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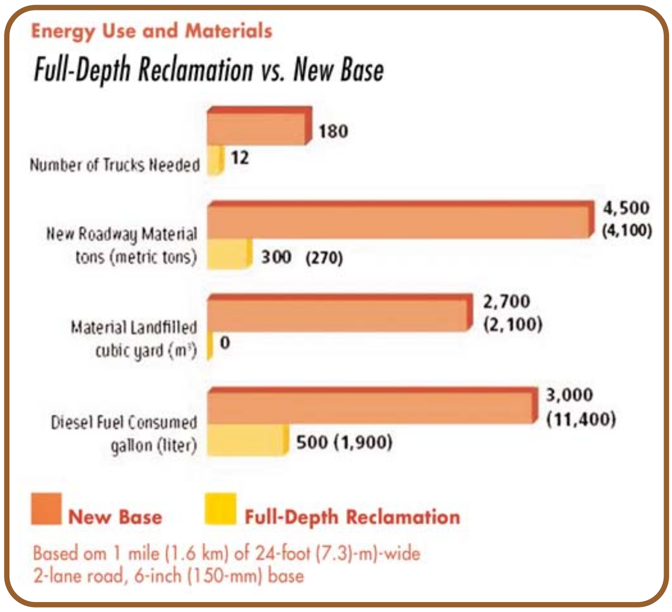
Full-Depth Reclamation with Cement

Deteriorating roads are a constant problem for cities and counties. Today engineers and public works officials are turning to a process called full-depth reclamation (FDR) with cement to economically and sustainably repair and replace damaged roads.

FDR with cement rebuilds worn out asphalt pavements by recycling the existing roadway. There is no need to haul in aggregate or haul out old material for disposal. Truck traffic is reduced, and there is little or no waste.

The recycled base is stronger, more uniform, and more moisture resistant than the original base, resulting in a long, low-maintenance life. And most important to the tight budget of a department of transportation, recycling costs are normally at least 30 to 60 percent less than the removal and replacement of the old pavement.



Saves money: FDR uses the materials from the deteriorated asphalt pavement, and, with the addition of cement, creates a new stabilized base. 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. Using recycled products can reduce the cost of the road repair by up to 60 percent, allowing for the completion of more miles.

Material conservation: Conserving virgin construction materials through recycling with cement makes smart economic and strategic sense. A century of modern growth and urbanization in America has depleted once plentiful aggregate supplies. Frequently, aggregates come either from distant quarries at great expense or from local sources offering only marginal quality. Continuing to exhaust these valuable resources to rebuild existing roads only propagates and accelerates the problem.

Recycle, rebuild: Recycling with cement makes the reconstruction of old roads a largely self-sustaining process. The original "investment" in virgin road materials becomes a one-time cost, which is renewed periodically, through cement stabilization and addition of a new, thin surface course.

Additionally, if old asphalt and base materials are not recycled, they must be disposed of or stockpiled, increasing transportation costs and utilizing valuable landfill space. In some locales, old asphalt can no longer be landfilled and must be transported to other communities, increasing costs and related traffic emissions.

Old asphalt, new foundation: Stabilizing the old asphalt surface, granular base, and underlying subgrade soil with cement creates a strong foundation for the pavement. Usually, there is little need for material to be removed or added. The old, brittle asphalt, when pulverized, becomes a "black gravel" that will bond to hydrated cement readily.

Simple and fast: The basic procedure is simple. The complete recycling process can be finished in one day, and local traffic can return almost immediately.

PCA SUSTAINABLE LEADERSHIP AWARDS

When They Said We Could Repair Our Asphalt Roads with Portland Cement, We Laughed!

Like most counties, Houston and Choctaw Counties in Alabama have their share of older asphalt roads that are failing due to age and lack of proper engineering. Additionally, skyrocketing fuel, asphalt and labor costs represent a larger share of their budgets.

Traditional road repair methods were quickly becoming a financial burden to the counties. Peeling up stretches of deteriorated asphalt, loading it onto trucks, hauling it off to dump it and hauling in new base was costing them not only money but precious time and labor.

They needed to find a better, faster, cheaper solution to their county road repairs. And, that solution needed to include longer-lasting roads

That's when county engineer, Mark Pool and assistant engineer, Barkley Kirkland, discovered full-depth reclamation (FDR) with portland cement.

