PAVEMENTS

Long-Term Performance of Full-Depth Reclamation with Portland Cement: Research Synopsis

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Introduction

This publication summarizes the findings of an extensive investigation into the design, construction, testing, and long-term performance of failed flexible pavements rehabilitated through full-depth reclamation (FDR) using portland cement. Objectives of this investigation included:

- Evaluating the in-service long-term performance of roads rehabilitated using FDR with cement
- Evaluating the design protocol for field and laboratory investigation for FDR with cement pavements
- Determining what problems agencies encounter by implementing this rehabilitation technique
- Developing guidelines for successful implementation

The complete research report is available as *Full-Depth Reclamation with Portland Cement: A Study of Long-Term Performance*, by Imran M. Syed, Ph.D., Portland Cement Association (PCA) publication SR016.

Axle loads on streets and highways have increased significantly over the years, while funds for road maintenance have shrunk. Most public agencies have existing road networks comprised primarily of flexible pavements. Progressive public officials looking to save time, materials and money needed to provide a safe and efficient road network are making it their top priority to salvage these existing flexible pavements at the end of their service lives.

The FDR with cement process has been used on pavement projects for more than 20 years and rebuilds worn out asphalt pavements by recycling the existing roadway. The old asphalt and base materials are pulverized, mixed with cement and water, and compacted to produce a strong, durable base for either an asphalt or concrete surface (see Reference 1). This cost-effective technique is popular with state, county, and city highway agencies attempting to correct their deteriorating pavements and increase the pavements' structural capacity.

State and Local Agencies

The actual field performance of more than 75 projects in eight states scattered across the country were evaluated. The age distribution of these projects is shown in Figure 1. Agency personnel involved with the FDR process were contacted and interviewed about the methodology used to select candidate projects, and about the design and construction of their FDR projects. Performance-related data such as pavement inventory, functional and structural information, traffic data, material composition, amount of cement added, and construction details were collected.

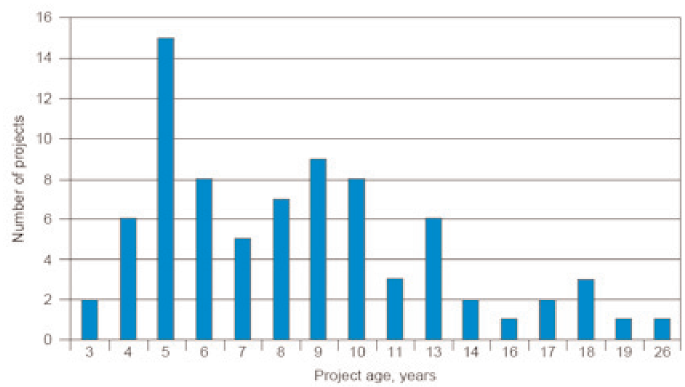

Figure 1 – Histogram showing age of projects in study.

Performance Evaluation

The performance evaluation process consisted of interviewing the agency/owner of the facility, performing visual pavement surveys, taking cores at select pavement locations, and performing strength measurements on the cores. This provided a qualitative assessment of the long-term strength and stiffness of the reclaimed bases.

"This performance evaluation clearly indicates that FDR with cement is a proven technique to extend the life of old flexible pavements in a cost-effective manner."

Detailed pavement evaluation results are presented in the full report and include those from six city agencies, three private developers, eight county agencies, and four districts within state Departments of Transportation.

Pavement Visual Surveys

Pavements rehabilitated using the FDR process underwent a visual inspection, which focused on finding evidence of pavement distress at the selected project sites – particularly distresses that may have been due to the condition of the base (such as block cracking, roughness, and deep potholes). The pavement distresses were systematically recorded to identify their type, extent and severity. From this data, a numerical composite distress index, termed the Pavement Condition Index (PCI), was calculated. The PCI values range from zero for a failed pavement to 100 for a pavement in perfect condition.

Table 1 summarizes the results of the pavement condition surveys in the study and shows that almost all of the roads rehabilitated using the FDR process are performing well. The average PCI for each agency type ranged from 88% to 97%, indicating an excellent rating.

Table 1 – Summary of pavement condition survey.

Agency	Pavement Condition Index, %			
	Min	Max	Average	Standard Deviation
City	73	100	89	6
Private Developers	95	98	97	2
County	43	100	89	10
State DOT	82	92	88	4
Overall	**43**	**100**	**89**	**8**

Most of the distresses noted during visual inspection of the pavement sections were in the asphalt layer. Any distresses caused by the base (such as minor reflective cracking) did not affect the roughness or overall road performance.

