EMC SQUARED® System
Advanced Stabilization Technology

Improvement of the Engineering Properties of Aggregate Materials, Recycled Pavement Aggregates, Granular, Cohesive and Highly Expansive Clay Soils





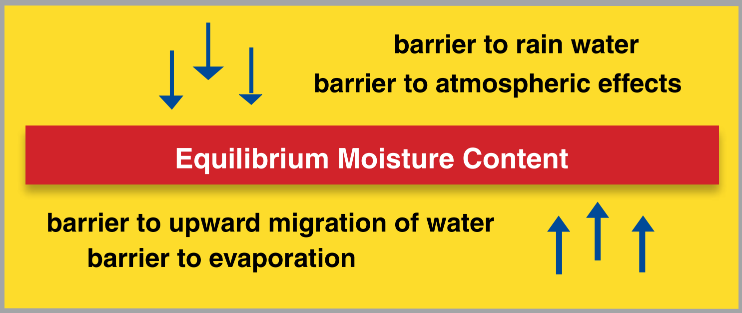


Sampling of Laboratory and Field Tests
Evaluating Effectiveness of EMC SQUARED System Stabilizer Products

Laboratory Test Results

EMC SQUARED System products are unique in many aspects, starting with the fact that they are Concentrated Liquid Stabilizers (CLS) that are neutral in pH. This is dramatically different than more traditional chemical stabilizers that are either highly alkaline (high pH) or highly acidic (low pH). EMC SQUARED System stabilizer products are uniquely broad-spectrum in their effectiveness, treating aggregate materials, recycled asphalt pavement (RAP) millings and mixtures of aggregate and asphalt materials from Full Depth Reclamation (FDR) projects, non-cohesive soils and expansive clay soils. Broad-spectrum performance is important in the field service environment, where soil types and material types often vary significantly along the length of a single kilometer or mile of road. For the past thirty years, EMC SQUARED System products have demonstrated effective performance for projects in arctic environments, arid desert conditions, temperate zones and tropical rain forests and have an outstanding track record in stabilizing unpaved roads — the most difficult of all applications. Where the EMC SQUARED System products are most remarkable, is in their ability to reduce hydraulic conductivity and permeability, and thus effectively treat moisture and frost susceptibility. Untreated aggregate and soil materials typically suffer loss of strength and stability when saturated with water. Untreated expansive soils experience volume change when their moisture content fluctuates, swelling as they take on water and exhibiting shrinkage and shrinkage cracking during desiccating weather conditions. EMC SQUARED System products directly address moisture fluctuation by stabilizing the moisture content of moisture susceptible materials at their Equilibrium Moisture Content (EMC) so that they function as moisture barriers and stable layers within road structural sections and for general earthwork applications.

A two year study was conducted at the Texas Transportation Institute (TTI) in 1996-1997 prior to the construction of freeway projects in the Dallas Area to be constructed above some of the most problematic soils in the state. The extensive laboratory study (Tx-98/3929-1) found that EMC SQUARED® System stabilizer products improved the strength of the highly expansive clay soils, and that the treatment was highly effective in keeping water out of the treated subgrade layer. As summarized by Dr. Robert Lytton, the Research Engineer in charge of the study: "The stabilized subgrade has a lower permeability and a lower suction than the untreated soil below it. This means that it will shed water and not soak up water from the soil below it." In summary, the upward and downward flow of water has been controlled by a stiffened layer within the structural section that provides a barrier to moisture flow.



Among several different test methods that proved this moisture barrier performance to be a fact, the TTI lab also ran permeability tests. The soil treated with EMC SQUARED System products had a permeability of 8.9x10^{-10} cm/sec., reducing moisture flow into the treated soil layer to less than one thousandth of an inch per month. The Tx98/3929-1 study was specifically designed to identify a product that could effectively stabilize the highly expansive soils in Dallas without generating a negative reaction with gypsum, a soluble sulfate prevalent in the local soils. Calcium-based stabilizers (cement, fly ash and lime) react with the sulfates and produce a dramatic expansion reaction known as sulfate heave, a costly problem that cracks and buckles asphalt and concrete pavements. The study found that EMC SQUARED System products were effective in stabilizing these soils and that they did not produce a negative

continued on page 3

Laboratory Test Results (continued from page 2)

reaction with the sulfate rich soil chemistry. Another laboratory study for a moderately expansive clay with very high sulfate content (36,700 ppm soluble sulfates*) also found that EMC SQUARED System products were effective in reducing permeability of the soil by almost a full magnitude, producing a stabilized soil with a permeability of 3.7×10^{-8} cm/sec.** Based upon that test result, water, if permanently ponded on the stabilized subgrade, would penetrate at a rate of less than one inch per year.