These engineers were already familiar with the benefits of FDR where the road surface is blended with a portion of the base. They learned that by adding portland cement to the surface of the road before reclaiming, they could make a better, longer lasting repair.

Key to making this process economical was the purchase of an Asphalt Zipper, a portable asphalt reclaimer that mounts on the bucket of a front-end loader. The model they chose features a 4-foot cutting head and a 185 hp diesel engine.

At first, the county applied cement from bags from the back of a truck. They soon realized that they needed a faster and more accurate and efficient way for the cement application. This was resolved by using a spreader box that fits on the rear of their dump truck. It allowed them to accurately meter the amount of cement they need–usually about 1/2 inch for 6”-8” of depth.

After spreading the portland cement on the road surface, they pulverize the old asphalt with the Asphalt Zipper and mix the portland cement and asphalt with an inch or two of the base. Water is injected from a water truck through the Asphalt Zipper's onboard spray bar during the reclamation process. The road is then graded and compacted and left to cure for a day or two.

The finished road base is very solid and will continue to strengthen for years to come. A wear course of asphalt or chip seal can then be applied for a beautiful, smooth road that will last for many years.

But does this process save Houston County the time and money they were hoping for? Assistant engineer, Barkley Kirkland smiled and said, “Oh, yeah, we can get a lot more done now. What used to take us 2 days to do, we can now get done in 1/2 a day! And we get a better road.”

Garry Grantham of Choctaw County, has discovered that FDR with cement is the best way to repair their older, damaged roads, too. Once the cement has cured they have found great success simply paving the reclaimed road with chip seal instead of asphalt.

When asked why chip seal instead of an asphalt surface, Grantham answered, “After we do full-depth reclamation on the road and compact it well, the road base is often so solid that chip seal is all it needs. But the biggest reason is savings. With the high cost of asphalt, we can do more roads using chip seal. We find we save over $10,000 per mile using chip seal instead of asphalt!”

“We're saving at least 50% in material costs and doing it all in one third of the time. When you can get the same or even better results in only a couple of days compared to what would have taken us a couple of weeks. Everyone is better off.”

Grantham sums it up, “We can only put off projects so long. The work has to be done. We've got to be looking for ways to be more productive and efficient, and right now full-depth reclamation is an affordable long-term solution that really works.”

With failed asphalt and a base damaged from groundwater, Antrim Road was a good candidate for full-depth reclamation with cement.

Doing Good for the Environment Means Doing Good for the Bottom Line

Much of the recognition for upgrading infrastructure in a sustainable and environmentally responsible fashion usually goes to larger cities. However, the success of innovative road rebuilding techniques in the town of Hancock, N.H. - population 1,823 - demonstrates that even the smallest of towns can save time, money and resources while minimizing their impact on the environment.

With an elevation change of almost 400 feet from the lowest point to highest point within the town's road system and harsh New England winters wreaking havoc on roadways, Director of Public Works Kurtis J. Grassett knows all too well the challenges of keeping these roads safe and in good repair while working within limited resources.

Antrim Road, in particular, posed a problem. A 2,000-foot section of the road has seen three 100-year floods in a three-year time frame - 2005, 2006

Rebuilding Antrim Road with FDR saved Hancock, New Hampshire, $100,000 in construction costs.

and 2007. This road also has a serious groundwater problem, which has damaged the road base and complicated the rebuilding process.

"The challenge of limited resources and an abundance of springtime floods had the city of Hanover looking for rebuilding techniques that were long-lasting and cost effective. Kurt Grassett evaluated many alternatives to rebuilding this road and selected full-depth reclamation (FDR) with cement because it was the most cost effective and reliable approach," said Heather Steffek of the Road Recycling Council–New England Region.

Rebuilding Antrim Road using FDR with cement saved the town about $100,000 in 2006. Hancock taxpayers saw further financial and environmental benefit since the existing base and pavement materials, already paid for by the town in previous years, were recycled into the new stabilized base. This environmentally friendly process significantly reduced fuel consumption by reducing the need to ship in new materials. It also eliminated the need to dispose of the old pavement, saving precious landfill space.

The 2007 flood hit Antrim Road in April while there was still snow on the ground. The runoff was caught between the edge of the pavement and the snow bank, resulting in severe erosion along the edge of the pavement. The velocity of the water dug a channel about eight inches deep and one foot wide right down the edge of the road.