"No cases were observed where severe road distress was caused by the reclaimed cement-stabilized base."

Long-Term Strength

Representative core samples of the reclaimed base from some of the pavement sections were obtained (see Figure 2) and subjected to laboratory Unconfined Compressive Strength (UCS) measurements to determine the in-place strength of the reclaimed base after many years of performance. UCS of these samples ranged from 260 to 2,110 psi (1.8 to 14.5 MPa), with the average of all samples being 914 psi (6.3 MPa). Typically, these FDR sections were originally designed for a 7-day UCS of between 400 and 600 psi (2.8 and 4.1 MPa).

The majority of cores were tested for UCS in accordance with ASTM C 42 while others were tested to determine their seismic modulus using the free-free resonant column method developed at the University of Texas at El Paso. The primary reason for performing the seismic modulus was to obtain the resilient modulus for the reclaimed base, which will be required input for the new American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical pavement design guide.

Based on the seismic modulus testing results, the lowest UCS value of 260 psi (1.8 MPa) would roughly correspond to a stiffness of 200,000 psi (1380 MPa), which is considered excellent in terms of the reclaimed base's ability to support traffic loads and minimize the stress that is transferred to the subgrade.

Figure 2 – Extracting FDR cores for unconfined compressive strength testing.

Durability

The durability of a roadway base subjected to wetting-drying and/or freezing-thawing cycles is a critical parameter for any roadway's satisfactory performance. Durability issues are especially challenging in wet, northern climates where deeply penetrating freeze-thaw patterns can cause an unstabilized pavement base to lose strength and stiffness. Of the 79 projects that were part of the study, more than 50 were in areas with moderate to severe winter weather conditions.

Volume change and loss of strength caused by traffic loads, environmental conditions and water movement within pavement layers cause heaving roadways, posing a serious safety risk to drivers. County engineers say road heaving due to winter freeze and rutting due to spring thaw are among their biggest challenges. The FDR process has proven very successful in combating freeze-thaw challenges. The heaving has been eliminated and the engineers are pleased to report that their roads are operable in cold-weather conditions.

Overall, the FDR process has been a very positive experience for agencies in northern areas that have severe weather. The agencies have successfully provided public roads that do not heave in the winters or lose shear strength during spring thaws, allow businesses to efficiently move goods, and have enhanced road safety. The FDR process has enabled counties to build "all weather" roads (see Reference 2).

Figure 3 – FDR base provides strong, durable foundation for roadway in South Carolina.

Design

Agency officials realize the importance of design, and do their best in spite of shoestring budgets to perform a proper engineering investigation prior to design and construction of the FDR process. Most agencies tend to follow PCA recommendations (see Reference 3) while others rely on past experience when deciding on the thickness of the reclaimed base and the amount of cement to be added to the mix. FDR base thicknesses typically range from 6 to 12 inches (150 to 300 mm) depending on the materials and traffic volumes.

In most cases, samples are compacted with varying cement contents using the standard Proctor test (ASTM D 558). Following an agency's experience, the minimum cement content is based on achieving a 7-day target UCS of between 150 and 600 psi (1.0 and 4.1 MPa) with most ranging from 300 to 400 psi (2.1 to 2.8 MPa). Some agencies in cold climates check the proposed mixture for frost susceptibility by performing freeze-thaw tests as recommended in ASTM D 560.

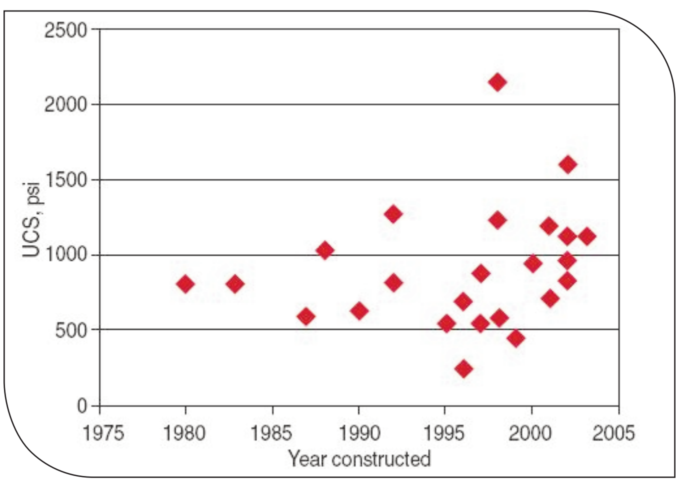

Figure 4 – Unconfined compressive strength measurements.

