

## **CHAPTER 16. FULL DEPTH RECLAMATION (CONSTRUCTION METHODS AND EQUIPMENT)**

### **INTRODUCTION**

Full depth reclamation has been defined as a recycling method where all of the asphalt pavement section and a predetermined amount of underlying materials are treated to produce a stabilized base course.<sup>(1)</sup> Different types of additives, such as asphalt emulsions and chemical agents such as calcium chloride, portland cement, fly ash and lime, are added to obtain an improved base. The five main steps in this process are pulverization, introduction of additive, shaping of the mixed material, compaction, and application of a surface or a wearing course. If the in-place material is not sufficient to provide the desired depth of the treated base, new materials may be imported and included in the processing.<sup>(1)</sup> This method of recycling is normally performed to a depth of 100 to 300 mm (4 to 12 in)<sup>(2)</sup>

The major advantages and benefits of full depth reclamation are as follows:<sup>(2,3)</sup>

1. The structure of the pavement can be improved significantly without changing the geometry of the pavement and shoulder reconstruction.
2. It can restore old pavement to the desired profile, eliminate existing wheel ruts, restore crown and slope, and eliminate potholes, irregularities, and rough areas. Pavement widening operations can also be accommodated in the process. A uniform pavement structure is obtained by this process.
3. It can eliminate alligator, transverse, longitudinal, and reflection cracking. Ride quality can be improved.
4. Frost susceptibility may be improved.
5. The production cost is low, and only a thin overlay or chip seal surfacing is required on most projects.
6. Engineering costs are low.
7. Materials and energy are conserved, and air quality problems resulting from dust, fumes, and smoke are eliminated. The process is environmentally desirable, since disposal problem is avoided.

Full depth reclamation has been recommended for pavements with deep rutting, load-associated cracks, nonload associated thermal cracks, reflection cracks, and pavements with maintenance patches such as spray, skin, pothole, and deep hot mix. It is particularly recommended for pavements having a base or subgrade problem.

### **CONSTRUCTION PROCESSES AND EQUIPMENT**

Figure 16-1<sup>(4)</sup> shows a flow chart for full depth reclamation. The first step is to rip, scarify or pulverize or mill the existing pavement to a specified depth. Four processes are listed in figure 16-1 for this step. The second process (from the top) involves central plant whereas the other three are in-place processes. The resulting material can be processed further for size reduction and mixed with recycling agents and new materials, if required, in-place or in a central plant. The choice between in-place and central plant depends on equipment availability, roadway condition,