"Without the cement-stabilized base, I know I would have lost the pavement and roadway. It acted as a barrier to the erosion that was occurring on the shoulder," said Grassett.

Kurt Grassett is a recipient of the 2008 PCA Sustainable Leadership Awards. These awards honor public officials who utilize cement or cement-based products to achieve sustainable benefits.

The use of FDR with cement in the rebuilding of failed asphalt pavements and poorly-performing pavement provides the town of Hancock with unmatched environmental and economic benefits. "Kurt Grassett should be recognized not only for his innovation, but for his stewardship of the environmental and financial resources of the townspeople he serves," said Steffek.

Cement is applied to the pulverized road in the form of a slurry for a thorough application and dust control.

FDR Makes Economic and Environmental Sense for City of Dallas

Since 2004, the City of Dallas has been committed to a sustainability policy to make it a "greener," more environmentally friendly city. Among the many environmental issues it faced was waste management and in particular, the disposal of materials resulting from road repairs. In keeping with the City of Dallas Environmental Policy, the Department of Street Services has established innovative programs to reuse, reclaim, and recycle the materials used in its street rehabilitation, restoration, and partial reconstruction.

One of the most cost-effective, durable and sustainable methods the Department of Street Services has embraced is the use of full-depth reclamation (FDR) with cement for its street restoration program.

"This process 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," said Dan Richwine of TXI, a leading supplier of building materials such as cement and concrete. "By using the old asphalt and base material for the new road, there is no need to haul in aggregate or haul out old material for disposal, reducing the amount of fuel consumed and reducing fuel emissions in the area."

Dallas commuters and residents also benefit FDR. "We were able to get our streets back to the motoring public faster than we've done in the past," stated Gilbert Aguilar, assistant director of the City of Dallas Department of Street Services. Street rehabilitation involves the repair of failed sections of asphalt streets followed by an under seal and 2" asphalt overlay. Asphalt and base material removed from failed sections of these streets are taken to the landfill. However, 100% of the material used for the new replacement base is a blend of recycled asphalt mixed with base material, cement and water.

Partial reconstruction involves the removal and repair of failed sections of concrete streets. In this program, 100% of the concrete removed from these failed sections is taken to a concrete recycling plant.

Through these three programs the City of Dallas estimates it is recycling an average of 80% of its existing street materials, thereby reducing road repair debris in landfills–a major goal of the City.

The City of Dallas Department of Street Services, which spearheads the Sustainable Rehabilitation, Restoration and Partial Reconstruction of Dallas Streets project, is a winner of the 2008 PCA Sustainable Leadership Awards. These awards honor public officials who utilize cement or cement-based products to achieve sustainable benefits.

"I was impressed by the variety of ways in which the Department of Street Services street rehabilitation and restoration plan helps Dallas in meeting its goal of becoming a 'greener' city," said Richwine. "This is certainly a major milestone in proving that being sustainable is not only obtainable, it makes good economic sense, too."

