Using Cement to Reclaim Asphalt Pavements

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ABSTRACT

The rehabilitation of old asphalt pavements is often an expensive process, especially if the pavement has base or subgrade problems and a simple overlay will not result in a long-term solution. This is often the case with low-volume roads, where minimum pavement structures can carry heavy traffic and experience serious pavement deterioration.

A procedure is available, called Full Depth Reclamation (FDR), which allows old deteriorated asphalt pavements to be recycled and stabilized with an additive, creating a new base that will provide an excellent foundation for long-term pavement performance. The principal stabilizing additives in use today for FDR are cement, asphalt emulsion, foamed asphalt, and lime/fly-ash. This paper will briefly discuss the differences in how the stabilizing additives work, and present in detail the specific use of cement in the FDR process.

The concept of recycling existing pavement materials is especially attractive in locations where quality aggregates may not be readily available. Instead of using new aggregate sources, the aggregates from the old pavement can be recycled, and with the addition of cement the materials will form a much stronger base to improve the pavement foundation.

Cost savings and environmental benefits result from use of existing pavement materials, reduced hauling associated with removing old materials and placing new materials, and from the longer expected life of a pavement with a cement-stabilized base.

The paper will include the engineering and construction steps involved in designing and building a reclamation project, with examples of successful projects in northern climates.

INTRODUCTION

When asphalt pavements fail, determining the best rehabilitation procedure can be difficult. A simple asphalt overlay or a “mill and fill” approach can improve the appearance of the pavement surface, but may do little to correct the underlying problems that caused the failure in the first place. Within a short period of time the problems will likely reappear. Long-term solutions to failed asphalt pavements include a thick structural overlay or complete removal and replacement of the existing base and asphalt surface. Both methods can be extremely expensive and wasteful of virgin aggregates.

A third choice, recycling the failed asphalt pavement through a process called “full-depth reclamation” (FDR) can provide the benefits of reconstruction without the substantial costs and environmental concerns. This procedure pulverizes the existing asphalt and blends it with underlying base, subbase, and/or subgrade materials, which are mixed with a stabilizing additive and compacted to provide a new stabilized base. A new surface is then applied, which completes the FDR process, providing a new roadway structure using recycled materials from the failed pavement. Through stabilization, the new base will be more uniform, stronger, and provide better long-term performance than the original pavement.

In the selection of a stabilizing additive, factors that must be considered are the type of materials to be stabilized, the purpose for which the stabilized layer will be used, the type of improvement desired, the required strength and durability of the stabilized layer, and the economic and environmental impacts. Some of the more commonly used stabilizers include portland cement, emulsion, expanded (foamed) asphalt, and lime/fly ash. All of these stabilizers are effective at bonding particles together, reducing permeability, and improving compaction.

There are cases where two or more stabilizers can be used together to improve the existing roadway materials. For example, it is common to add small amounts of portland cement to bituminous stabilizers (emulsion and expanded asphalt) in order to provide increased strength and to greatly reduce curing times. A comparison of flexible pavement rehabilitation strategies is shown in Table 1.

The cost advantages of recycling materials from the original pavement are obvious; however, there are environmental advantages that are important to the FDR process:

- Conservation of aggregates that must be quarried and transported to the site
- Conservation of land areas that would be used to dispose of the asphalt and base materials from the failed pavement
- Reduced air pollution, traffic congestion, and damage of nearby roadways resulting from hauling new materials to the site, and disposal of old materials

FDR is most appropriate under the following conditions:

- The pavement is seriously damaged and cannot be rehabilitated with simple resurfacing.
- The existing pavement distress indicates that the problem likely exists in the base or subgrade.
- The existing pavement distress requires full-depth patching over more than 15%-20% of the surface area.
- The pavement structure is inadequate for the current or future traffic.

An engineer can evaluate the reasons for pavement failure by observing the types of distress that are visible. For example, alligator cracking, deep depressions, or soil stains on the surface are all signs of base or subgrade problems in the pavement structure (Figure 1). Although patching is often necessary to keep a road serviceable, it can be expensive. In fact, once the area of full-depth patching exceeds 15%-20%, simple math proves it less expensive to use FDR than to perform the patching. Of course, the final product achieved with FDR is far superior to a road that is patched.

Often the traffic patterns on a road will change over the years. This sometimes results in roads that were originally constructed for light traffic but are now significantly under-designed for existing and future traffic loads. When this happens, often a road is "built-up" by increasing the thickness of the existing pavement structure. However, increasing the pavement thickness also requires building up and extending the shoulders, since a reasonable shoulder slope needs to be maintained for safety. This can require significantly more right-of-way. An alternative exists with FDR, where the pavement can be strengthened by "building the pavement down" (Figure 2). Through the FDR process the road is strengthened without the requirement of more right-of-way.