<u>Treating Moisture and Frost Susceptibility</u>

Many highway base course and subgrade materials are known as being Moisture Susceptible, since they actually attract or suction water into the road structure. In cold regions, the presence of water in the road structural section also makes it Frost Susceptible and subject to damage by freeze-thaw cycles. The ability to effectively treat moisture and frost susceptibility problems with EMC SQUARED System stabilizer products to make road base course and subgrade soils effectively impermeable is a relatively recent advancement in highway construction technology. Electrical property measurements of the rate of moisture flow through aggregate and soil materials are the most effective method for determining if they are moisture and frost susceptible. These tests confirm the effectiveness of stabilization products that can treat these problems. On page 4, dielectric test results validated the effectiveness of EMC SQUARED System products in treating three different aggregates known to be highly moisture and frost susceptible in their untreated state. The stabilized aggregate materials were placed as unpaved road running surfaces that performed as water shedding pavements under heavy traffic through severe winter conditions and freeze-thaw cycles. These road installations confirmed the ability of the test method to accurately predict performance in the field service environment. No coincidence that the stabilized aggregates had tested in the materials laboratory as being most similar to concrete and asphalt materials in their resistance to moisture intrusion. On page 5 under <u>Moisture Susceptibility Testing Using Electrical Property Measurements</u>, an expansive clay soil that tested as being highly moisture susceptible as an untreated material (test result 42 DCV) was effectively treated with EMC SQUARED System products, testing at a reading of 4 DCV, which is far below 10 DCV, the upper limit of acceptance for use as a highway subgrade material.

<u>What Does This All Mean?</u>

Road base courses and subgrades designed with adequate elevation, proper drainage, and compacted according to engineered Moisture-Density controls begin their service life in an unsaturated condition, at or near optimum moisture content for greatest load bearing strength. Decades of accumulated laboratory and field test results plus project case histories verify EMC SQUARED System products effectively treat moisture susceptible aggregate and soil materials to maintain equilibrium of the optimum moisture content. Soils and aggregates strengthened with EMC SQUARED System products maintain a stable moisture content, preserving strength by eliminating moisture fluctuations and the related shrink-swell cycles. Properly treated soil and/or aggregate materials can function as moisture barriers that shed rainwater, snowmelt, and stop the upward movement of capillary water into the road foundation by groundwater from below. Foundational road materials kept in an Equilibrium Moisture Content (EMC) state stay full strength throughout the year and eliminate concerns about freeze-thaw cycles and the need to implement seasonal load restrictions. Low materials and application costs add to the advantage of building durable roads with EMC SQUARED System products.

*Chemical Analysis by John C. Kephart & Co. Grand Junction Laboratories
**Permeability Testing by Lambert and Associates, Montrose, Colorado

A Sampling of EMC SQUARED® System Laboratory Test Results

Stabilization of Moisture Susceptible Aggregate Materials

Suction and Dielectric Testing (Tube Suction Testing)[1]

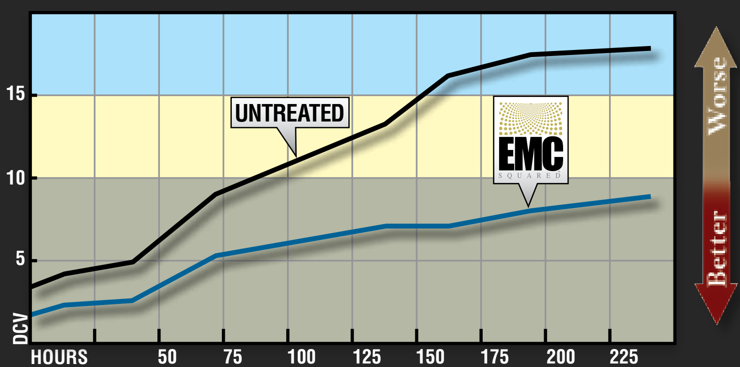
A Dielectric Value of greater than 15
indicates that the aggregate is wet or water saturated and extremely moisture and frost susceptible