Road Recycling is the Sustainable and Economical Choice for Fort Worth

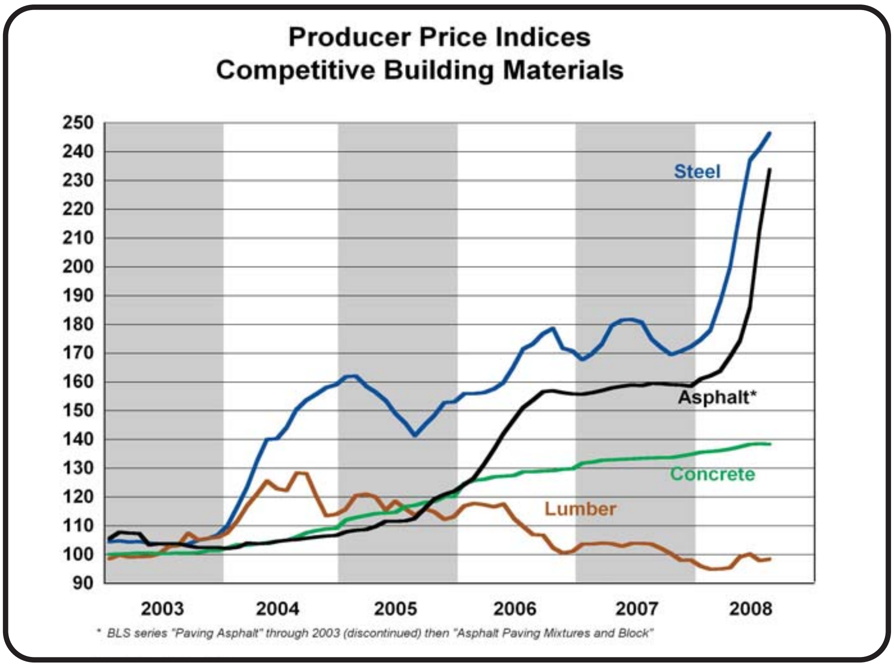
To create a longer service life and eliminate continuous pothole-filling, cities and counties across the country are adopting programs to recycle their streets and roads with cement. In Fort Worth, Texas, full reconstruction of failed asphalt roads currently costs the city about $380,000 per lane mile and requires replacing curbs, gutters, sidewalks and driveway approaches; by comparison, completely rebuilding a street using full-depth reclamation (FDR) with cement costs in the range of $250,000 per lane mile. However, with FDR with cement, the city is often able to keep existing curbs, gutters and sidewalks, cutting the cost even further.

Crews incorporate cement into the pulverized roadway during the recycling process.

Since 1996, Fort Worth's street maintenance program has saved taxpayers millions of dollars by recycling the city's deteriorating and failed asphalt streets with cement. The city has rebuilt 619 lane-miles – or 4.72 million square yards – of roadway using FDR with cement, according to Najib Fares, infrastructure manager for the City's Transportation & Public Works Department.

In addition to making good economic sense, recycling rutted and failing roadways with FDR is also better for the environment. FDR with cement often replaces the traditional but burdensome and costly method of full reconstruction, which requires completely ripping out the old, worn out roadway and replacing it. Since FDR allows old roadway materials to be reused, the need for new raw materials is greatly reduced and previously-used materials are no longer sent to already-overburdened landfills. The FDR process also reduces the need for bringing new materials to the construction site and hauling old materials out, thus reducing fuel consumption and cutting down on vehicle emissions.

"This new cement stabilized base, a product of in-place recycling, provides a strong, durable foundation for the chosen pavement surface," said Matthew Singel, program manager of the Cement Council of Texas. "In addition to the reduced



With rising asphalt prices, public works officials are turning to FDR to do more with less. According to Producer Price Index published by the U.S. Bureau of Labor Statistics, asphalt prices are up 46.6% for the first eight months of 2008.

construction time and conservation of natural resources, the FDR process provides superior performance to minimize the need for maintenance going forward."

This philosophy has resulted in significant savings to Fort Worth in their annual road maintenance program. This savings translates into more roads being properly maintained per budget year. The implementation of FDR for reconstruction of failed asphalt pavements saved the City an estimated $130,000 per lane mile over conventional methods or a 34% savings.

Rather than resting on his laurels after 20 years of working for the city of Fort Worth - 12 as the City's infrastructure manager - Mr. Fares refuses to be satisfied with the status quo. He continuously evaluates his programs to ensure they provide the best value and performance. "We've tried several processes for street rehab, but found FDR with cement to be the best fit," Fares says.

Fares' implementation of FDR to recycle city streets for the Annual Street Maintenance Program for the City of Fort Worth, Texas, is a winner of the 2008 Portland Cement Association Sustainable Leadership Awards. These awards honor public officials who utilize cement or cement-based products to achieve sustainable benefits.

"Fares has created a superior street maintenance and improvement program by implementing techniques that save construction time, money and natural resources while providing long-term performance solutions," concluded Singel. "The program has positively impacted the street and roadway infrastructure programs for the City of Fort Worth, Texas."

Coweta County Uses Innovative Construction Techniques to Rebuild County Roads

One of the most daunting tasks any county commissioner faces is maintaining a county's road system. As counties are expanding at an exponential rate, road maintenance in Georgia is becoming even a larger challenge because the Georgia Department of Transportation's (GDOT) maintenance funding is shrinking and the cost of roadwork increasing. Coweta County is overcoming its aging road system challenge by implementing an innovative process called full-depth reclamation (FDR).