Because the pulverized asphalt from the existing pavement (called "reclaimed asphalt pavement," or RAP) is blended with the underlying base materials, the thickness of reclaimed asphalt cannot exceed the depth of reclamation for an extended length (short sections of full-depth asphalt, like a patch, are allowed). If a long section of thick asphalt is selected for reclamation, the asphalt layer can be partially milled and the RAP stockpiled for future use. The remaining asphalt in the old pavement is then reclaimed and blended with the base.

Another consideration when evaluating FDR is the existence of large rocks (larger than 100 mm in diameter) in the base or subgrade. If this material is within the depth of reclamation, the costs of reclaiming may be high because the contractor must take into consideration the slower and more difficult construction that is posed by the rocks.

DESIGN

After a road is selected as a candidate for FDR, a field evaluation should be performed to determine what materials make up the current pavement structure. The principal reason for the field evaluation is to determine: 1) the thickness of the pavement layers, and 2) the materials in each layer that will be blended for the reclaimed base.

In many cases, little will be known about the materials in the existing pavement and the thickness of the existing layers. The best way to determine these will be to sample the roadway. How frequently the samples should be taken depends on how variable the existing pavement is. Roadways are sampled in a range from 100 to 500 meters depending on the existing pavement conditions. Obviously, a roadway with constantly changing materials should be sampled more frequently than one with more uniform materials. Sampling can be done using a coring rig or a jackhammer for the asphalt and an auger or post-hole digger for the base and subgrade.

At each location the thickness of the asphalt layer should be determined. If a core is taken it can be visually examined to see the condition of the asphalt and the size of the aggregate. Digging below the asphalt with an auger or post-hole digger will allow sampling of the base and subgrade materials. The thickness of the base layer and the type of aggregate should be noted. Also, the depth to subgrade and type of subgrade material should be recorded. From a representative location, a sample of road materials should be taken back to the laboratory to perform a mix design. If the materials are relatively consistent along the project, only one location needs to be used to collect the laboratory sample. If a significant difference occurs in the materials along the project, then a second mix design may be necessary.

The easiest way to obtain a laboratory sample is to dig a small “test pit.” For example, a 300 x 300 x 300 mm excavation will provide the materials necessary for the mix design, and when exposed will provide a good “picture” of what the individual layers look like. Normally about 45 kg of material is sufficient (this can be carried in two 19-liter buckets). It is advantageous if the asphalt, base, and subgrade materials can be kept separate, allowing for different blending ratios in the lab. For example, if the existing pavement is 75 mm of asphalt and 75 mm of base, in the laboratory it would be possible to make a 50:50 blend of asphalt and base (for a 150 mm stabilized base), or a 33:33:33 blend of asphalt, base, and subgrade (for a 225 mm stabilized base).

During the field evaluation is an excellent time to note drainage problems, locations where culverts or utility crossings are required, any recommendations to change grade or cross-slope, or locations where widening is desired. Since the roadway will be reconstructed from the base up, it is the best time to make desired permanent changes.

The thickness design for a reclaimed pavement is similar to that for a new pavement structure, since the pavement is being rebuilt from the subgrade up. In most design procedures an engineer has the option of selecting a “cement-treated base” (CTB) for the pavement structure. A FDR pavement is designed the same way as a CTB pavement. The American Association of State Highway and Transportation Officials (AASHTO) procedure for pavement design, for example, uses a Structural Layer Coefficient to model base materials. Typical layer coefficients used in the AASHTO procedure range from 0.12 to 0.30 (the Portland Cement Association (PCA) recommends using a conservative value of 0.20 for properly constructed FDR bases). Thickness design procedures that follow a more mechanistic-empirical process can also be used [1]. The new cement-stabilized base from the FDR process will normally be between 150 mm and 300 mm in depth. Any depth of reclaimed base that is more than 300 mm will be difficult to compact in one lift and is not recommended.

The ability of a pavement base to carry loads depends on the strength of the base material and the depth of the base layer. A thin, but strong base can theoretically carry the same load as a thick, but weaker base. However, the thin, strong base should be avoided because it can become brittle and fracture, resulting in reflection cracks in the pavement surface. When selecting thicknesses for reclaimed pavements, a thicker base with less strength should be preferred. Today's more powerful in-place pulverizing equipment has made the job of obtaining thicker mixed-in-place layers much easier and more reliable compared with equipment used years ago.

Designing the proper amount of water and cement for the stabilized base is not only important to obtain a good final product it also provides important information for quality control during construction. Publications exist that provide information on testing procedures for determining the appropriate cement content, water content and compaction requirements for cement-stabilized materials [2]. Research has shown that cement-stabilized materials have better strength and performance when they are well compacted, so determining compaction density is fundamental to the design procedure.