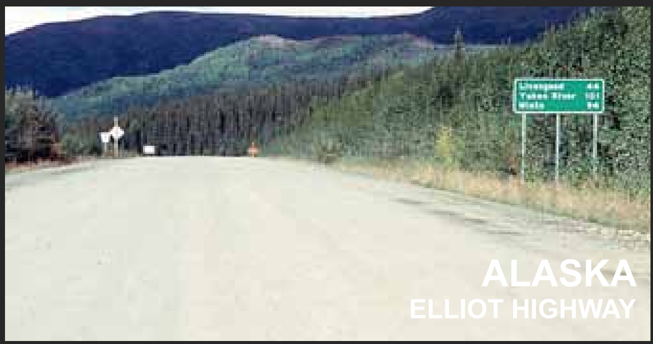
A Dielectric Value of 10 to 15
indicates that a significant amount of free water has accumulated within the aggregate during the testing period and is a warning signal that the material is moisture sensitive and frost susceptible

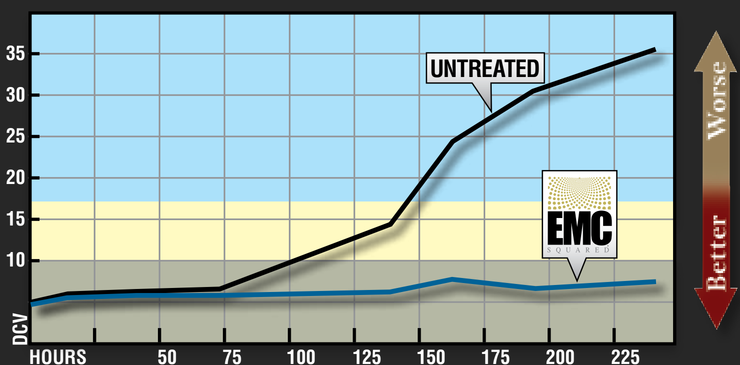
Aggregate materials with a Dielectric Value of less than 10
are considered non-moisture sensitive and non-frost susceptible in service for road and highway base applications

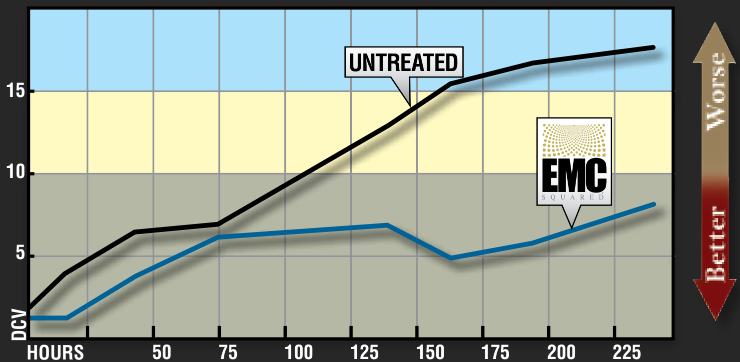
References for Dielectric Constant Values of Highway Materials

MATERIAL	DIELECTRIC VALUE
Dry Aggregates	4 - 6
Asphaltic Concrete	5 - 7
Portland Cement Concrete	7 - 9









1) Syed and T. Scullion, Texas Transportation Institute, Texas A&M University, College Station, TX 77843-3135. R.B. Randolph, Soil Stabilization Products Company, Inc., Merced, CA 95344 "Tube Section Test for Evlauating Aggregate Base Materials in Frost and Moisture Susceptible Environments" Transportation Research Record 1709, January 2000, 78-90

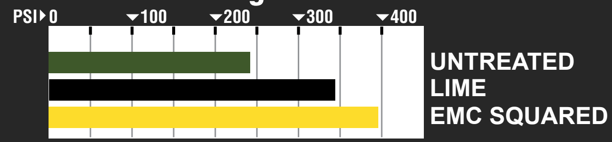
An Additional Sampling of EMC SQUARED® System Laboratory Test Results

Stabilization of Soils: Highly Expansive Clay

EMC SQUARED System vs. Lime Texas SH - 161 Project Testing

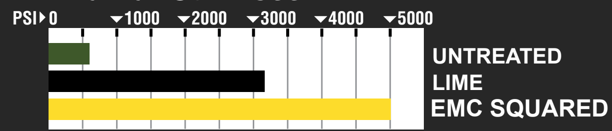
Prior to the application of the EMC SQUARED System for stabilization of expansive clay subgrade soils under the SH-161 section of the President George Bush Turnpike, the Dallas District of the Texas Department of Transportation (TxDOT) funded a research study at the Texas Transportation Institute (TTI). Results from six of the different laboratory tests that were conducted are summarized here.

