INTERSTATE 40

INTERSTATE 40 FREEWAY
FHWA Demonstration Projects

International Roughness Index (IRI) Monitoring Proves EMC SQUARED® System Stabilizer Products Superior for Extending Service Life of Interstate Freeway Pavements

EMC SQUARED

"It is my professional opinion that all subgrades should be stabilized and the EMC SQUARED system product is the most cost effective, easiest to handle and apply, and long lasting stabilizing product I have worked with."

— Ray Pederson P.E., Area Engineer and Materials Engineer (FHWA & BIA)

International Roughness Index (IRI) Monitoring

The Ultimate Evaluation of Base Course and Subgrade Performance

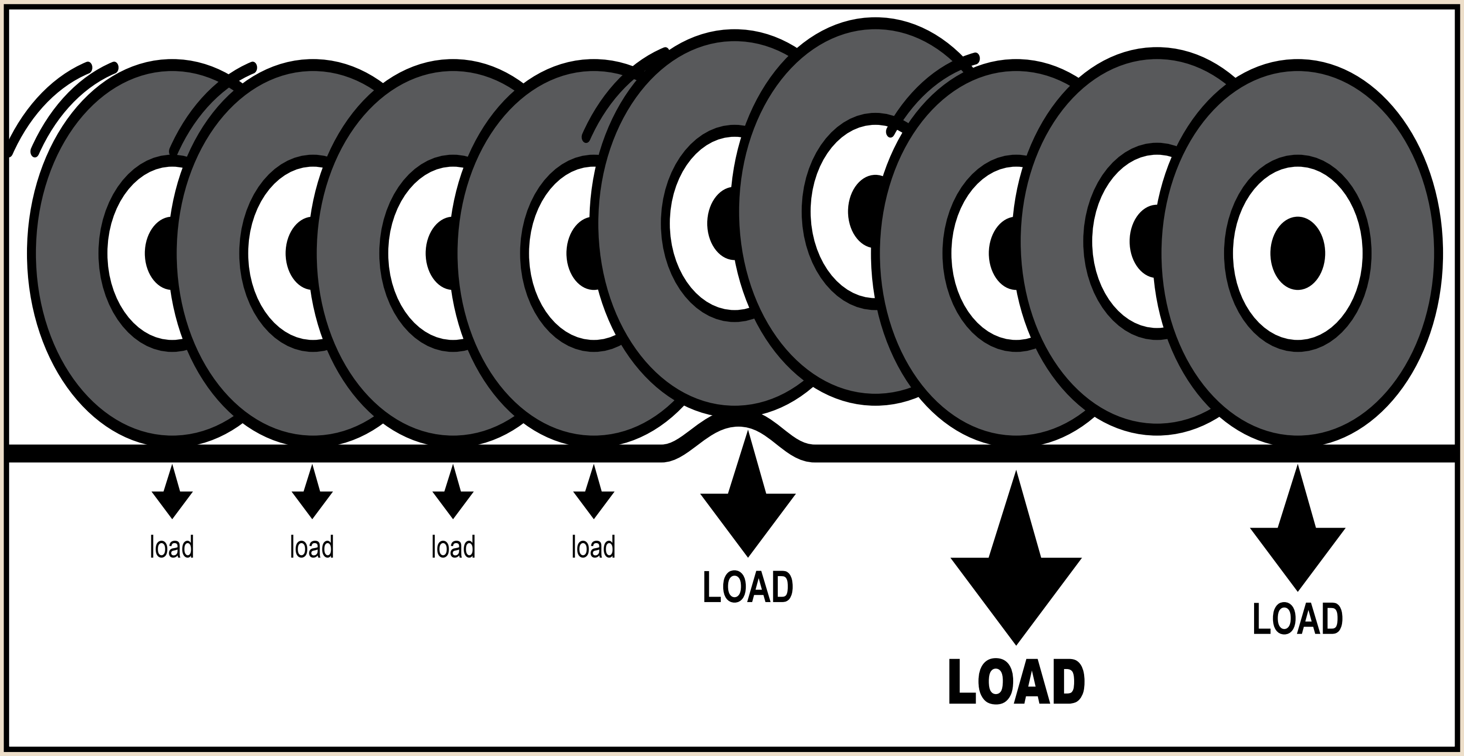
Pavement smoothness has become the most recognized international index for the evaluation of pavement performance. IRI measurement has been in nationwide use since 1990 when the Federal Highway Administration (FHWA) mandated implementation by all state highway agencies. The ultimate goal of subgrade stabilization, beyond providing an effective working platform, is to maintain pavement smoothness. IRI testing evaluates this fundamental performance criteria more directly than any other field test or test method in the materials laboratory.

While tests in the soil materials laboratory that are conducted preliminary to the construction of a road or highway can provide valuable input for the design of the pavement structural section, the ultimate measurement of the performance of a pavement design is how well the constructed pavement retains its smooth running surface and how many years of service it provides before repairs are required.

The rate at which a pavement develops roughness is a generally accepted index for predicting the limits of the remaining service life of a specific section of highway pavement. The development of roughness between successive IRI measurements is translated into the percent of Theoretical Design Life that is lost and the decrease in load carrying capacity, or ESALs (Equivalent Single Axle Loads). Finally, these relationships can be converted into the number of truck passes, something more simple to visualize in regard to lost carrying capacity.

How Pavement Roughness Generates **Dynamic Load**

Pavement roughness leads to higher dynamic loads on localized pavement sections which increases pavement deterioration at those locations. This not only lowers ride quality, but also leads to a cycle of increasing deterioration rates with increasing roughness severity.



The load is relatively constant on smooth roads, while on rough roads the pavement receives higher loads *at and after the point of roughness*

NOTE TO SECURITY CONSCIOUS REVIEWERS: This case study includes five hyperlinks to additional technical documents. If you would prefer the option with Password Protected Links, please forward an email with your request and contact information to info@stabilizationproducts.net.