Compaction density is determined through the ASTM International (ASTM) Standard Test Method for Moisture-Density Relations of Soil-Cement Mixtures (ASTM D558). The test procedure uses the standard compaction effort similar to ASTM D698 (Standard Proctor Test) for soils. The ASTM D558 test method is a common (as well as inexpensive) procedure for most construction testing labs. The test can be performed in either the laboratory or the field, and determines the maximum dry density (unit weight) for the FDR mix, and the influence of moisture content on obtaining that density. Figure 3 shows a typical compaction curve from the ASTM D558 test method. If the mix is too dry, there is not enough moisture available to lubricate the particles into a denser formation. If the mix is too wet, the excess moisture pushes the particles apart. The moisture content where maximum density is selected for mix design and field quality control is called the "optimum moisture content."

The amount of water in the mix is called the water content, and is defined as the weight of water in the mix (expressed as a percentage of the dry material).

$$\text{water content, } w\ (\%) = \frac{\text{weight of water in mix}}{\text{weight of oven-dry material}} \times 100$$

The amount of cement in the mix is expressed similarly:

$$\text{cement content, } c\ (\%) = \frac{\text{weight of cement in mix}}{\text{weight of oven-dry material}} \times 100$$

The amount of water and cement required in the mix will depend upon the project specified strength and gradation of the final blend obtained from pulverizing the asphalt during construction and mixing it with the base material. Typical specifications for pulverizing call for a minimum of 100% passing the 75 mm sieve, 95% passing the 50 mm sieve, and 55% passing the 4.75 mm sieve. If the blend contains more fine-grained soil, then more cement and water will be required because of the larger surface area of the finer particles.

The next step is to conduct a moisture-density test to determine the moisture content for molding the FDR specimens for compressive strength testing. Since the exact cement content is not known at this stage of the design, an assumed cement content can be chosen in conducting the test. Cement contents within a range of one or two percent will not significantly influence the results. However, once the exact cement content is established, a moisture-density test should be conducted with the established cement content in order to determine the control factors for field construction.

Using the optimum moisture content from the initial moisture-density test, a series of FDR specimens are prepared at different cement contents to determine compressive strength. Typically three cement contents are chosen (for example, 3%, 5%, and 7%). It is recommended that a minimum of two specimens be prepared for each cement content. These specimens are moist-cured for 7 days, and then tested for unconfined compressive strength according to ASTM Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders (ASTM D1633). This will give a range of strength results in which to determine the required cement content.

The stabilized base must be strong enough to provide adequate pavement support for the current and future traffic loading conditions. In addition, the stabilized base needs to remain hard and durable and be able to resist the volume changes or hydraulic pressures caused by freezing-and-thawing and moisture changes that could gradually break down the cementitious bonds.

In general, a cement content that will provide a 7-day unconfined compressive strength between 2.1 MPa and 2.8 MPa is satisfactory for most FDR applications. Higher strengths may be required if it is determined that the base materials are moisture sensitive, or that special conditions exist that warrant more strength. The main reason for limiting the strength is to keep the cement-stabilized base from becoming too brittle. Experience has shown that high strengths can cause additional cracks to reflect through the pavement surface. The objective is to have a “balanced design,” where enough cement is used so that the resulting stabilized base is strong, durable, and relatively impermeable, but not so strong that it results in other types of distress in the pavement.

In some cases FDR is the preferred solution, but the existing asphalt and base layers do not provide the desired amount of aggregate for the new base. This can happen when the original pavement structure was under-designed, or traffic conditions have changed over the years, and a substantially heavier pavement is required. In this situation an “aggregate adjustment” can be made, where additional aggregate is placed on the pavement surface in a thin lift, and is then blended into the base during the reclamation process.

A new test procedure that shows a great deal of promise for future implementation is the Tube Suction Test (TST) [3]. This test helps to identify base materials that may be particularly sensitive to moisture degradation in the field, and to determine the correct amount of cement to use for stabilization. The concept behind the TST is to measure the movement of water in a sample of cement-stabilized material. The test results can be evaluated to make sure that enough cement is used to “choke off” the permeability and capillarity of the specimen. PCA currently recommends the use of the TST when working with materials that may be moisture sensitive, or when the presence of water may be especially detrimental (such as in areas with deep frost penetration).

CONSTRUCTION

The construction process for FDR is straightforward. Typical equipment requirements include a pulverizer/mixer, grader, cement spreader, water truck, and a roller. The process begins by pulverizing the existing asphalt pavement (Figures 4 and 5). As discussed earlier, the depth of pulverizing should be more than the thickness of the existing asphalt. Modern equipment can pulverize to depths exceeding 450 mm, but the difficulty lies with getting compaction deeper than 300 mm. If the depth of pulverization exceeds 300 mm, then the material should be windrowed and compacted in two lifts after treatment.