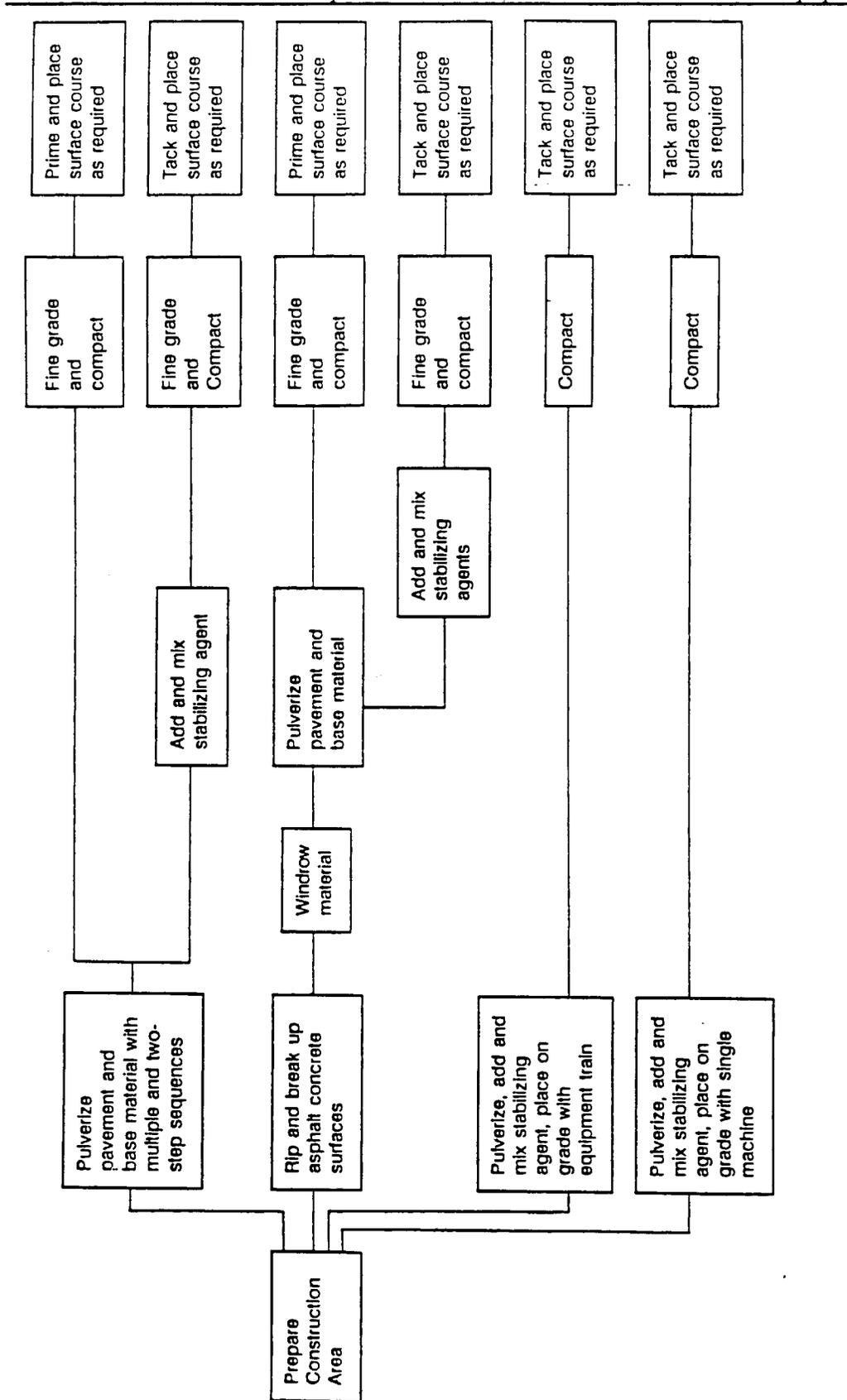


Figure 16-1. Flow chart for full depth reclamation.<sup>(4)</sup>

and economics.

The in-place method is generally more economical than the central plant method. The different mixing methods include blade, flat type, windrow type and hopper type (figure 16-2).<sup>(5)</sup>

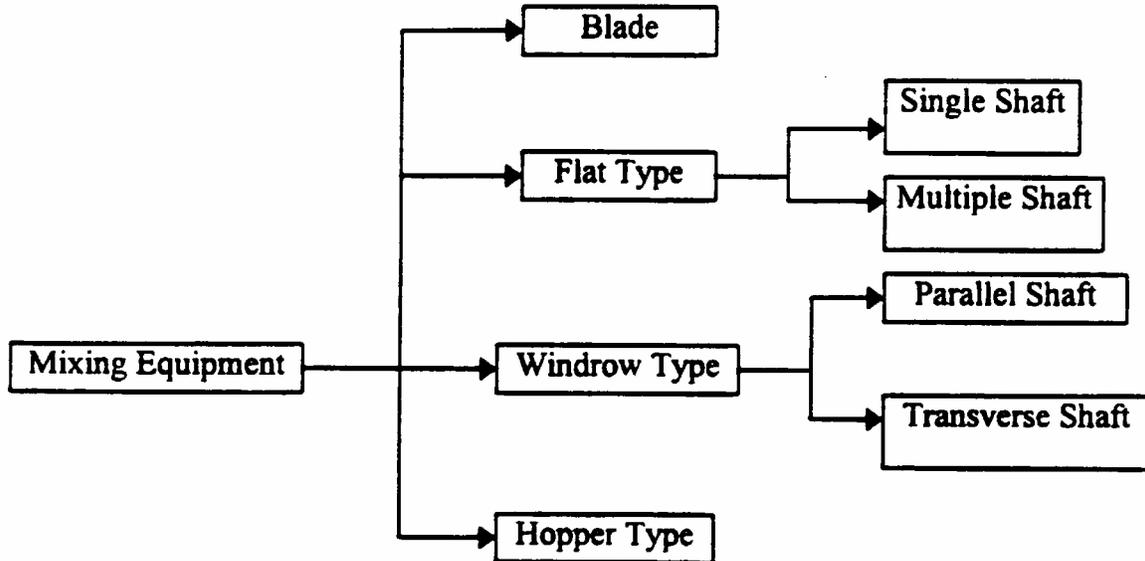


Figure 16-2. Soil and stabilization equipment used for full depth reclamation.