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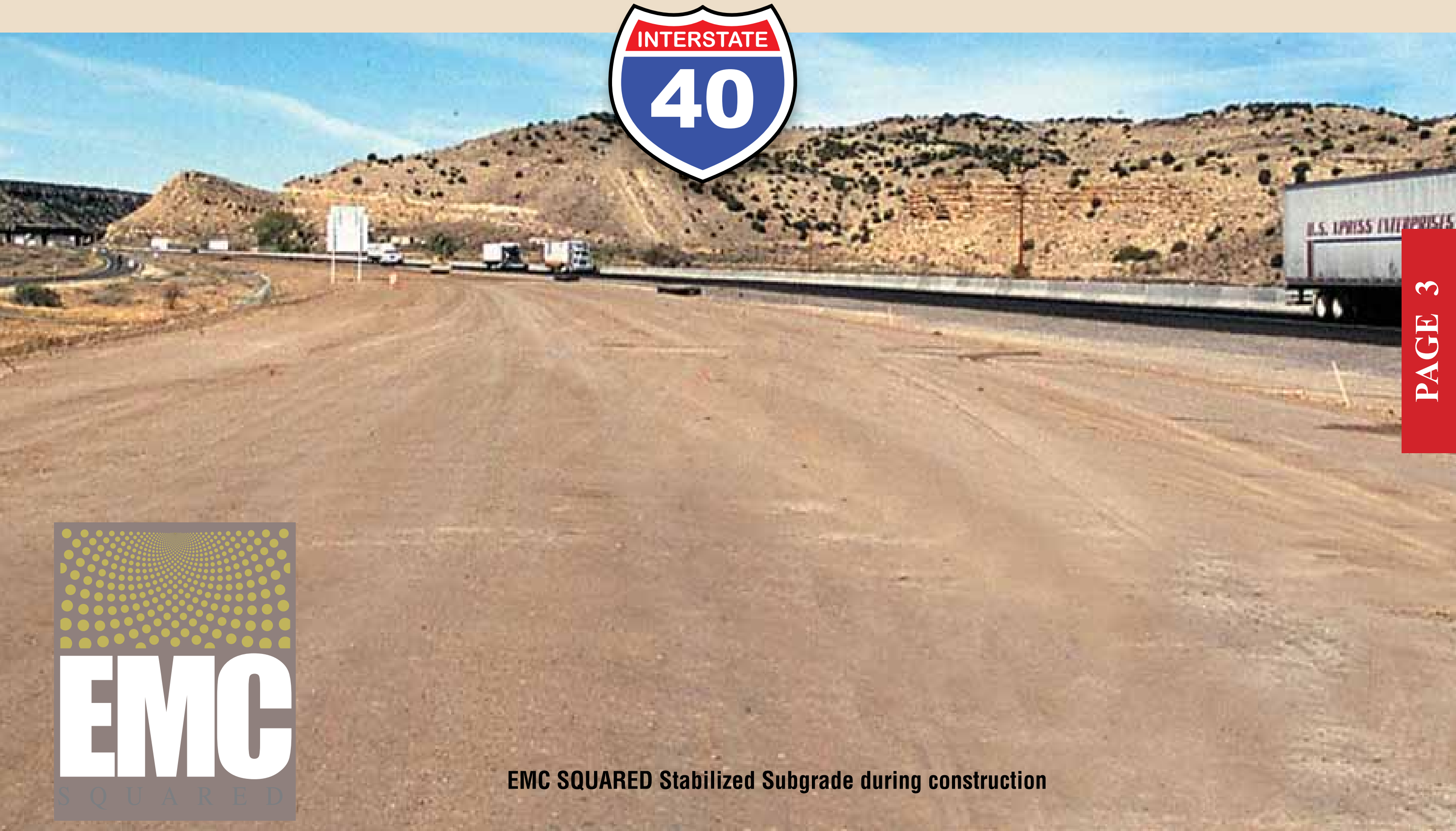


EMC SQUARED Stabilized Subgrade during construction

ABSTRACT

Two Demonstration Projects sponsored by the Federal Highway Administration (FHWA) for reconstruction of highly problematic sections of the Interstate 40 (I–40) freeway in New Mexico featured the use of innovative Concentrated Liquid Stabilizer (CLS) products added to the compaction water and mixed with the subgrade soils during subgrade construction and with the aggregate materials during construction of the stabilized base course. As evidenced by the results of the annual profilometer monitoring that FHWA mandates each state department of transportation to conduct on all federally funded freeways and highways, these two Demonstration Projects exhibited exceptional performance in retaining pavement smoothness and extending the maintenance-free service life of the asphalt pavements. The case studies for these Demonstration Projects include project and construction histories, summaries of the annual profilometer monitoring of pavement smoothness, testimonial letters from the FHWA Area Engineer monitoring the construction of these projects and from the Superintendent of the Heavy Highway Contractor that completed these highway construction projects. The primary focus of this report is on the construction and the monitoring of pavement performance for the project identified as I–40 Milepost 93 – 97 (MP 93–97). While other sections of I–40 in this area of the state typically required full depth reclamation every four to six years, the exceptionally problematic MP 93–97 section of freeway previously needed localized pavement repairs on a continuing basis and required full depth reconstruction on a repeated cycle of three to five years. When reconstructed with the stabilized subgrade and stabilized base course, the pavement was reported after 13 years of service under extremely heavy interstate truck traffic as remaining in excellent condition and retaining smooth running ride quality. The use of subgrade and base course stabilization in the pavement design reduced the thickness of the asphalt pavement by two inches, which more than paid for the addition of the economical stabilization treatments. In addition to the major cost-benefits for the federal and state governments, equally noteworthy is the benefit to highway users and the environment as smooth-running pavements are well documented as reducing the fuel consumption of automobiles and trucks.

PROJECT HISTORY AND CONSTRUCTION DETAILS

The section of the Interstate 40 Freeway (I–40) just east of Grants, New Mexico, identified as Milepost 93 to 97 (MP 93–97) was a nightmare for the New Mexico Department of Transportation (NMDOT) in past years. Grants is at an elevation of approximately 6,500 feet and the MP 93–97 Project is located where I–40 crosses the Continental Divide at the southern end of the Rocky Mountains. This section of I–40 is impacted by high frequency heavy truck traffic, cold winters, cycles of very wet and then very dry weather, extremely poor quality soils and bad drainage conditions with trapped groundwater under the freeway alignment. While the average cycle for full depth reconstruction of the I–40 freeway pavements in the west end of the state was 4 to 6 years at this point in time, the frequency of full-depth replacement for the entire pavement structural section in the vicinity of the MP 93–97 Project was on a 3 to 5 year cycle. The Federal Highway Administration (FHWA) is the primary funding source for state freeway projects. Given the poor performance history of the previous highway pavement designs used in this area of the state, the MP 93–97 project was approved as a FHWA Demonstration Project so that more options would be available as the project engineers and contractor encountered what they knew would be very problematic working conditions.