Pulverization can occur safely in urban areas with curb and gutter, manholes, and valve covers. The manholes, valve covers, and other buried obstructions are removed below the depth of the pulverization. Wooden or steel plates are used to cover and protect the structures during the processing operation. More than one pass of the pulverizing equipment may be necessary to achieve the required gradation.

Once the existing roadway has been pulverized and blended together, the material is graded to the desired elevation and shape (Figure 6). When working between curb and gutter, there may be a need to remove some of the pulverized material and haul it away in order to leave room for the pavement surface layer.

When the reclaimed road is being graded, it is an ideal time to make improvements to the road crown, grade, drainage, and superelevation, because after stabilization the improvements will be permanent. It is also an excellent time to perform road widening. Stabilizing the entire roadway creates uniformity of the pavement base that greatly reduces maintenance compared to roads that are widened without being reclaimed. Often following grading and shaping, the pulverized material will be compacted to accommodate traffic during construction and improve uniformity for subsequent cement placement and mixing operations.

Cement is usually spread in a controlled manner by spreader trucks that are designed for this operation. Placing the cement in an uncontrolled manner by blowing under pressure should be avoided. Cement is most commonly applied dry (Figure 7), but can also be applied in a slurry form (Figure 8). Most specifications call for the application of cement in terms of weight per area (e.g., kilograms of cement per square meter). The most important time for dust control is when cement impacts the ground. Special enclosures can be used to minimize the amount of dust when cement is applied. Except for very windy days, dust should not be a problem once the cement is on the ground. With a slurry application, it is important that the slurry be dispersed uniformly over the placement area so that it will not pool or run off in any manner.

Mixing is performed by the reclaimer/mixer, either by injecting the proper amount of moisture into the mixing chamber (Figure 9), or by placing water on the ground with a water truck in a separate operation. In either case, obtaining the correct amount of moisture is very important in achieving the target compaction.

After the materials are well mixed, it is time for compaction and final grading (Figure 10). Smooth-wheeled vibrating rollers or tamping rollers can be used to provide initial compaction, with smooth-wheeled or pneumatic-tire rollers used to complete the operation. Once the cement is mixed with water and the pulverized base material, the maximum time allowed for compaction is 2 hours.

Proper curing is very important to the quality of the final product. If the base is allowed to dry, it will develop cracks, and the continued gain in strength over time will be compromised. The CTB must be kept moist a minimum of 7 days following compaction. Proper curing can be achieved by continuous water spraying or application of an approved sealing compound or membrane. If the road will have an asphalt surface, a bituminous prime-coat can be applied at any time, as this acts as a curing membrane.

The CTB that results from the FDR process can have any type of pavement surfacing (e.g., chip seal surface treatment, hot mixed asphalt (HMA), or concrete). The surfacing can be applied as soon as the CTB is stable (does not rut or shove) under construction traffic. The time required for this can range from 4 to 48 hours. Traffic can be placed on the CTB in the same time frame, as long as repeated applications of heavy trucks are not involved. In many cases with low-volume roads, traffic is allowed to run on the compacted base until the project is ready for surfacing. For conditions where heavy truck traffic is involved, up to 7 days may be required to make sure the base has gained sufficient strength for a high volume of heavy trucks. Field quality control procedures are similar to those used for standard CTB [4].

The FDR process can be performed under traffic. With low-volume roads, traffic is usually allowed on one side of the road while construction occurs on the other. Traffic is controlled with flagmen. With some projects, vehicles are allowed on the finished CTB prior to surfacing. On other projects, traffic will not return to the lane until surfacing is finished. For projects with higher traffic volumes, a surface treatment over the new CTB acts as an excellent curing membrane and allows traffic to travel easily until the roadway is ready for surfacing.

Cement-treated materials will shrink naturally while curing. With properly designed pavements, and good construction procedures, the resulting cracks in the base will not significantly affect pavement performance. In some cases larger cracks in the base layer can result in stress concentrations, and the cracks may reflect from the base into the surface [5]. With the exception of excessively large cracks, this does not normally affect pavement roughness, but may influence the overall appearance of the pavement.

Usually proper construction procedures, crack minimization strategies, and maintenance sealing, if necessary, can eliminate requirements for significant maintenance due to reflective cracking. Newer techniques, such as micro-cracking or using a stress absorbing inter-layer, have been very successful [6]. A well designed and properly maintained CTB will normally outlast several asphalt overlays, providing decades of low maintenance service.

PROJECT PROFILES

Perhaps the biggest advantage of using FDR with cement is the versatility that it offers in terms of its use in various applications as follows:

Port Facility, Seattle, Washington [7] – On average, 51700 metric tons of cargo is pushed through the Port of Seattle's Terminal 115 each month. Located just south of downtown Seattle, Washington, the terminal is occupied by Northland Services Incorporated, the port's fourth-largest tenant. The busy yard takes a lot of pounding, so when rehabilitation became necessary, special consideration was given to the available alternatives before deciding on a paving and pavement foundation method. FDR proved to be the foundation method of choice, as it provided greater strength and durability than most of the other pavement alternatives.