Triaxial Strength



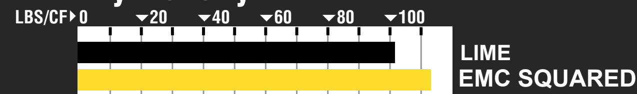
SH-161 TEXAS
Expansive Clay Soil
Texas Transportation Institute - College Station, Texas

Triaxial Stiffness



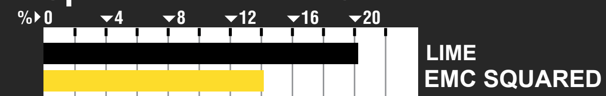
SH-161 TEXAS
Expansive Clay Soil
Texas Transportation Institute - College Station, Texas

Dry Density



SH-161 TEXAS
Expansive Clay Soil
Texas Transportation Institute - College Station, Texas

Optimum Moisture Content



SH-161 TEXAS
Expansive Clay Soil
Texas Transportation Institute - College Station, Texas

Moisture Susceptibility Testing Using Electrical Property Measurements

Electrical Conductivity

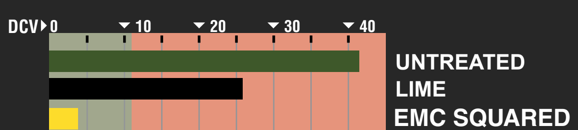
Texas Transportation Institute researchers subjected both untreated soil specimens and stabilized specimens to electric property measurement. One hundred milliSiemens per centimeter is the upper limit for Electrical Conductivity. Specimens testing above this value were classified as moisture susceptible and subject to loss of strength due to moisture infiltration. As indicated below, the Electrical Conductivity of EMC SQUARED treated SH 161 soil specimens remained well within acceptable tolerances prior to and following four months of moisture conditioning treatment.

EMC SQUARED

Dry	Moisture Conditioned
53.75 (mS/cm)	34.50 (mS/cm)

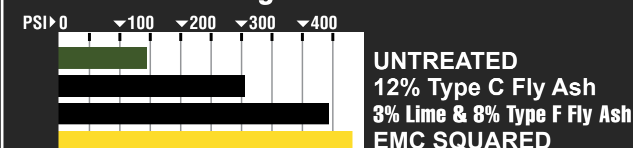
Dielectric Constant

As indicated below, the dielectric measurements for the EMC SQUARED System treated specimens were well below 10, the upper limit for expansive clay soils if they are to be considered suitable for use as highway subgrade materials. This is also significantly below the dielectric value of 15, at which point it is predicted that plastic deformation will occur within the structure due to physical property changes in the soil which are driven by moisture infiltration and fluctuations in moisture content. Note also that the untreated soil and the lime treated soil greatly exceed the upper limit for Dielectric Value. The test values indicate that both the raw soil and the lime treated soil are highly moisture susceptible.



EMC SQUARED® System vs. Lime and Fly Ash Franklin County Texas Project Testing

Triaxial Strength



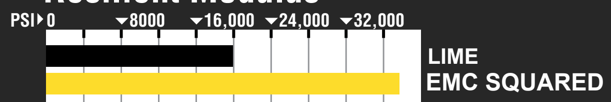
FRANKLIN COUNTY, TEXAS
Expansive Clay Soil
Terra Mar, Inc., Dallas, Texas

An Additional Sampling of EMC SQUARED® System Laboratory Test Results

Stabilization of Soils : Expansive and Non-Expansive

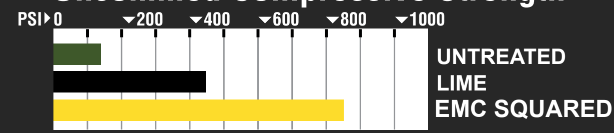
Expansive or High Plasticity Index (P.I.) Soils
EMC SQUARED System vs. Lime