Westbound Lanes

Starting with the reconstruction of the westbound lanes of the MP 93–97 Project, the contractor first milled and removed the highly distressed asphalt pavement and cement treated base (CTB) layers. The subgrade soils were so soft and saturated that their scrapers and excavators were constantly stuck. Excavating as deep as six feet and more, they found the native soils were more saturated the deeper the dug. Using geotextile fabrics and geogrids in combination recycled with aggregate materials to fill the deep excavations was far too time-consuming and expensive. This situation was both unworkable and impractical. NMDOT and FHWA approved a Value Engineering proposal to instead treat the upper eight inches of the subgrade of the westbound lanes with a lime stabilizer product. Three miles of westbound subgrade were ultimately treated with lime stabilizer product while the remaining one mile section was either rock solid Malpais lava flow or soft saturated soils excavated and replaced with aggregate materials reinforced with geosynthetic products during the initial construction effort. The lime treatment proved to be nearly as problematic as the cross-shaft rotary mixers required for the lime treatment process were also constantly stuck in the mud. Once the lime treatment was

Finished freeway project in service above EMC SQUARED Stabilized Subgrade
NOTE: High Frequency Heavy Truck Traffic Typical of Interstate Highway 40

finally cured, the trucks hauling the aggregate materials for construction of the base course were soon punching through the lime treated subgrade, forcing the contractor to constantly repair the failed layer.

Eastbound Lanes with the EMC SQUARED System Stabilization

Given the failures of all the conventional construction products to satisfy their requirements during reconstruction of the westbound lanes, contractor W W Construction, Inc. (WWC) investigated potential alternatives with the FHWA Area Engineer assigned to this project before starting reconstruction of the even more problematic freeway alignment for the eastbound lanes. WWC had a previous successful experience with the EMC SQUARED System concentrated liquid stabilizers (CLS) on a nearby airport project for the city of Gallup (see link: **The City of Gallup Does It All**) where an alternative to lime treatment was required. The EMC SQUARED System subgrade and base course treatments had quickly bridged the deep deposits of highly saturated silty clays soils and WWC was able to pave the project without delay. NMDOT and the FHWA encouraged WWC to prepare a Value Engineering proposal for use of the EMC SQUARED System products and approved the contractor's submittal. The cost for the EMC SQUARED System products was far less than for lime or geosynthetic products, so they also approved use of an EMC SQUARED System stabilizer treatment for the lower half of the aggregate base course layer. The application process was much faster as the liquid stabilizer products were mixed with subgrade soils and aggregate base materials using tractor-drawn discs, rather than the slow and expensive cross-shaft rotary mixers required for cement and lime-based treatments. Best of all for the contractor's schedule, the EMC SQUARED System quickly bridged the deeper soft subgrade and allowed the contractor to being base course placement within days with minimal repairs of the stabilized subgrade required during the trucking haul. As is typical for highway projects under the jurisdiction of state highway departments, there had been no previous interest in investigating the use of the innovative technology until every other conventional option failed. In this case, the eastbound lanes where the EMC SQUARED System products were approved for use were also the worst of their worst case conditions.

NMDOT maintenance staff reported that the entire annual budget of their local maintenance station had been exhausted in the year prior to this reconstruction project by the constant repair required for the eastbound lanes in the MP 93–97 section. Historically, the eastbound lanes were particularly problematic with significantly more differential settlement (more rolls and dips and roughness in the running surface) and a far higher frequency of repairs than the westbound lanes. Once the contractor milled and removed the distressed asphalt and cement treated base materials, they treated two miles of subgrade with the EMC SQUARED System products and the other two miles were either solid Malpais lava flow or pockets of subgrade soils that were removed and replaced with aggregate and geosynthetic reinforcement products. As with the earlier airport paving project, WWC was quickly able to apply the EMC SQUARED System stabilization treatment, effectively bridge the soft soil deposits below and proceed with placement of aggregate base course and asphalt pavement. The subbase aggregate layer was also stabilized with an EMC SQUARED System treatment.

Self-propelled Sheepsfoot Compactor Operating on Subgrade Soils Treated with EMC SQUARED Stabilizer Solution

EMC SQUARED Stabilized Subgrade in Foreground with View of Water Truck Applying EMC SQUARED Stabilizer Solution to Aggregate Base Course Materials

The thickness of the aggregate base course and asphalt pavement layers were the same for the construction of both the westbound and eastbound lanes on the MP 93–97 Project, which provided the opportunity to compare the cost and the performance of the different highway structural section designs. The monitoring test results are provided in the Performance Data chart on Page 9. The test results for the pavements constructed above the Malpais lava flow and the areas of geosynthetic reinforcement are identified in the chart as "Unstabilized & Reinforced Subgrade". Since the MP 93–97 Project was reconstructed as part of a program that included 11 miles of adjacent freeway running through similar or better subgrade conditions, this also provided the opportunity to compare the benefits of stabilization and reinforcement treatments in prolonging the service life of the pavements. While the asphalt pavement layer thickness was reduced to nine inches for the MP 93–97 Project, the 11 miles adjacent freeway that were reconstructed during this same period of time were paved with a total of 11 inches of asphalt pavement. The stated position of the State Materials Engineer at the time was that there was little benefit in improving the strength and stability of the subgrade and he mandated more costly designs using thicker asphalt pavement and base course layers as his solution to the ongoing pavement failures in this area.

In response to the FHWA mandate to state highway agencies for annual reports on pavement smoothness, NMDOT conducts yearly profilometer testing of its highway system. Since the ultimate goal of subgrade stabilization is to maintain pavement smoothness, the profilometer testing therefore is the best examination of the effectiveness of a stabilizer treatment in retaining that smoothness and extending pavement service life. Annual profilometer test results were available for the stabilized and unstabilized subgrade segments of the Interstate 40 Freeway project over a thirteen year period of monitoring. As the primary source of funds for state highway construction and maintenance, FHWA had a vested interest in ascertaining the learning lessons that could be gained in tracking pavement smoothness performance through the IRI data. This was in contrast to the attitude of NMDOT's engineers, who were working on the assumption that frequent highway reconstruction was inevitable, and that more Federal funds would be made available when needed. Ray Pederson, the FHWA Area Engineer for the project at the time of construction (and then Area Engineer for the Bureau of Indian Affairs in the same region of New Mexico) continued to monitor project performance through visual observation and review of the annual IRI or profilometer data collected by NMDOT and produced the Performance Data Chart on page 9.