Agencies realize that strength and performance are not the same thing and that durability is the key issue in the design of the FDR mixtures. This study showed that the minimum cement content should be based on the mixture passing the durability test (ASTM D 559 and D 560 or the Tube Suction Test as described under Innovative Techniques).

Construction

Most agencies use equipment called a "reclaimer" to pulverize their old, distressed flexible pavements so that the maximum size of the crushed pavement is no more than 2.5 to 3.0 inches (63 to 75 mm). If thicker sections are required, some agencies add aggregate or soil base material and blend them with the pulverized pavement. Water and cement are then added in either a dry or slurry form to the pulverized material to form a stabilized mixture, which is compacted and becomes the base or subbase of the new pavement structure.

Figure 5 – FDR construction, Spokane County, WA.

While most agencies use the standard Proctor (ASTM D 558) procedure to determine compaction requirements, some now actually require the use of modified Proctor (ASTM D 1557) energy or similar in the laboratory evaluation. Whether standard or modified, the required in-place field density for all agencies is between 95% and 98% of the laboratory-measured density.

Depending on the agency, the curing of the completed FDR base and its opening to traffic varies between one-half and seven days. Some prefer to use moist curing over a period of three to seven days while others prefer the use of a bituminous coating or a curing compound that can allow the road to be opened to traffic within one-half to one day.

"The economics of the FDR with cement process has helped the highway agencies reconstruct 50% to 100% more projects than the conventional construction process."

Innovative Techniques

Some agencies use a process called "microcracking" to reduce reflection cracking (see Reference 4). This procedure uses a compaction roller on the surface of the cement-stabilized base one to two days after construction. The effect of the roller is to initiate numerous tiny microcracks in the base to absorb the shrinkage, rather than single shrinkage cracks that are wider. The tiny cracks are too small to reflect up through the asphalt surface.

Some agencies do not allow the blending of subgrade soils into the reclaimed layer because the silt and clay content of these soils can sometimes influence the shrinkage and durability characteristics of the reclaimed mix. However, because of budget constraints, other agencies are forced to cut into subgrade soils and blend them with the reclaimed pavement and base material. In these instances, agencies are obtaining enough reclaimed material to widen their roads up to 4 feet (1.2 m).

Many agencies address durability issues during the design phase by subjecting duplicate samples to UCS measurements as per ASTM D 1633. One sample will employ standard curing techniques, and the other will employ a 4-hour soak or 24- to 72-hour freeze. The soaked or frozen sample is required to retain between 75% and 85% of the strength obtained from the standard cured sample.

The Tube Suction Test (TST) is another technique to address moisture sensitivity issues (see Reference 5). Standard test specimens are placed in a 1/4-inch (6 mm) deionized water bath whose surface is monitored for ten days by measuring the dielectric constant with a probe. Samples that do not exceed the surface dielectric constant of 10 over the ten-day period correlate with samples that are likely to pass the wet-dry (ASTM D 559) and freeze-thaw (ASTM D 560) tests.

Conclusions

The FDR with cement process is a popular technique used by state, county, and city highway agencies that seek a speedy and cost-effective method to improve their roads. Agencies that use the process save between 30% and 60% over conventional reconstruction methods.

There was no evidence of structural failure in the FDR sections. The distress identified on the pavement surface was restricted to the hot-mix asphalt (HMA) overlay and was not a result of failures in the stabilized base layer. This investigation has also provided evidence that the FDR pavement sections with sealed shrinkage cracks are performing satisfactorily.

Another major benefit of the FDR with cement process is its environmental soundness. The sources of good-quality aggregate and HMA are limited and FDR conserves virgin construction materials and makes smart economic and strategic sense. Stabilizing the old HMA surface, granular base, and underlying subgrade soil with portland cement creates a solid foundation for pavements.

References

1. *Full-Depth Reclamation: Recycling Roads Saves Money and Natural Resources,* SR995, PCA, 2005
2. *FDR Provides Reliable All-Weather Roadway,* PL619, PCA, 2005
3. *Guide to Full-Depth Reclamation (FDR) with Cement,* EB234, PCA, 2005
4. *Microcracking,* LT299, PCA, 2006
5. *Evaluating the Performance of Soil-Cement and Cement-Modified Soil for Pavements: A Laboratory Investigation,* RD120, PCA, 2005

Figure 6 – Before and after photos of FDR for rediential street in Westminster, CA.

More Information

PCA offers a broad range of resources on soil-cement applications for pavements. Visit our Web site at **www.cement.org/pavements** for design and construction guidelines, technical support, and research on cement-modified soils, cement-treated base, and full-depth reclamation.

For local support, tap into the cement industry's network of regional groups covering the United States. Contact information is available at **www.cement.org/local.**

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