In the summer of 2007, Coweta County awarded the largest FDR contract ever in the state to the Miller Group based in Morrow, Georgia. The $2.6 million FDR contract was for reconstructing five different major county roads totalling nearly ten miles.

Coweta County's road department has been actively involved in maintaining its road system with longer term solutions. Bill Cawthorne, public works director, routinely placed 30-60,000 tons of hot mix asphalt to resurface the county's roadways annually. "We would grade our worst roads and address the immediate needs as they arose," said Cawthorne. "When some of our major roadways began to show signs that a resurfacing alone would not be adequate we began to look for alternatives." Wayne Kennedy, county engineer, noticed a FDR article in a trade magazine and directed Fred Landrum, transportation project manager, to look into the process.

Coweta's roads and other Georgia counties' roads are alike because they were built on what GDOT terms a sand-clay base. In other words, the asphalt for the roadway was placed directly over the underlying soil rather than being constructed on a crushed stone or soil-cement base. This construction technique has been used throughout Georgia for many years. Most of these roads performed quite well over the years. However, Coweta and many other counties are experiencing exponential growth, which has lead to new development for residential, retail and industrial. Development and construction involves moving many heavy products. This type of heavy wheel loadings eventually takes its toll, especially on roads built with a sand-clay base. Because these roads were not designed for current traffic conditions, they began to deteriorate. Some signs of deterioration are the appearance of potholes and serious rutting along with alligator cracking, which can then lead to substantial failures. "Resurfacing a roadway that has a failed base is a waste of time and money," said Cawthorne. "We had to do something different!"

For years, Coweta addressed its road problems by deep patching most of the isolated failures prior to resurfacing, but some of their roads were beyond having isolated failures. "With deep-patching contracts now costing the county in excess of $100 per ton of asphalt, full-depth reclamation using cement was an alternative that made sense," said Landrum. Traditional reconstruction techniques were totally cost prohibitive, not to mention the extended time element in reconstruction. A traditional reconstruction can take months and cost can be overwhelming he said. "FDR can rebuild the road in-place in a matter of days and the cost savings are about one-third of traditional methods," said Landrum. "We can essentially rebuild an entire section of roadway for relatively the same investment of dollars spent for deep patching."

In 2005, their first project was reclaiming a one-mile section of Palmetto-Tyrone Road. The Miller Group was the successful low bidder, and the county officials were anxious to get started to see how it would perform. "After seeing the process we were pretty convinced that FDR using cement was a viable alternative to extensive deep patching," said Landrum. Regional Manager for the Miller Group, Kim Stokes, explained "We had just been hired by a private developer to reclaim a private sub-division in Coweta County that had somehow been built to sub-standard conditions." Landrum and other county officials watched their work closely and were impressed with the results. The county was concerned about the cost and speed of construction. But after some discussion they decided to give FDR a try. "The project went very well, and when we were finished they were ready to consider other county projects," said Stokes.

FDR with cement makes the reconstruction of roads a largely self-sustaining process. The complete recycling process can be finished in one day, and traffic can be maintained throughout construction. The old asphalt and any existing base material are pulverized, mixed with portland cement and water, and then compacted to produce a strong durable base for either an asphalt or concrete surface. FDR uses the old asphalt and base material for the new cement stabilized roadway base. There is no need to haul in aggregate or haul out old material for disposal. Construction truck traffic is greatly reduced, and there is little or no waste of

Coweta County uses FDR with cement as an economical, environmentally sound method of rehabilitating roads.

materials from the original roadway investment. FDR conserves virgin construction materials, saves fuel, and truck loads from tearing up the road. This process of reusing roadways and saving resources is moving Coweta County to a leadership role in sustainability.

The process starts by evaluating the condition of the existing pavement including the sub-layers and preparing a mix design. Next, pulverization sizes the materials back down to a two–inch minus material. A predetermined amount of portland cement and water is blended into the pulverized material. Reshaping, proper compaction, grading and curing follow. This gives the new base the strength and durability to achieve long lasting, cost effective pavements.

By addressing the entire pavement section, FDR is able to correct delinquent cross sections, widen roads, increase the load-bearing strength of the base, and utilize 100 percent of the existing materials. Substantial savings can be attained while meeting environmental goals. Cement stabilization increases the stiffness and strength of the base material. A stiffer base reduces deflections due to traffic loads, which results in lower strains on the asphalt surface and sub-grades. A cement treated base also forms a moisture-resistant layer that keeps out water that routinely destroys untreated aggregate bases thereby resulting in potholing and alligator cracking.