In addition to FHWA's use of the data for its International Roughness Index (IRI) monitoring, the data is also useful for performance comparison of different stabilization treatments. NMDOT developed a formula to predict the percent of remaining pavement design life as related to the surface roughness of the pavement determined by the IRI data. As summarized on Page 9, the review by the FHWA Area Engineer who monitored the project states that the pavement constructed above the EMC SQUARED® System subgrade treatment retained its smoothness better than the pavement above the adjacent unstabilized and reinforced sections of the eastbound lanes, and better than the pavements in the westbound lanes constructed above the lime treated subgrade. Using the calculation formulas furnished by NMDOT and the FHWA, the IRI test results indicated that the EMC SQUARED System had done the best job retaining pavement smoothness and extending the Theoretical Design Life of this heavily trafficked section of Interstate 40. This degree of improvement during the monitoring period translated into a gain in load carrying capacity over the lime treated section of **5,155,966 ESALs, or 4,687,242 truck passes***, according to the NMDOT Materials Bureau model. **For sake of perspective, at one truck pass per minute, twenty-four hours per day, the EMC SQUARED System stabilization treatment would extend service life by approximately 9 years beyond the results achieved with the lime treatment.**

NMDOT's District Engineer responsible for this section of Interstate 40 Freeway provided additional perspective important to the evaluation of benefits of the soil stabilization applications under the Interstate 40 pavement structural section. He commented in December 2005 that NMDOT had reconstructed approximately fifteen miles of the I–40 freeway through this area, including the EMC SQUARED System project. While all of the projects from 1999 forward utilized NMDOT's newer design with thickened layers of asphalt pavement and aggregate base course materials, only the MP 93–97 Project constructed with the combination of stabilized and reinforced subgrade sections remained smooth running and free of pavement damage. Three years later, while the stabilized sections of MP 93–97 continued to be smooth running and in excellent condition, it was reported that the pavements constructed at both ends of the project, without used of chemical or mechanical stabilization, had already been undergoing extensive full-depth repairs and the addition of an asphalt pavement overlay. While the costly addition of thickened layers of hot mix asphalt pavement to the adjacent

** using an estimated ESAL Factor of 1.1 ESALS (Equivalent Single Axle Loads) per truck (WSDOT) based upon 3/25/10 test results after ten years of monitoring.*

sections of the freeway clearly contributed some incremental improvement in service life over the previous pavement designed with asphalt over cement treated base (CTB) that failed within a few years after construction, the stabilization treatments provided a completely new level of pavement performance and service life in the face of these highly problematic freeway service conditions.

As detailed earlier, the EMC SQUARED System treatment was the most effective construction working platform. It was also less expensive and less time-consuming to install in comparison to the conventional design, which called for subgrade excavation and replacement of the soft and saturated silty clay and organic soils with more suitable road base materials. It was also less expensive and less time-consuming to install than reinforcement with geosynthetic products or lime treatment. Finally, the IRI data on the Interstate 40 project clearly demonstrated the superior performance of the EMC SQUARED System stabilizer products over all other chemical and mechanical stabilization products in extending pavement service life of an Interstate Highway in an area that can truly be described as having worst case native subgrade conditions.

The four mile long section of the MP 93–97 Project reconstructed with chemical and mechanical stabilization methods outperformed eleven miles of adjacent sections of Interstate 40 freeway constructed without subgrade stabilization or subgrade reinforcement. The service life of the entire fifteen mile section of Interstate 40 freeway was improved by NMDOT's expensive new pavement structural section design that incorporated a thicker aggregate base course layer and a far thicker layer of hot mix asphalt pavement than had ever been used for previous Interstate 40 freeway construction projects. While the conventional design called for eleven inches of asphalt pavement, the value engineering design based upon using the EMC SQUARED Stabilizers for treatment of the base course materials and subgrade soils reduced the asphalt layer by two inches, the savings of which more than paid for the stabilization treatments. While the costly addition of thickened layers of hot mix asphalt pavement clearly contributed some incremental improvement, the stabilization and reinforcement treatments provided a completely new level of pavement performance and service life in the face of these highly problematic freeway service conditions.

Summary

Of particular note is the conclusion that can be drawn from the IRI Data used in combination with NMDOT's design service life formula after 13 years of IRI data accumulation. While lime stabilization proved to be a distant second best solution in prolonging pavement service life, the application of the EMC SQUARED System stabilizer products theoretically will extend pavement service life by 5,155,966 ESALs, or 4,687,242 truck passes beyond the benefits offered by the lime treated subgrade or any other structural section designed by NMDOT for this four mile project or the adjacent eleven miles of freeway that were reconstructed during this same time period. These conventional designs and other chemical and mechanical stabilization measures simply proved to be years behind the innovative EMC SQUARED System stabilizer products in extending pavement service life. For readers less interested in reviewing the engineering data, the simple conclusion that can be drawn here is that the section of I–40 constructed above the EMC SQUARED System treatments, after thirteen years in service, had already extended pavement service life by a factor of over three times beyond the expectations of NMDOT's District Engineer and W W Construction's Superintendent, two professionals with extensive highway construction experience in this area.

Interstate 40 Freeway 10-year Performance Data

	Monitoring Dates*				
	February 19, 2001**	February 26, 2008	March 18, 2009	March 25, 2010	
Average IRI Measurement					**Smoothness Lost**
Lime Stabilized Structural Section Design	38.9	51.6	53.0	56.9	31.59%
Unstabilized & Reinforced Structural Section Design	41.0	52.3	55.6	59.0	30.41%
EMC2 Stabilized Structural Section Design	41.4	47.8	49.6	52.8	21.65%
Percent of Theoretical					**Design Life Lost**
Lime Stabilized Structural Section Design	109.6	81.4	78.7	71.4	38.2%
Unstabilized & Reinforced Structural Section Design	104.5	80.3	73.7	67.6	36.9%
EMC2 Stabilized Structural Section Design	103.6	89.2	85.5	79.0	24.6%
Number of Theoretical					**Design ESALs Lost**
Lime Stabilized Structural Section Design	41,545,099	30,867,798	29,826,403	27,058,832	14,486,268
Unstabilized & Reinforced Structural Section Design	39,453,798	32,880,788	28,298,269	28,289,425	13,164,373
EMC2 Stabilized Structural Section Design	39,275,357	33,814,686	32,416,488	29,945,054	9,330,302

*Profilometer monitoring conducted by New Mexico Department of Transportation on an annual basis starting in 2001.