At Terminal 115, heavy equipment had destroyed the bituminous pavement surface and caused foundation deterioration. FDR was found to be the most cost-efficient solution, especially when working through Seattle's naturally wet environment. A 14 hectare FDR trial repaving project took place in March and April of 2005. During the six weeks of construction, 200 mm of rain fell in the Seattle area. Because of Seattle's heavy precipitation, it is important that marine terminals carrying heavy loads drain properly and resist pavement deflection. For this project, a properly designed FDR pavement was selected that could distribute large wheel loads to weak subgrade soils, maintaining a stable platform for many years.

A section of the existing asphalt surfacing, stone base and subgrade soils was pulverized and then blended together. Samples of this material were taken to a local materials laboratory where their maximum dry density and optimum moisture content were determined. Test specimens at 8-, 10-, and 12 percent portland cement by dry weight of this material were prepared, cured and tested for unconfined compressive strength. This laboratory testing showed that 9 percent cement, incorporated into the pulverized and blended material, produced a consolidated base with a maximum dry density of 2315 kilograms per cubic meter at 9 percent moisture, exceeding the three-day design strength requirement of 4.5 MPa.

Pavement design engineers recommended the use of 400 mm of FDR covered with 150 mm of new asphalt surfacing. M & M Road Recycle Incorporated of Redmond, Washington, performed the pulverization and incorporation of cement, while SCI Infrastructure, LLC of Pacific, Washington, completed the compaction and grading. An initial trial area used approximately 1180 metric tons of cement, including some for wet weather modification of the subgrade soils. Because all design strength requirements were met or exceeded, an additional 6 hectare site was proposed for rehabilitation using FDR and is anticipated to use approximately 5440 metric tons of cement for FDR, including allowance for adverse weather construction.

In anticipation of wet weather, additional laboratory testing was conducted to ensure proper strength with increased cement content and higher soil moisture. This effort proved valuable during the spring of 2005. Testing determined that adding cement controlled the excess moisture and increased foundation strength, thereby allowing construction to continue during the adverse weather conditions. Exposing small areas to rainy weather prior to constructing the FDR helped to control foundation saturation and optimized cement utilization.

Minimal tenant disruption was essential. FDR saved both time and money. It solidified and stabilized the pulverized asphalt surfacing, stone base and subgrade soils, and eliminated the need to export unusable materials. A reconstruction process that would have taken months was reduced to mere weeks, and the tenant resumed a new, efficient operation quickly. By phasing and pre-staging construction, only small portions of the yard were removed from the tenant's operation at any given time (Figure 11).

One key to success at Terminal 115 was full-time inspection and ongoing laboratory analysis. Combining the laboratory results from previous years, including in-place testing and preparing additional laboratory specimens throughout construction, proved much larger areas could be reconstructed than other options would allow. There can be little doubt that FDR accelerated this project and reduced the downtime of the Terminal. The Port subsequently was able to add two hectares to the project due to cost savings.

County Roads, Spokane County, Washington [8] – Spokane County in Northeastern Washington State has been using the FDR with cement process to full benefit. The county first used FDR with cement in the late 1990s, and is currently maintaining a steady program of 8-10 kilometers of FDR construction per year. The county's reclamation program allows them to gradually improve the quality of their road network at a very reasonable cost.

Being located in the foothills of the Rocky Mountains, and only 160 kilometers from the Canadian border, Spokane County experiences the type of weather that can cause serious pavement damage. In spring, warmer weather brings melting conditions that can cause serious road deterioration. This causes truck restrictions on rural roads that are not built to handle heavy loads during the spring conditions. The road restrictions cause interruptions for commerce and industry that can affect the local economy.

The FDR process results in a reconstructed CTB, which greatly increases the strength of the pavement structure, and does not weaken during seasonal changes. For example, in areas with frost conditions, the stabilized base tends to raise and lower as a platform, reducing the effects of frost heaves. Spokane County has not noticed any frost problems with roads that have been reconstructed with the FDR process. In fact, they are programming the FDR work in order to build routes of cement stabilized all-weather roads that will not have to undergo spring load restrictions.

The county developed a very effective pavement design that incorporates 200-250 mm of CTB. The typical design for the base is 2.8 MPa compressive strength in 7 days, usually requiring about 4% cement. In situations where the soil conditions are poor, the county prefers to keep the strength of the base unchanged, and increase the thickness from 200-250 mm.