Four different types of in-place sizing and mixing operations are used at present. These include the multiple-step sequence, two-step sequence, single machine, and the single-pass equipment train. The different methods are discussed in the following paragraphs.

### Multiple-Step Sequence

In this process, the existing pavement is broken, pulverized, and mixed with a recycling agent. The equipments available for initial ripping or scarifying include motor grader or dozer with either front- or rear-mounted ripper teeth (figure 16-3). This method is believed to be efficient with thin Hot Mix Asphalt (HMA) layers, but it may produce larger chunks of material than needed when cutting deeper.<sup>(8)</sup> Materials produced by this method may need additional size reduction.

A variety of equipment is available for size reduction or pulverization after the initial ripping. The different equipment are as follows:<sup>(4,6)</sup>

1. Sheep foot, grid, or similar type of roller. This type of roller can also be used for initial scarification or crushing of thin seal-coat roads. A vibratory padfoot type roller is shown in figure 16-4.
2. Motor grader with ripper teeth, equipped with a cutter-crusher-compact in the rear. This equipment combines the scarifying and size reduction operations. Figure 16-5 shows a typical motor grader.



Figure 16-3. Dozer with ripper teeth.



Figure 16-4. Vibratory padfoot roller.



Figure 16-5. Motor grader.

3. Towed or self-propelled hammermill (or impact breaker or preparator). Figure 16-6 shows a traveling hammermill.
4. Rotary mixers. The self-propelled, single-pass mixer with single or multiple transverse rotary shafts, each containing multiple mixing paddles, can be used for removal, crushing, and mixing operations.

The mixing operation is generally performed with a blade mixer or a transverse-shaft mixer.

The drawbacks of using the above equipments are that they need multiple passes to achieve required size reduction, may cause lack of uniformity in depth of cut, have low production rate and have limitations on depth of cut. Construction coordination and traffic control can be major problems. The major advantage of this method is that readily available equipment can be used.

### **Two-Step Sequence**

In this process, the breaking and pulverizing or sizing operations are combined together with a cold milling machine or a large pulverizing machine. The second step involves addition of the recycling agent with soil stabilization mixing equipment and traveling mixers. Figure 16-7 shows a cold milling machine. The main feature of a cold milling machine is a rotating drum lined with a variable number (depending on width) of replaceable, tungsten-carbide-tipped cutting teeth, which is used to grind the existing pavement. These machines can provide accurate control of depth and profile as well as pulverize and size in a single pass, resulting in less interference with traffic. They can also be equipped with a pump and metering system to serve as a mixing unit.



Figure 16-6. Traveling hammermill.



Figure 16-7. Cold milling machine.

The cold milling machine can provide a high production rate in almost any weather.<sup>(2)</sup> However, trained personnel is required for operation of the cold milling machine. Also, the entire pavement should be reduced to the proper size, and the increase in amount of fines due to milling should be considered during mix design.<sup>(9)</sup>

The drum of the cold-milling machine can be set to operate either in the up cutting or the down cutting mode. In the up cutting mode, the teeth cut from the bottom of the pavement layers upward as the machine moves forward. This method provides accurate cutting depth with lower cost, greater speed, less tooth wear, less power to operate, and less damage to the underlying surface. The only drawback is that this method can produce a significant amount of oversized material.<sup>(2)</sup> In the down cutting mode, the teeth strike the top of the pavement surface in a downward direction as the machine travels ahead. This method is appropriate for full-depth cuts, since the reclaimed materials are pinched against the underlying layers resulting in proper sizing.<sup>(2)</sup>

Material quality and depth of cut are the two main factors affecting the resistance of pavement to the penetration of the cutting teeth, which in turn control the productivity of the milling machine. The main factors related to material quality can be summarized as follows.<sup>(2)</sup>

1. **Structural soundness of the pavement.** A pavement layer with alligator or fatigue cracks is easier to cut than a pavement which is structurally sound.
2. **Hardness or toughness and gradation of aggregate.** Productivity decreases and tooth wear increases as the hardness or toughness of the aggregate increases and as the gradation becomes finer.
3. **Characteristics of binder agent.** Material with a stiffer binder is harder to mill than a material with a softer grade of binder.