**The first monitoring of the Milepost 93 – 97 Project took place on February 19, 2001. At this point in time, during the first year of pavement service life, the results of the International Roughness Index (IRI) monitoring by profilometer equipment largely reflected the smoothness of the original base course and subgrade construction work and the asphalt paving work. Highway contractors are often awarded bonus payments for constructing sections of highway with exceptional smoothness, since pavement smoothness during initial construction typically translates into extended service life. The contractor for the MP 93 – 97 Project, in fact, was given an award by the New Mexico Department of Transportation for constructing the smoothest running section of pavement in the state that year. As evident by the IRI measurements in the chart above, the initial IRI measurements of the asphalt pavements for the Westbound lanes of the MP 93 – 97 Project, where the subgrade had been treated with lime stabilizer product, started off as smoother running than the Eastbound pavements constructed above the EMC SQUARED Stabilized Subgrade. As reported in this chart provided by the FHWA Area Engineer, and then in his letter that follows with monitoring information 13 years after construction, the Westbound lanes lost their superior smoothness over time as the results of the IRI monitoring began to reflect the comparative performances of the different base and subgrade treatments under the asphalt pavements.

Comment from FHWA Area Engineer after 13 years of Project Monitoring

New Mexico Interstate 40 Mile Post 93 To Mile Post 97 Reconstruction 1999 – 2000

Interstate 40 (I-40) from the Arizona state line to Albuquerque, New Mexico, has been known for its poor subgrade soils from the time it was first constructed. Servicing very heavy cross-country truck traffic, the new pavements of the I-40 freeway running through this entire area have typically required complete full-depth reconstruction at a frequency of every four to six years. This has provided job security for the contractors in the area that have repeatedly won contracts to reconstruct the same sections of freeway.

In August 1999 I moved, as an Area Engineer, to the New Mexico Division Office of the Federal Highway Administration (FHWA). In the fall of 1999 I was assigned three four to six mile long I-40 projects already under reconstruction between mile post (MP) 93 and mile post 110. Project MP 93 to MP 97 was scheduled for geotextile fabric reinforcement of the subgrade to provide a stable foundation. The contractor found that installing the fabric was more difficult than planned and convinced the New Mexico Department of Transportation (NM DOT) to change to lime stabilization at a large increase in cost. This operation was nearing completion when I arrived on the project. MP 97 to MP 94 westbound lanes were stabilized and traffic moved there for the winter.

Over the winter, at an innovation conference, Soil Stabilization Products Company, Inc. (SSPCo) made a presentation of the EMC SQUARED System stabilizer products. The contractor had previously used EMC SQUARED System products under an airport parking lot and the NM DOT District Construction Engineer had known of the products and agreed to try this subgrade stabilization treatment on the subgrade for the eastbound lanes when construction resumed in the spring of 2000. EMC SQUARED Stabilizer was used, at a very small change in cost, on MP 94 to MP 96.

For purposes of monitoring the performance of the two subgrade stabilizer products, the NM DOT Lab Supervisor devised a chart to insert average International Roughness Index (IRI) numbers, measured with high speed profilers as required by FHWA on all federal highway routes each year, and calculate the percent of design Equivalent Single Axle Loads (ESALs) remaining. NM DOT uses this information to determine the winner of the much coveted smoothness award given for the smoothest project constructed each year (this project was the awarded state winner) and to forecast the need to reconstruct or resurface a project.

I have used a revised copy of this chart to monitor this project every year since 2001. A routine Nova Chip surface treatment was applied westbound in the fall of 2008, eastbound in the spring of 2009, and an Open Graded Friction Course (OGFC) in 2010 when an adjacent project was completed. The IRI numbers on both west and east bound lanes are lower than the first numbers in 2001. This indicates no noticeable breakdown of the subgrade has occurred in 13 years.

% Design ESALs

	Westbound		Eastbound	
Project MP 93 – MP 97				
	2001	**2013**	**2001**	**2013**
	108.2	113.6	104.1	119.6
Lime	109.4	113.8		
Un-stabilized	104.1	112.6		
EMC SQUARED			104.6	124.9
Un-stabilized			103.6	113.8

In 2001, the first year of testing, the percentage of design ESALs ranged from 104.1 to 109.4 westbound and 103.6 to 104.6 eastbound, with the lime stabilized section 5.3% design EASLs greater than the un-stabilized section. The eastbound EMC SQUARED stabilized section was only 1.0% design EASLs greater than the un-stabilized sections.

The test results in 2013 show that westbound lime stabilized section is 1.2% design EASLs greater than the un-stabilized section. The eastbound EMC SQUARED stabilized section is 11.1% design EASLs greater than the un-stabilized sections and also 11.1% greater than the westbound lime treated section.

Clearly the freeway pavements constructed on top of the stabilized subgrades have out-performed the typical four to six year expected life span for reconstructed sections of freeway in this area of the State and the eastbound EMC SQUARED stabilized section has greatly out-performed the sections of this project that were built to the same standard, but without application of the stabilizer treatment, and out-performed the westbound lime treated section.

The above are my statements regarding this New Mexico, I-40 MP 93 to MP 97 project, which I have watched with great interest for the last 13 years. It is my professional opinion that all subgrades should be stabilized and the EMC SQUARED System product is the most cost effective, easiest to handle and apply, and long lasting stabilizing product I have worked with.

Ray Pederson – P.E. (FHWA & BIA)
(505) 730-0772 (cell)
September 8, 2013

Project Review Letter from Superintendent of Heavy Highway Contractor, W W Construction, Inc., 5 Years After Completion of Construction

Recalled by Project Contractor WWC Inc. Superintendent Ron Clark and Recorded by BIA Highway Engineer Ray Pederson on April 28 & 29, 2005

The roadway surface had heaves, bumps and dips with patched and repaired asphalt pavement.

Asphalt and cement treated base were removed with a milling machine and stockpiled for later use.

The sub-grade was soft wet silt, clay, and dark stinking organic soils. Over excavation started using scrapers that soon became stuck in the unstable soil. A track-hoe was used for a short time but it soon became apparent that over excavating was not a cost effective way of solving the ongoing soil problems. Lime treatment was suggested, drawing the response from a long time New Mexico State District Six engineer, “that lime is only good for des-infecting around out-houses”. WWC had a soil mixing machine which they tried to use to incorporate lime into the top eight inches of the sub-grade. This machine was also stuck more time than it was mixing. Brown and Brown Company, known for lime treatment of soils, was hired to do the lime treatment. With much difficulty they completed the treatment of the west bound lanes from west of the railroad bridge to the end of the project. The base material was placed and the lanes paved. The added calculated strength of the treated sub-grade made it possible to reduce the pavement thickness by two inches helping pay for the lime treatment.