To complete the pavement structure, a 25-75 mm layer of crushed stone is used on top of the base for leveling and as a mat for the surface, which consists of a "triple-shot" bituminous surface treatment. This surface treatment is constructed by placing three light bituminous surface treatments. The leveling course also acts as an effective "stress relief" layer, to prevent reflective cracks in the pavement surface. The county is currently evaluating the thickness of the leveling course, and recently built some sections with 25 mm, 50 mm, and 75 mm thicknesses and will monitor their performance. They are also considering the use of a paved asphalt concrete surface (instead of the triple surface treatment) for roads that carry high levels of traffic.

Conventional design methods, such as using an additional 200-250 mm of stone base, requires changing the road cross-section, because the additional road elevation must be accompanied by building up the shoulder slope. This can be expensive because of the additional material and construction required. Using FDR provides the capability of "building the pavement down"; strengthening the existing pavement using the materials already there, and eliminating the need for changing the road elevation.

On all of their FDR projects, Spokane County has been involved as a partner in the construction process, thereby reducing costs and having more control over the final product. The county will typically contract out the pulverization of the existing pavement, placement of cement, and mixing of the base materials, and will complete the grading, compaction, and surfacing with county forces (Figure 12). The county does a thorough evaluation of the costs of pavement design alternatives, and feels that the substantial increase in pavement strength from FDR with cement will lead to much better long-term pavement performance.

Downtown Streets, Reno, Nevada [9] – Recently, the Regional Transportation Commission (RTC) in Reno, Nevada, which plans and implements the ground transportation program in Washoe County, completed the rehabilitation of three downtown streets using FDR with portland cement. Through the use of a Pavement Condition Index system it was discovered that portions of three streets were experiencing base failures and in need of immediate repair.

Issues considered while determining which rehabilitation strategy would work best included project-specific limitations such as the maintaining of curb lip elevations, the presence of cobbles in the subgrade, insufficient or contaminated base, and shallow utilities. The urban setting of these streets and their associated high traffic volumes only added to the challenge. In addition, a limited budget required that the solution be one that minimized construction costs while meeting pavement structural requirements.

Lumos and Associates, a multi-disciplinary consulting firm located in Reno, Nevada, served as both the engineer and construction manager on these projects. After it was determined which structural section would be required to support projected traffic loading, rehabilitation options were evaluated, including full removal and replacement, partial removal and replacement incorporating geotextiles, thick HMA layers, and FDR using cement. FDR proved to be the winner, meeting structural criteria for the roadways while also saving time, money, and reducing construction traffic. Inn fact, FDR saved more than 50 percent over the full removal and replacement alternative.

A simple design process was followed that involved digging test pits to obtain representative samples of surface, base, and subgrade materials from the roadways; pulverizing the HMA in the lab; blending the HMA, base, and limited native materials to a representative gradation; adding cement; preparing specimens at optimum moisture and maximum dry density using the modified Proctor test; and testing them for unconfined compressive strength. Four specimens each were prepared at 2%, 4%, and 6% cement and were tested for strength after 2, 7, and 28 days. The emphasis on early strength of these specimens was due to the urban nature of the project and the fact that the roadways had to be paved and open to traffic as soon as possible. A cement content of 3.5% by dry weight of the pulverized material was found to meet the strength and durability requirements established by the RTC.

The FDR work was performed by Sierra Nevada Construction, Reno, Nevada, and started with the pulverization of the existing roadway to a depth at or slightly below the final bottom of the treatment elevation (Figure 13). Then 125 to 150 mm of pulverized material was removed to ensure that, once completed, the final surfacing course would match existing curb and gutter elevations. Dry cement was spread directly onto the pulverized materials with a cement spreading machine that produced little to no dust. The pulverized, reclaimed material was blended with the cement and, with the addition of water, was brought to optimum moisture. This material was then graded to the appropriate plan lines, grades, and cross-sections, and compacted to a minimum of 95% of the established modified Proctor density.

The RTC mandated that all the FDR roadways had to be repaved within 7 days due to events planned in the downtown core and to minimize disruption to the traveling public. Because the cement in these roadways was designed to achieve the highest balance between strength and durability, there were some concerns that shrinkage cracking might occur that could reflect back up through the newly placed HMA surfacing. In order to minimize the potential for any reflective cracking of this nature, the roadways were “microcracked.”

Microcracking is the application of several vibratory roller passes to a cement-stabilized base after a short curing stage to create a fine network of cracks. This fine cracking is intended to prevent wider, more severe cracks from forming. Each section of roadway was pulverized, blended with cement, shaped, and compacted in one day, and then moisture cured for 48 hours. The microcracking process was performed at the 2-day mark on each roadway, and all sections were paved within 12 hours of microcracking. This process allowed the roadways to be back under traffic in half the time required by the RTC-an added bonus in an urban area.