The productivity of cold milling operation is also affected significantly by the depth of the cut. As the depth increases, in a single pass, more amount of material is produced, but at the cost of reduced speed and greater demand for cutting power. The net number of tons of material reclaimed increases as the depth of cut increases up to about 75 mm to 100 mm (3 to 4 in) depth, depending on the quality of the material. Beyond this depth the net productivity decreases as the traveling speed of the machine becomes the dominant factor affecting the productivity. Hence, beyond 75 mm to 100 mm (3 to 4 in) depth of cut, two passes of the cold milling machine may be more efficient than a single pass.

For a given cold milling machine, the travel speed can vary from as low as 2.4 m to 3.0 m (8 to 10 ft) per minute to 30.5 to 45.7 m (100 to 150 ft) per minute, depending on the quality of the mix. Hence, the machine can have a wide ranging production rate.

Automatic grade and slope controlled cold milling machine are very common nowadays. Both sides of the equipment can be regulated, using either dual grade references or a grade control on one side and a slope control on the other side of the machine. The type of grade reference controls the leveling performance. If a joint machine shoe is used, the machine will duplicate the profile of the surface being matched. If a mobile ski or erected string line is being used, the cold miller will do the required leveling work.<sup>(2)</sup> The machine can be used with dual-grade controls to remove a constant depth of material. It can also be operated using a combination of grade control and slope control to produce the required cross-section across the existing pavement. However,

the contractor cannot operate the cold-milling machine to obtain a constant depth of cut and a constant cross slope at the same time.<sup>(2)</sup>

Material quality and depth of cut affect the life of cutting teeth, and hence the cost of operation of a cold-milling machine. The other important factors affecting the cost of operation are: operating hours per year or annual ownership costs, maintenance and repair or operating costs, labor expenses, and fuel, lubrication and auxiliary equipment charges.<sup>(10)</sup>

The important advantages of this method are that partial depth removal of asphalt layer is possible, and that it has high production capacities. The disadvantages are that the depth of cut is limited, can result in aggregate oversize, and needs specialized equipment.<sup>(2)</sup>

### **Single Machine**

The reader should refer to section on single machine in chapter 13. An example of single machine operation used for FDR is shown in figures 16-8 through 16-11. The existing road in Quebec was cracked because of freeze-thaw cycled, and needed major increase in structural capacity because of increasing semi-tractor-trailer loadings. It was decided to conduct FDR of the existing material with asphalt emulsion and cement. Figure 16-8 shows a schematic of the machine. The single machine was attached to a slurry mixer, which was connected to an emulsion tanker (figure 16-9). The single machine received the emulsion from the tanker and cement-water slurry from the slurry mixer. The single machine milled the existing road, mixed the lime and cement-water slurry with the milled material. A grader was then used to profile the treated material. Figure 16-10 and 16-11 show the grader and the completed base course, respectively.

### **Single Pass Equipment Train**

The reader should refer to section on single pass equipment train in chapter 13.

### **Recycling Additives**

To improve the mechanical property of recycled base, liquid additives such as asphalt products are used as recycling agents in cold recycling. These include emulsified asphalts (either slow or medium setting), cutback asphalts, and emulsified versions of commercial recycling agents. Water is also added initially sometimes to help in the dispersion of the asphalt modifier during the mixing operations. A small percentage of portland cement may also be added to emulsified asphalts to help stabilize the recycled mix and reduce curing time.