In the spring of the year 2000 the east bound lanes surface was removed and stockpiled. The sub-grade was shaped and all parties involved with the project talked about the possibilities of trying some other faster, less costly type of treatment on the east bound lanes.

WWC had used a soil stabilizer, EMC^2, successfully on the sub-grade of the Gallup airport several years before and several of the other contract parties had heard of this product. Everyone was willing to try the EMC^2 to see if it could be stand up under the Interstate traffic.

Eight inches of surface materials were loosened with a large farm disk, EMC^2 mixed with water and applied through a modified spray bar on a water truck, disked again to blend the product with the soil, and compacted. This process was much faster and much more cost effective than the lime treatment. The added calculated strength of the EMC^2 treated sub-grade made possible a two inch reduction of the pavement thickness more than paying for the EMC^2 treatment.

Everyone expected both sides to fail again within several years because of the poor sub-grade soils and heavy truck traffic. I personally would have bet any amount of money that the road would be re-constructed again within two years.

I travel this section of I-40 frequently to and from my home in Farmington and have been surprised that I have seen no signs of cracking or sub-grade failure during the five years since completion of the project.

Sign and dated: Ron Clark 5-17-05

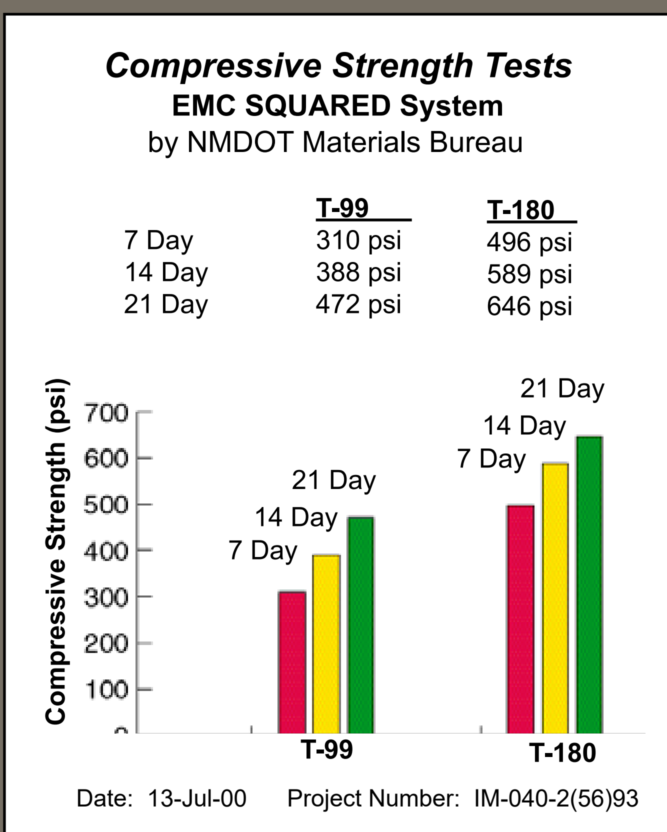
LABORATORY TESTING – EVALUATION OF STRENGTH, MODULUS, RESILIENCY, & RESISTANCE TO MOISTURE INFILTRATION

The selection of road building materials that are suitably matched for the loading conditions that the pavement will be subjected to and for the local native subgrade and environmental conditions is critically important. Prior to the construction of the Milepost 93–97 Project in New Mexico where EMC SQUARED System stabilizer products were used to stabilize subgrade soils and aggregate base course materials, the state had constructed many miles of freeway using Cement Treated Base (CTB) materials without success, as evidenced by a history of full depth reconstruction of the freeway pavements on a three to five year cycle. Cement treatment produces base course layers that are high strength, but rigid in behavior and subject to shrinkage cracking and layer cracking. This cracking interrupts the ability of the treated base course layer to effectively bridge the soft subgrade soils below and properly support the asphalt or concrete pavement above that is experiencing the repetitive dynamic loading of heavy truck traffic moving down the freeway. Public transportation agencies have historically used Unconfined Compressive Strength (UCS) tests to evaluate the strength of cement and lime treated aggregate and soil materials because this now dated laboratory test is fast and cheap to conduct. A UCS test simply measures the amount of loading a material can bear before fracturing. The limitation is that this is an individual static load test that does not model the real world conditions where the loading factors are dynamic and repetitive nor does it address the ability of the treated material to resist moisture flow through the constructed layer. As evident from the rapid deterioration of the conventionally designed freeway pavements in this area of New Mexico, the failure of a laboratory test to accurately model the pavement service conditions can ultimately fail a costly pavement installation designed with materials that are not well matched to the task.

While NMDOT conducted UCS laboratory tests to evaluate the performance of the EMC SQUARED System treatment in stabilizing the subgrade soils for the MP 93–97 Project, they did not test the EMC SQUARED Stabilized Aggregate Base materials used for MP 93–97 freeway reconstruction project. Fortunately, very similar EMC SQUARED stabilized aggregate materials from other road construction projects in New Mexico have been evaluated in far more modern and sophisticated laboratory testing series that have direct relevance to the performance of the EMC SQUARED Stabilized Base materials for the I–40 MP 93–97 Demonstration Project and the I–40 FDR Demonstration Project discussed on page 17. The results of these tests provide the engineering basis that explains why the pavement structural section design based upon using the EMC SQUARED System stabilized materials was so superior

Unconfined Compressive Strength Test Results for MP 93 – 97 Project

Prior to approval of EMC SQUARED® System, the NMDOT Materials Bureau testing laboratory in Santa Fe conducted compaction control testing and standard Unconfined Compressive Strength (UCS) tests. Tests were also conducted by the district materials testing laboratory. The EMC SQUARED System easily passed the Materials Bureau's laboratory index requirements of 200 psi after 7 days of curing with a 310 psi result (AASHTO T-99 ASTM D 698 Compaction Energy), as well as testing at 496 psi after 7 days using the compaction energy specified for EMC SQUARED System field application (AASHTO T-180 ASTM D 1557). Note the continuing strength gains the following 2 weeks.