FDR provides higher load carrying capacity utilizing the cement treated component. Crown and slope corrections, drainage problems, reflective cracking, rutting, and potholing are all corrected. Road widening can easily be accomplished during the FDR process creating a much safer road. According to a research study contracted by the Portland Cement Association evaluating the FDR process over the last 20 years roads that were reconstructed using the FDR process had a life expectancy up to three-times of non-treated roadways.

"Even before the cost of asphalt went sky high, FDR with cement was a better value than deep patching," said Landrum. "By utilizing FDR on our major roadways providing a stabilized rigid base, we are expecting our asphalt investment to double or perhaps triple in longevity." The county plans on bidding an additional ten plus miles of FDR this year.

FDR Becomes Foundation for Holiday Season

For rehabilitation of its deteriorated asphalt parking lot, J.C. Penny chose recycling with FDR.

Full-depth reclamation (FDR) with portland cement was the clear choice in the recent rehabilitation of a 15,000 yd^2 parking area at the Hanes Mall of Winston Salem, N.C. In need of a facelift, the parking area of JCPenney underwent a transformation just in time for the winter holiday season.

The parking area, consisting of severely cracked and oxidized asphalt surfacing, was in desperate need of repair. A regional office of Professional Service Industries, Inc. (PSI) located in Charlotte, N.C. decided to include FDR in the contract bid as an alternate to the traditional "remove and replace" base reconstruction of the JCPenney parking area. A 2-inch asphalt surface course would provide the riding surface. The FDR was designed for a 40 lbs/yd^2 portland cement application rate to a depth of 12 inches. When bids were opened, FDR was the "clear choice due to its overwhelmingly lower bid and shorter construction schedule compared to the complete reconstruction option" said Don Brown, project manager for PSI. The project was awarded to Thompson Arthur Paving of Greensboro, N.C. who selected Propst Construction of Concord, N.C. to perform the FDR work.

Construction work began on September 17, 2007 with the complete pulverization of the parking lot using a CMI-Terex RS-425B. After complete pulverization, a small amount of material was removed to accommodate the new specified grade elevation after placement of the 2-inch asphalt surface. Portland cement was incorporated across the area for the next four days with a total of 300 tons being utilized.

Proper density and moisture levels were ensured through a QC testing and inspection program by PSI with no problems reported. With the expectation of needed parking for the weekend, Thompson Arthur Paving began surfacing operations on Friday, September 21, after successful proof-rolling was performed the day before on approximately one-half of the reclaimed area. Even though the area had only a two- to three-day cure, no sign of movement was reported under the fully loaded tandem axle water truck used for proof-rolling. Further adding to the observed stability of the FDR, no observed damage to the FDR section occurred when a 50-ton crane sat on jacks for several hours while repairing a malfunctioning high-mast light. Paving was completed the following Monday after successful proof-rolling operations of the remaining unpaved reclaimed section.

With a lower cost and timely construction schedule, FDR provided JCPenney an alternative rehabilitation technique for a deteriorated parking area. Shoppers for years to come will now have the support of a strong and durable base created through FDR with portland cement.

Long-Term Performance of Full-Depth Reclamation with Portland Cement

Introduction

This article 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. 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. 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.

Performance Evaluation

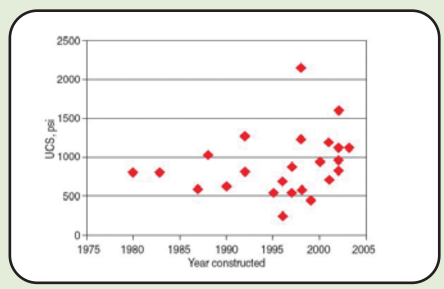
The performance evaluation process consisted of interviewing the agency/owner of the facility, performing visual pavement surveys, taking cores at select pavement locations, and performing strength measurements on the cores. This provided a qualitative assessment of the long-term strength and stiffness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

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.

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.

UCS measurements



Long-Term Strength

Representative core samples of the reclaimed base from some of the pavement sections were obtained 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), as shown in the figure above 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 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.

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**

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.

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.