Resilient Modulus



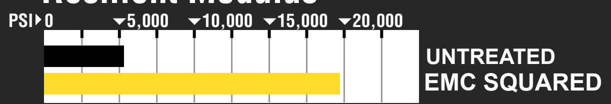
MENDOTA FEDERAL PENITENTIARY
Expansive Clay Soil
Kleinfelder, Inc., Fresno, California
(Terracon Consulting Engineers & Scientists)

Unconfined Compressive Strength



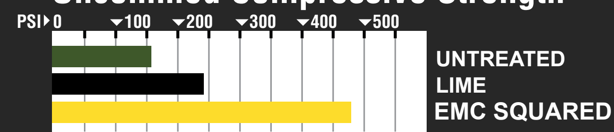
SH-N55 NEW MEXICO
Silty Clay
Kleinfelder, Inc., Stockton, California

Resilient Modulus



MOUNTRAIL COUNTY ROADS
Moderately Expansive Clay Soil
Ground Engineering Consultants Inc., Englewood, Colorado

Unconfined Compressive Strength

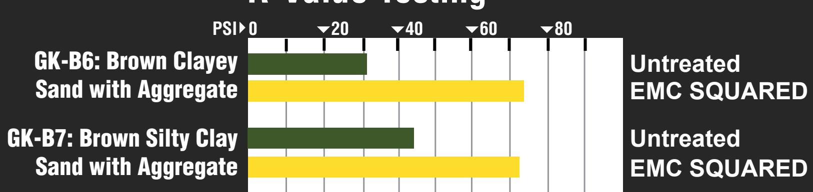


SH-N55 NEW MEXICO
Sandy Silty Clay
Kleinfelder, Inc., Stockton, California

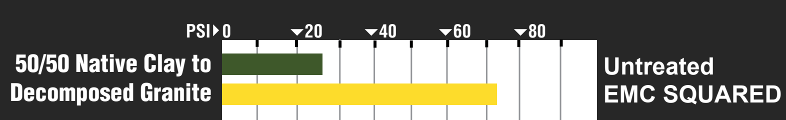
Non-Expansive or Low Plasticity (P.I.) Soils
EMC SQUARED System

While expansive clays are often considered the most problematic soils due to their volume changing characteristics, shrinking in dry conditions and swelling in response to moisture, non-expansive soils can also be a problem. While non-expansive soils may not shrink and swell, they are subject to weakening with increasing moisture content if they contain fine particle silt and clay materials. EMC SQUARED System treatments are often applied to improve the all-weather stability and strength of low P.I. or granular soils with silt and clay content.

R-Value Testing

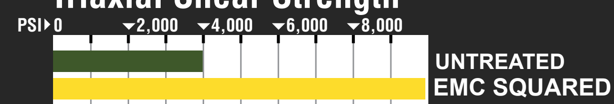


PORT OF OAKLAND BERTHS 57 & 58
Kleinfelder, Inc.



San Jacinto Wildlife Auto Loop Road
Inland Foundation Engineering, Inc.

Triaxial Shear Strength

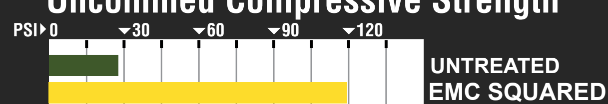


STATE OF CALIFORNIA
Silty Clayey Sand with Gravel
Kleinfelder, Inc., Santa Rosa, California

Unconfined Compressive Strength

I-40 NEW MEXICO
Silty Clay Soil
New Mexico DOT Materials Bureau, Santa Fe, New Mexico

Unconfined Compressive Strength

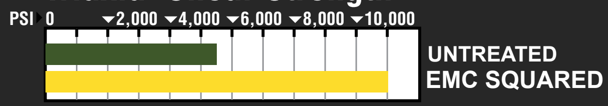


BALDWIN COUNTY, ALABAMA
Silty Fine Sand
Terra Mar, Inc., Dallas, Texas

An Additional Sampling of EMC SQUARED® System Laboratory Test Results

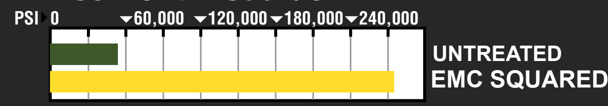
Stabilization of Aggregate Materials

Triaxial Shear Strength



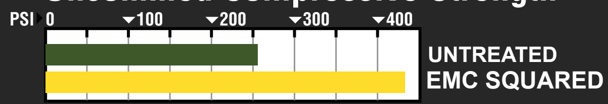
STATE OF CALIFORNIA
Aggregate Base (Non-Plastic)
Kleinfelder, Inc., Santa Rosa, California