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LABORATORY TESTING – EVALUATION OF STRENGTH, MODULUS, RESILIENCY, & RESISTANCE TO MOISTURE INFILTRATION

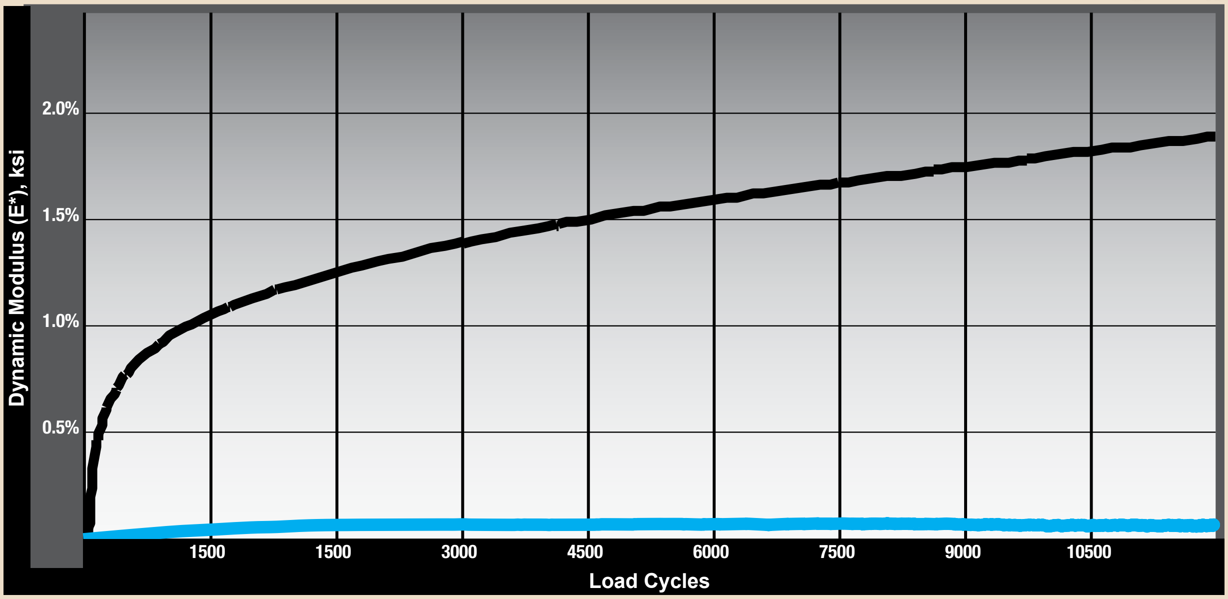
in pavement smoothness and service life in comparison to all the conventionally designed pavement structural sections that were adjacent to these two Demonstration Projects. These tests were conducted in the materials testing laboratories of two of the most highly regarded highway research organizations in North America, the Western Regional Superpave Center (WRSC) and the Texas Transportation Institute (TTI). Three modern test methods were used to evaluate the engineering properties of road building materials in regards to three important performance metrics.

1. Modulus – Dynamic Modulus Test – This is the state of the art test method for evaluating the performance Hot Mix Asphalt (HMA) pavement materials, which are known as flexible pavements (in contrast to concrete pavements, which are rigid). Hot mix asphalt mixtures are viscoelastic materials, meaning that they suffer significant loss of strength, or modulus, under slow moving heavy loads and during warm and hot weather conditions. The Dynamic Modulus test method applies repeated and variable loading to model a range of highway traffic, all the way from fast moving light vehicles to slow moving heavy truck traffic. It also tests the modulus of the material in temperatures ranging from below freezing (28.4°F) up to a temperature that black heat absorbent asphalt pavements easily reach during hot summer weather (130°F). While EMC SQUARED Stabilized Aggregate materials are not viscoelastic, they are elastic in behavior and they provide impressive modulus values. They have a history of excellent field performance as flexible road surfacing materials servicing heavy truck traffic and tactical military equipment. Given the fact that EMC SQUARED Stabilized Aggregate materials exhibit elastic, rather than rigid behavior, a comparison with typical HMA materials in Dynamic Modulus testing is therefore most appropriate as HMA pavement materials provide a performance base line that is universally familiar. See link: https://stabilizationproducts.net/docs/18828.pdf

2. Resiliency – Repeated Load Triaxial Test – This is another state of the art test method which is most typically used to evaluate the resilient performance of aggregate and soils materials and for determining their Resilient Modulus. It is also used for testing the resistance of Hot Mix Asphalt materials to permanent deformation (Rutting) under repeated loading. This test method was used to provide a comparison between an EMC SQUARED Stabilized Aggregate material and typical Hot Mix Asphalt materials. While typical Hot Mix Asphalt materials suffer permanent deformation under repetitive loading in this test method, the test results indicated that EMC SQUARED Stabilized Aggregate was highly resilient and not anticipated to experience any permanent deformation under a wide range of loading conditions. See chart on Page 15.

3. Moisture Susceptibility – Tube Suction Test (Suction and Dielectric Measurements) – This method essentially measures capillary rise in aggregate and soil materials with a dielectric probe to determine whether they are moisture and frost susceptible. Moisture susceptibility affects the strength of a material and its ability to withstand repeated freeze-thaw cycling. The test is used to determine the effectiveness of stabilizing agents in treating moisture susceptible aggregate and soil materials. Tube Suction Test results confirm that the EMC SQUARED System stabilizer products are effective in transforming highly moisture susceptible materials, such as the aggregate base course materials used in the construction of the I–40 MP 93–97 Project, into non-moisture susceptible materials. See link: https://stabilizationproducts.net/docs/18587.pdf

Comparison of Typical Permanent Deformation Characteristics of Hot Mix Asphalt (HMA) Mixtures with EMC SQUARED® Stabilized Aggregate



compared with EMC SQUARED Stabilized Aggregate Cured for 72 hrs at 104°F.

The data in this table is compiled from reports by Peter Sebaaly, Ph.D., P.E. University of Neavada, Reno, Director of the Western Regional Superpave Center. The charts on the opposite page are extracts from those reports.

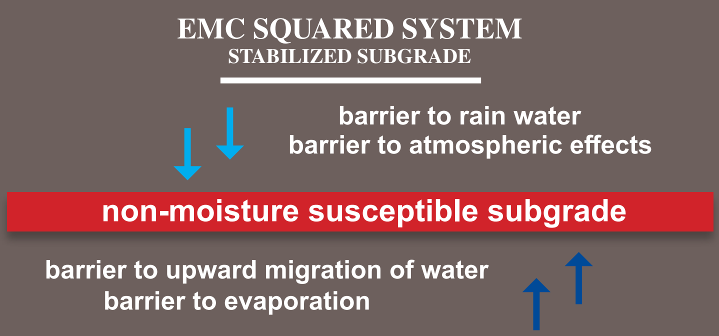
The Typical Deformation Curve for HMA Mix and the Permanent Deformation Characteristics of the EMC SQUARED Stabilized Aggregate, as shown above, are developed from the results of Repeated Load Triaxial (RLT) testing. RLT testing measures the resistance of a material to rutting and permanent deformation. In comparison to the HMA Mix, the EMC SQUARED Stabilized Aggregate Mix showed only 0.1% permanent axial strain. The report on the testing indicates that the deformation characteristics of the stabilized aggregate are expected to remain constant at all temperatures used in the related Dynamic Modulus testing and that the stabilized aggregate is not anticipated to generate any permanent deformation under a wide range of loading conditions.