While most agencies use the standard Proctor (ASTM D558) procedure to determine compaction requirements, some now actually require the use of modified Proctor (ASTM D1558) 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 percent 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.

Innovative Techniques

Some agencies use a process called "microcracking" to reduce reflection cracking. 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.

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 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.

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 (TST) as described below).

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.

TST is another technique to address moisture sensitivity issues. 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.

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 25% and 50% 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.

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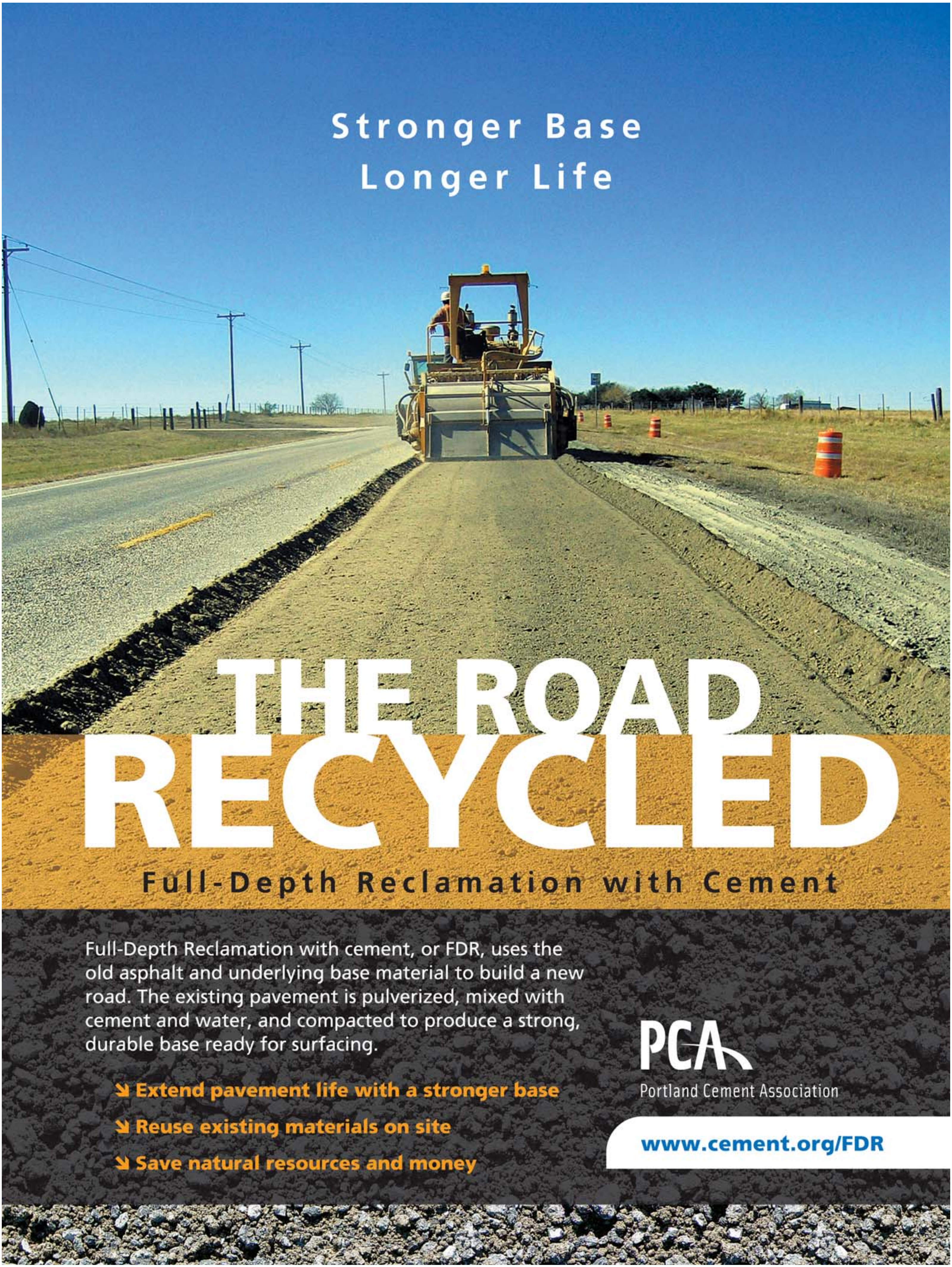
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