The choice of stabilizing agent depends on several factors including the composition of the existing structure, the type of subgrade soil, and the recycling objective. If the recycled base material is mixed with untreated subgrade soil, then additives required for soil stabilization are used. Some of the commonly used recycling agents are:<sup>(11)</sup>

1. Asphalt emulsion.
2. Portland cement.
3. Lime.

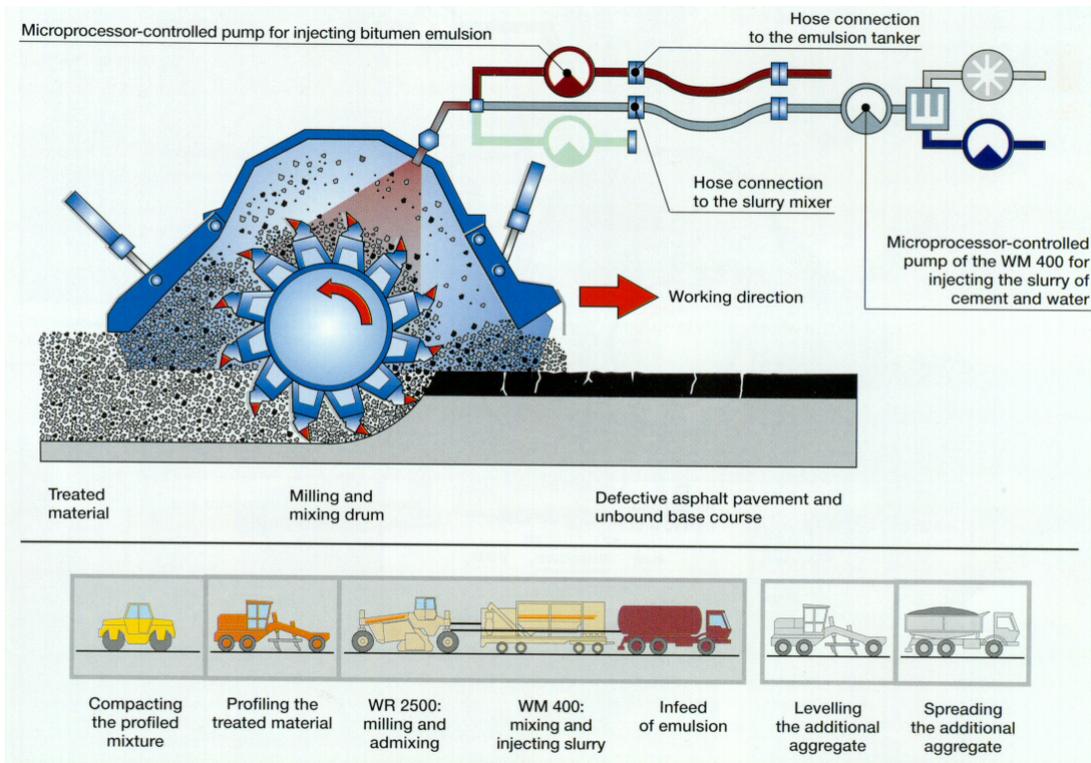


Figure 16-8. Schematic of single machine (Wirtgen America Inc.).



Figure 16-9. Single machine.



Figure 16-10. Grader.



Figure 16-11. Completed base course.

4. Fly ash.
5. Calcium chloride.
6. Foamed asphalt.

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

**Portland cement:** This additive is used to increase compressive strengths of bases. When cement, soil and water are combined, a cementitious bond between the soil particles is formed immediately, and the mix continues to gain compressive strength over a long period of time. Addition of cement is best effective in granular and low plasticity base or subgrade.

**Lime:** Lime is used as an additive to mitigate the effect of reactive clay in base materials. Lime reduces the plasticity within days and brings down the swelling potential. It also helps in resisting water damage and increasing tensile and compressive strengths of the recycled mix.

**Fly ash:** The main reasons of using fly ash as an additive are to form cementitious bond in soil (in presence of water) and increase impermeability and strength of the recycled mix. Fly ash is generally spread by a mechanical spreader and then blended with a reclaiming machine in a second pass.

**Calcium chloride:** Calcium chloride is used to lower the freezing point of reclaimed base material and thus helps against freeze and thaw problems. Load-bearing capacity of base can also be improved by the addition of calcium chloride. Liquid calcium chloride can be added in three steps: primary application, blending, and secondary application to seal the shaped and compacted surface. An onboard liquid additive system or a distributor truck can be used for application of calcium chloride.