(continued from page 14)

The three references (hyperlinks and chart) provide the reader with summaries of the actual test results. The summaries include hyperlinks to the original research study reports and technical papers. Note that password protected hyperlinks can be provided by email request to info@stabilizationproducts.net for reviewers with cybersecurity concerns. The conclusions that can be drawn from the test results are that the EMC SQUARED System stabilizer products effectively eliminated moisture and frost susceptibility problems, they produced resilient and elastic base course materials that were resistant to permanent deformation under severe heavy loading as well as high temperature conditions, and under repetitive loads they provided excellent modulus values that were most similar to those for typical hot mix asphalt materials. EMC SQUARED Stabilized Aggregate materials for these tests were sampled from street construction projects in Gallup, New Mexico and Fort Bliss, a large U.S. Army tactical training base overlapping the border between New Mexico and Texas where more than 116 miles miles of stabilized Military Supply Routes (MSR's) were constructed. As reported in these research papers available for review in the hyperlinks provided on the previous page, the performance of these low-cost stabilized aggregate materials in comparison with typical hot mix asphalt materials were favorable to the EMC SQUARED Stabilized aggregate materials.

MOISTURE BARRIER PERFORMANCE

The EMC SQUARED® System product technology is focused on treatment of subgrade moisture susceptibility. The goal of the treatment is to create an effective moisture barrier layer that protects the native subgrade below from rainwater and that resists saturation by the upward flow of capillary water from groundwater sources. The laboratory study (see link: **Summary of Research Report 3929-1**) conducted under the direction of Dr. Robert Lytton at the Texas Transportation Institute (TTI), clearly addressed this aspect of moisture barrier performance of the EMC SQUARED System treatment.



The moisture barrier approach is not a new concept for construction over saturated clay subgrades. It has long been understood that there are two very different routes to stabilizing clay soils. Cement and lime are used in attempts to overwhelm volume change problems with cementation and reduction of plasticity. The moisture barrier approach instead controls volume change by maintaining the moisture content of the clay within the treated subgrade layer in a state of "near-optimum" condition.

Cement and lime treatment have been successful in providing rigid construction platforms, but less successful in addressing the development of roughness in highway pavements over time. The interest in application of moisture barrier technology has in large part been driven by the desire to construct pavement structural sections that would retain smoothness better over time in comparison to results with lime and cement treated subgrades. The limitation, until recent years, with the moisture barrier approach is that flexible membrane liners (also known as FML's or plastic liners) were the only technology available. Unfortunately, flexible membrane liners are expensive and a nightmare for contractors to install. The availability of the EMC SQUARED System technology, which is low cost and relatively simple to install, has changed this picture. Moisture barriers have an additional advantage over cement and lime treatment as they effectively stop the upward flow of capillary water from the groundwater sources by sealing off the underlying native subgrade soils from atmospheric contact. The native subgrade is then far less influenced by seasonal weather fluctuations ranging from arid to monsoon conditions, as soil volume change is controlled by limiting fluctuations in soil moisture content. The net effect of the moisture barrier layer is improvement of the stability of the native subgrade as well as the treated subgrade.

Interstate 40 Freeway Full Depth Reclamation (FDR) FHWA Demonstration Project

With reconstruction cost savings of 40% forecasted by the NMDOT project engineers for another section of Interstate 40 scheduled for complete reconstruction, the FHWA state office in New Mexico approved a second Demonstration Project on Interstate 40 using an EMC SQUARED System stabilizer product. As was revealed by NMDOT District engineering staff after completion of the FHWA Demonstration Project, they had selected this particular section of interstate freeway pavement for the second demonstration project because it had highly problematic soil conditions that were even worse than the soft saturated soils under the MP 93–97 Project. Based upon previous testing of the native subgrade under the pavement structural section that had been conducted with Ground-Penetrating Radar (GPR) equipment, they were aware that thiswas their very worst problem section of I–40 pavement in the entire district.

The 40% cost savings would result from an approach to highway reconstruction known as Full Depth Reclamation (FDR), which relies upon recycling the existing distressed pavement and base course materials in place, and utilizing the pulverized FDR mixture as the base course for the new pavement structural section. They would be demonstrating two relatively new pieces of construction equipment, an Impactor and a Roto Trimmer, equipment that would be used in combination with the innovative EMC SQUARED System stabilizer product. In addition to the reduced construction costs, they would also be demonstrating the capability to eliminate the need to detour traffic during construction, with all the safety hazards and traffic delays associated with the traditional detours required during their frequent freeway reconstruction projects.

Following completion of the demonstration project, the asphalt pavement placed on the base course constructed with the recycled pavement mixture treated in place with the EMC SQUARED System stabilizer treatment was reported by the FHWA Area Engineer as remaining smooth running, based upon his review of the IRI test data, and in excellent condition. This was in contrast with the adjacent pavement built according to NMDOT's conventional reconstruction strategy which had required the complete removal of the distressed pavement and base course materials and deep excavation of areas of failed subgrade before constructing the new pavement structural section. For more information on this FHWA FDR Demonstration Project, visit website link: **I–40 FDR Demonstration Project**.

OTHER HIGHWAY PROJECTS CONSTRUCTED ON SUBGRADES STABILIZED WITH EMC SQUARED SYSTEM TREATMENTS

EMC SQUARED® System products are used in combination with natural earth materials such as aggregates and soils and mixtures of reclaimed asphalt and concrete pavements. The products are components in the construction of a final product. Engineering and construction controls are vital to the selection of all the ingredients and construction processes which will deliver the final product, and the excellence of that end result is, in large measure, dependent upon engineering judgements and construction quality control measures. This publication is solely for use by professional personnel who are competent to evaluate the significance and limitations of the information provided. It was reviewed carefully prior to publication. Stabilization Products LLC and Milieu Road Technologies, Ltd., assume no liability for its accuracy or completeness. Final determination of the suitability of any information or material for the use contemplated, or for its manner of use, is the sole responsibility of the user.

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