The stiff, durable cement-treated FDR base layer provided such a stable deck that it allowed the expensive HMA thicknesses to be reduced by 25 to 75 mm, decreasing asphalt quantities by as much as 30%. FDR cut construction time from eight weeks to six weeks. Reduced construction time allowed for quicker back-to-normal traffic loads and less traffic congestion due to construction barriers. Environmentally, FDR with cement also cut down on the amount of virgin natural resources needed and the amount of hauling and fuel used on the projects.

Gravel Roads, Fairfield County, South Carolina [10] – Located between Columbia, South Carolina and Charlotte, North Carolina, Fairfield County has an area of 1800 square kilometers and a population of 24,000. Budgets are tight, and the maintenance of approximately 355 kilometers of gravel surfaced county roads is an ongoing problem. Although the unpaved roads have low-volume traffic, maintenance requires frequent blading of the gravel, and the surface aggregate has to be replenished on a regular basis. In addition to the maintenance headaches, the citizens are faced with lower quality roadways, with dust and other associated problems of unpaved surfaces.

Dennis Corporation, an engineering consulting firm based in Columbia, South Carolina, was looking for a solution to help Fairfield County's Transportation Committee upgrade the road conditions in a cost conscious manner. They were familiar with the process of FDR using cement as a means of rehabilitating failed asphalt pavements. The South Carolina Department of Transportation has been using FDR with cement for over 10 years with excellent results, and the Dennis Corporation thought the same procedure could be used on the county's gravel roads.

Their plan was to upgrade the gravel roads to a bituminous surface treatment (chip seal), which would provide a smoother, safer road surface and eliminate the problems with dust and the expensive maintenance of blading and gravel replacement. The FDR process on the gravel road would make use of the existing gravel by blending it with cement and subgrade materials to a depth of 150 mm. This cement-stabilized material would make an excellent base for a triple bituminous surface treatment (or a thin asphalt surface).

In September of 2006 the county contracted with Site Prep Incorporated of Monroe, North Carolina to perform the upgrading of 14 sections of unpaved road in different locations around the county (totaling 22 kilometers). The design called for 17.9 kilograms of cement per square meter of roadway, mixed and compacted to a depth of 150 mm. The FDR process would also allow the road template to be improved by establishing road crown and shoulders, which would improve drainage and road safety.

Construction was completed at the rate of 450 – 600 meters per day, with a single treatment of chip seal applied the same day (Figure 14). The initial surface treatment provided protection for the new base and an improved surface for residents to travel on during construction. After completion of each section a double chip seal was applied to complete the triple surface treatment.

The fact that the road base is cement stabilized will improve the long-term performance of the reconstructed sections, since the higher strength base can carry heavier loads and is much less susceptible to water damage than a gravel base. The county was so impressed by the process that they are planning to upgrade 25 more kilometers in their roadway improvement program for 2007. By making improvements each year, it won't take long for the county to substantially increase the quality of their road system, and make excellent use of their scarce resources by stretching those construction dollars.

REFERENCES

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5 Reflective Cracking in Cement-Stabilized Pavements, IS537, PCA, 2003
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8 FDR Provides Reliable All-Weather Roadway, PL619, PCA, 2006
9 FDR with Cement Pays Off for Downtown Streets of Reno, PL622, PCA, 2007
10 County Uses FDR with Cement to Upgrade Unpaved Roads, PL621, PCA, 2006

TABLES

Table 1 - Characteristics of Flexible Pavement Rehabilitation Strategies

Solution	Advantages	Disadvantages
Thick Structural Overlay	• Provides new pavement structure • Quick construction • Only moderate traffic disruption	• Elevation change can present problems for existing curb & gutter and overhead clearances • Large quantity of material must be imported • Old base/subgrade may still need improvement • High cost alternative
Removal and Replacement	• Provides new pavement structure • Failed base and subgrade are eliminated • Existing road profile/elevation can be maintained	• Long construction cycle requiring detours and inconvenience to local residents/businesses • Increased traffic congestion due to detours, construction traffic • Rain or snow can significantly postpone completion • Large quantity of material must be imported • Old materials must be dumped • Highest cost alternative
Recycling Surface, Base and Subgrade with Cement (Full-Depth Reclamation)	• Provides new pavement structure • Fast construction cycle • No detours • Minimal change in elevation, thus eliminating problems with curb/gutter, overhead clearances • Minimal material transported in or out • Conserves resources by recycling existing materials • Local traffic returns quickly • Rain does not affect construction schedules significantly • Provides moisture- and frost-resistant base • Least cost alternative	• May require additional effort to correct subgrade problems • Some shrinkage cracks may reflect through bituminous surface

FIGURES

Figure 1 – Example of pavement distress indicating base problems.