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

**Foamed asphalt:** Foamed asphalt is being used increasingly in FDR. Foaming facilitates better dispersion of the asphalt into the materials to be recycled. A small amount of water is sprayed into hot asphalt as it is mixed with pulverized recycled pavement and soil. As the hot liquid and water mix, the liquid expands in a mini-explosion, creating a thin film of asphalt with about 10 times more coating potential. In another system, instead of adding water to the asphalt during mixing, foamed asphalt from a separate foaming chamber is added directly to the pulverized road material.

## Curing, Compaction, and Application of Wearing Surface

Curing or aeration of the mix is required to reduce the water and volatile content of the recycled mix. The material can be placed in a windrow after mixing, after which it can be leveled to proper cross slope with a motor grader. The motor grader can also be used to aerate the mix by blading the mix back and forth across the roadway. This aeration process helps in reducing the fluid content of the mix so that it becomes stable enough to support the weight of the compaction roller. The rate of volatile loss will be controlled primarily by the type of asphalt modifier, mix water content, gradation of the aggregate, wind velocity, ambient temperature, and humidity.

Compaction can be done with static steel-wheel, pneumatic-tired, and vibratory rollers, and combination of two or all three. Figure 16-12 shows a combination of steel-wheel and pneumatic-tired rollers for compacting cold recycled mixes. The factors controlling the number of passes required for compaction are properties of the mix, lift thickness, type and weight of roller, and environmental conditions.<sup>(8)</sup> Cold-recycled mixes tend to be “fluffy” and, therefore, the uncompacted thicknesses of the mat should be increased to achieve the desired compacted thickness. The moisture content is very critical to compaction of the mix. Sufficient moisture lubricates the particles and helps in compaction, whereas excess moisture causes low density and moisture retention in the sealed layers. If it is found that the mix has an unacceptably high moisture content, then compaction should be delayed or completed after mix aeration and relaying if traffic disruption is a major problem. Usually a wearing course, in the form of an HMA overlay, or a single or double surface treatment is applied over the cold-recycled asphalt base. The application of the overlay should be delayed for sufficient time if the mix needs additional curing to avoid excessive moisture retention and loss of stability. Ideally, heavy traffic should not be allowed on the surface during this delay. A light application of an asphalt modifier or an emulsion fog seal may be necessary over cold recycled base before opening to traffic to minimize raveling.

## Other Construction Considerations

The following additional guidelines are recommended specifically for full depth reclamation.<sup>(12)</sup>

1. The unbound base course must be free of 100-mm (4-in) bones and cobbles, large boulders, rocks, and tree stumps.
2. There must be limitations for gradation with the reclaiming machine. Maximum particle size typically allowed is 100 percent passing 50 mm (2 in). The percentage of material passing 75  $\mu$ m (No. 200) sieve is sometimes less than three percent. If the depth of cut is 100 mm (4 in), fines must sometimes be added. It may be extremely difficult to achieve 100 percent passing through a 25-mm (1-in) screen, which is a typical specification for materials on a project using calcium chloride as an additive.

Other important elements which should be monitored in a full depth reclamation process are summarized as follows:<sup>(11)</sup>

1. Method of Cut: The existing pavement structure can be cut in either of the two ways:  
(a) the machine is lined up along one edge of work area. With the machine stopped, the rotor is lowered and the pavement is ground from the surface to the base until the depth of cut is reached. This method can cause accelerated tool wear and the rear of the machine can experience some bouncing when cutting through thick dense



Figure 16-12. Rollers used for compaction of cold recycled mixes.

