future traffic are accounted for.

The CIR process minimizes traffic disruptions and user inconvenience, due to the short construction time compared to conventional pavement rehabilitation methods. CIR can be undertaken in off peak hours to further reduce the traffic disruptions, but this results in reduced daily productivity.

Depending on the width of the existing roadway the CIR operation will occupy 1 1/4 to 1 1/2 lanes within the CIR construction zone. For narrow roadways, accommodation of large/wide truck or oversized loads will need to be addressed.

On two lane roadways, one-way traffic through the construction zone will need to be maintained, with appropriate traffic control such as flag people, lane demarcation devices and/or pilot vehicles. Very narrow two lane roadways increase the traffic accommodation difficulties, particularly if there is little or no paved shoulder.

Traffic control at intersections and at business approaches also needs to be addressed in an urban environment. Due to the speed of the CIR processes, the intersections and approaches are not out of service for very long, and traffic is usually controlled with flag people and lane demarcation devices.

14.7 CONSTRUCTABILITY ASSESSMENT

As the CIR equipment is relatively wide and long, overnight parking/storage of the equipment is a concern. A sufficiently wide overnight parking area is required or the equipment must be allowed to be park on the side of the roadway with use temporary traffic delineation devices, warning lights and/or temporary signals to direct traffic. The width of the roadway being treated will determine whether this is a viable alternative.

The location/spacing of these parking/storage areas are critical since a multi-unit recycling train can process approximately 2 lane miles (3.2 kilometers) per day. Typically, parking areas should be on the order of 1 3/4 to 2 1/2 miles (3 to 4 kilometers) apart, to reduce the amount of equipment travel during the daily mobilization and demobilization. The individual pieces of CIR train have good clearance, so access to the parking area is generally not a problem.

Very steep, long, uphill grades are difficult to process with a multi-unit recycling train since the cold planer will have a difficult time maintaining enough traction to pull the train up the hill. Downhill grades are routinely handled. Single or two-unit recycling trains will be able to handle steeper and longer uphill grades. Grades over 5 percent or 2,500 feet (750 meters) in length generally result in reduced production rates and increased traffic control requirements.

Clear span heights for bridges and underpasses must be checked for not only the CIR equipment but for the haul trucks, as well.

Generally, CIR equipment can process to the edge of a curb and gutter section. For straight-faced concrete sections (with no gutter), a portion of roadway will not be able to be treated. Those areas, not accessible by the large CIR train, can be pre-milled with a small milling machine and the area replaced with CIR mix by use of an extendable screed on the paver or by hand work, similar to what is done on conventional paving projects.

If granular material is required in the CIR process, then the availability of aggregates of suitable gradation and quality must also be assessed.

14.8 ENVIRONMENTAL IMPLICATIONS

Areas that are extensively shaded receive little or no direct sunlight to assist in the breaking and initial curing of the recycling additive, and therefore, take longer to cure and compact. Extended traffic control, for a day or more, will be required to ensure the extensively shaded area does not ravel when opened to traffic. Similar curing conditions/problems can occur if the work is being undertaken in cold, damp conditions typical of late fall or winter weather, when there are pavement areas with poor drainage or higher than average moisture content. In these types of conditions, the use of an additional modifier such as lime or Portland cement or a chemical additive such as Type C fly ash can prove beneficial. The above additives and modifiers usually reduce the curing period and accelerate the strength gain sufficiently to permit the areas to be opened for traffic within a couple of hours.

As with all rehabilitation construction projects, there will be a certain amount of noise associated with the process. Typically, due the speed of the CIR operation and the transient nature of the process the noise effects will be short term. Once again, this issue will have increased concerns is an urban setting.

14.9 ECONOMIC ASSESSMENT

The expected service lives of the various CR rehabilitation techniques, when undertaking a life-cycle economic analysis, generally fall within the following ranges:

• CIR with surface treatment	6 - 8 years
• CIR with HMA overlay	7 - 15 * years
• CCPR with surface treatment	6 - 8 years
• CCPR with HMA overlay	12 - 15 * years

Note: * Equivalent to agency’s thick lift HMA service life.

The effectiveness and performance of the various CR rehabilitation techniques varies from agency to agency and is dependent on:

- local conditions
- climate
- traffic
- type of technique and quality of materials used
- quality of the workmanship

Figure 14-2: Completed CIR Project with a Hot Mix Overlay