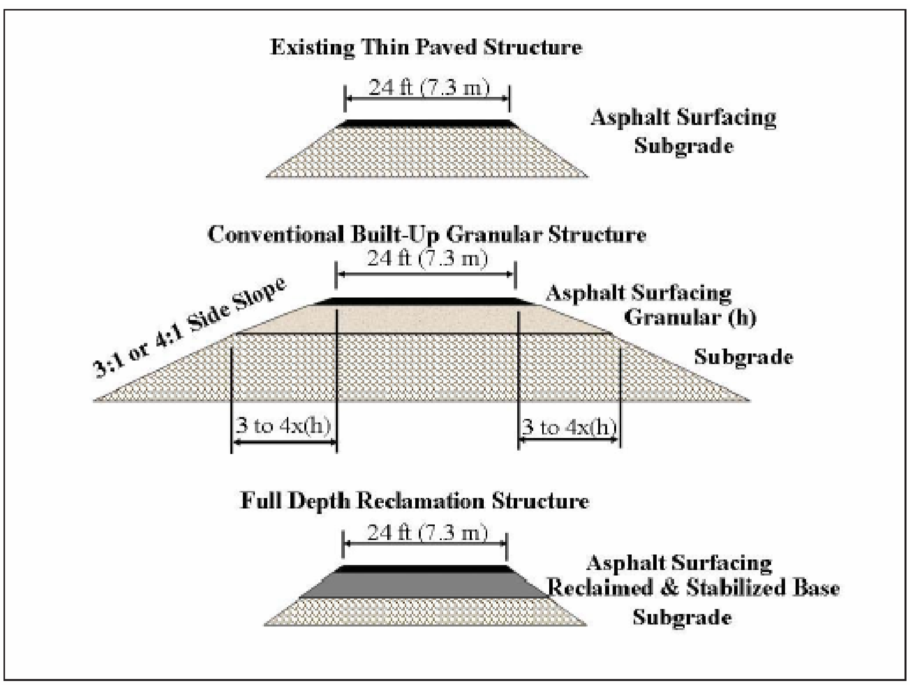

Figure 2 – Using FDR to "build the pavement down."

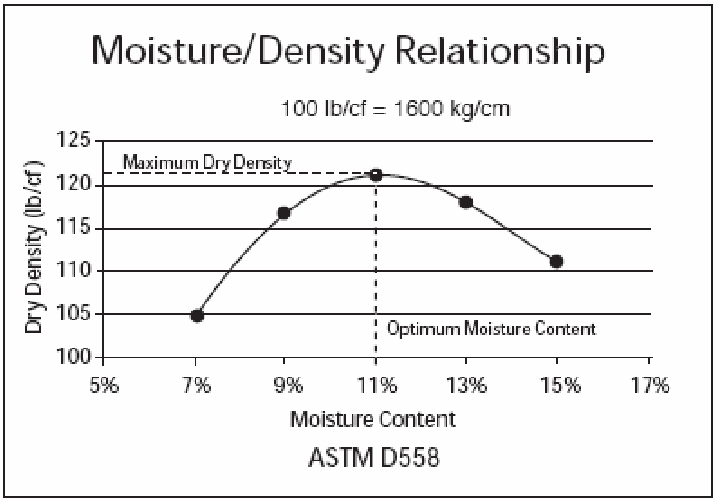

Figure 3 – Determining the Maximum Dry Density and Optimum Moisture Content.

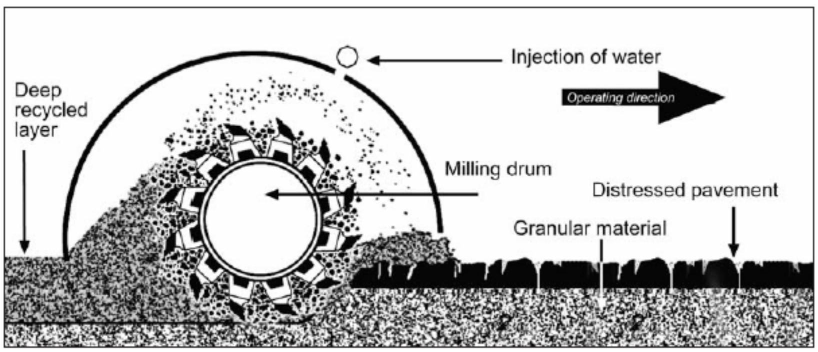

Figure 4 – Inside a reclaimer.

Figure 5 – Pulverizing a failed asphalt pavement.

Figure 6 – Grading and shaping.

Figure 7 – Placing cement dry.

Figure 8 – Placing cement in slurry form.

Figure 9 – Water being injected during mixing operation.

Figure 10 – Compaction and final grading.

Figure 11 – New pavement next to curing FDR at Terminal 115 in Seattle, Washington.

Figure 12 – Pulverizing and grading operations in Spokane County, Washington.

Figure 13 – Pulverizing failed flexible pavement in downtown Reno, Nevada.

Figure 14 – Application of bituminous surface treatment in Fairfield County, South Carolina.