- material; (b) the machine can be positioned laterally along the work area with the rotor over an unpaved surface. The rotor is lowered to the depth of cut through softer material, and then the machine is driven across the width of the area. This way, a neat 90° joint can be achieved at the start. This method reduces tooth wearing and lowering of the machine while cutting.
2. **Depth of Cut:** The depth of the cut should be a minimum of 25 mm (1 in) below the full depth of the paved layer to provide relief to the rotor tools. If water is not added when pulverizing, then the cutting of some underlying material is required to have moisture for tool cooling and reduction of wear. If there is unsuitable material directly below the asphalt layer, the rotor may be kept even with the bottom of the asphalt layer.
  3. **Width of Cut:** The width of the cut can be limited to the width of the pavement. However, an existing pavement can also be widened by reclaiming the shoulders on each side of the driving lanes. There are some important considerations if a widening is planned. The shoulder material properties must be considered when selecting a recycling agent or stabilizing agent or virgin materials for modification of engineering properties. Next, the total square meter (or square yardage) of the project (including the shoulders) should be considered for application of additives. The total width of the pavement to be reclaimed should be compared to the width of the rotor (of the cutting machine) before planning the number and location of passes required for the cut. Normally, if the pavement is less than 7.3 m (24 ft) in width, the total width can be processed by three passes. If the pavement width is greater than 7.3 m (24 ft), one half of the pavement is typically closed to traffic and processed for the length of the

- project. The other half remains open to the traffic. Next, the other half is processed, and finally the full length and width of the base is paved. Care should be taken to remove the contaminants (such as vegetation) from the shoulder materials before blending them into the recycled mix.
4. Gradation: The position of the discharging door from the mixing chamber in the reclaiming machine should be so adjusted as to avoid generation of excessive amounts of fines.
  5. Rotor Speed: The speed of the rotor used for pulverizing asphalt and base materials should be controlled to produce the RAP material with proper aggregate size. Higher the rotor speed, finer is the mixture.
  6. Machine Speed: Generally, the slower the machine speed, the finer is the gradation. Hence the speed should be controlled so as to produce required aggregate size in the RAP material.
  7. Ambient Temperature: Properties of HMA layers are greatly affected by the ambient temperatures. A high ambient temperature ( $> 32^{\circ}\text{C}$ ,  $90^{\circ}\text{F}$ ) increases the chance of breaking off large chunks (“slabbing”) in front of the cutting machine. The machine speed should be decreased and the discharge door opening from the mixing chamber should be reduced for effective processing of larger chunks of HMA.

## SUMMARY

Full depth reclamation is a process in which all of the asphalt pavement section and a predetermined amount of underlying materials are treated with recycling agents to produce a stabilized base course. Asphalt emulsions and/or chemical agents like fly ash or portland cement are added as recycling agents. The advantages of this method include improvement of pavement structure, restoration of desired profile, and elimination of cracks. The process can be accomplished without changing the geometry of the pavement or shoulder reconstruction. The main steps include pulverization, introduction of additive, shaping of the mixed material, compaction, and application of wearing or surface course. Sizing and mixing operations can be achieved in four different ways—multi-step sequence, two-step sequence, single machine, and the single-pass equipment train. In the multiple-step sequence different machines are involved in the different phases of operation. These include motor grader for initial scarifying, sheep foot roller for size reduction, and blade mixer for mixing operations. Although readily available equipment can be used in this method, there are several disadvantages including lack of depth control, limitation of operating width, contamination of asphalt layer with base material, and traffic control problems. In the two-step sequence, the breaking and sizing operations are combined with a cold milling machine and the mixing is done with a soil stabilization mixing equipment. This method needs trained personnel and specialized equipment, but has a high production capacity. The single machine combines the breaking, sizing, and mixing operations with a single specialized equipment. The advantage is high production rate, but the drawbacks are aggregate oversize, depth limitation, and need for specialized equipment. A single pass equipment train consists of a set of equipment for breaking, sizing, mixing and laydown operations. The material from a cold milling machine is screened and sized in a portable crusher and delivered to the pugmill of a traveling mixer. The mix is then windrowed or deposited on the hopper of a laydown machine. This method has a high production rate, produces no oversize material, and allows partial removal of asphalt layer. However, the method needs specialized equipment. The recycling agents, in the form of emulsified asphalt, cutback asphalt, and/or stabilizing agents such as portland cement, lime, fly ash

and calcium chloride, are added to the mix with soil stabilization equipment. Proper aeration of the mix is required before compaction to reduce the water and volatile content of the recycled mix. A motor grader can be used to level and aerate the mix by blading back and forth across the roadway. Finally, the mix can be compacted with a steel wheel, pneumatic-tired or vibratory roller, or combinations of two or all three.

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