Resilient Modulus



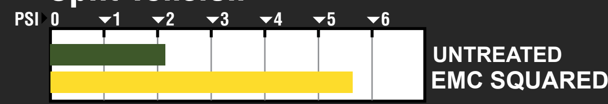
LAS VEGAS SPRINGS PRESERVE
Aggregate Base (Non-Plastic)
Professional Service Industries, Inc.
University of Nevada, Reno

Unconfined Compressive Strength



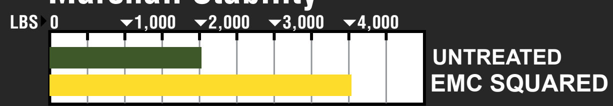
ALASKA DOT&PF - ELLIOT HWY
Aggregate Base (Plastic)
Shannon & Wilson Laboratory

Split Tension



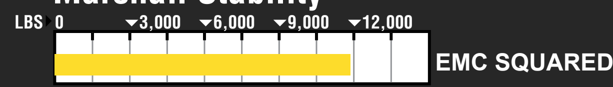
USDA NATIONAL FOREST SERVICE ROAD
Aggregate Base (Non-Plastic)
Region 6 Materials Laboratory, Portland, Oregon

Marshall Stability



MISSISSIPPI DOT
Aggregate Base (Non-Plastic)
District 5 Materials Laboratory

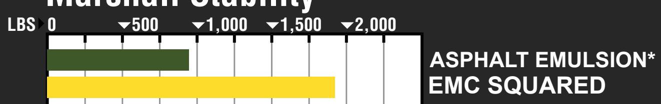
Marshall Stability



CEMEX, ARIZONA
Aggregate Base Rock
Kleinfelder, Inc., Fresno, California

Stabilization of Recycled Asphalt Pavement Millings (RAP)

Marshall Stability



MOJAVE COUNTY, ARIZONA
Recycled Asphalt Pavement Millings (RAP)
Kleinfelder, Inc., Fresno, California

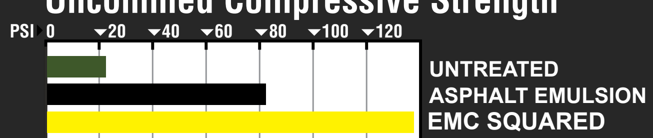
* 2% CSS-1h Asphalt Emulsion Only

$$ NOTE

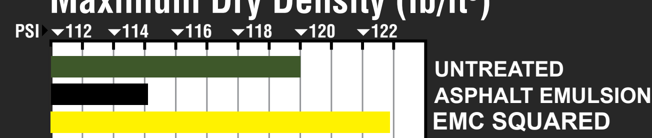
The EMC SQUARED System treatment provides a stronger pavement product than asphalt emulsion at a fraction of the cost. This is worthy of note at a time when asphalt emulsion products are rapidly escalating in price.

Asphalt emulsions are used in some areas as binders for base course materials. Depending upon the rate and type of asphalt emulsion selected in the mix design, asphalt emulsion can run ten to twenty times the cost required for treatment than the EMC SQUARED System product for the same volume of aggregate. The results graphed below from a laboratory testing program at Oregon State University provide an opportunity to compare an EMC SQUARED Stabilizer treatment with a 6 percent asphalt emulsion treatment (CSS-1) in Unconfined Compressive Strength and Maximum Dry Density testing.

Unconfined Compressive Strength



Maximum Dry Density (lb/ft³)



USDA NATIONAL FOREST SERVICE ROAD
Aggregate Base (Non-Plastic)
Oregon State University, Corvallis, Oregon

COMPARISON OF TYPICAL DYNAMIC MODULUS AND REPEATED LOAD TRIAXIAL TEST RESULTS FOR HOT MIX ASPHALT (HMA) MIXTURE AND EMC SQUARED® STABILIZED AGGREGATE

Evaluation of EMC SQUARED Stabilized Aggregate in Pavements/Materials Laboratory

The laboratory evaluation under the direction of Dr. Sebaaly included both Dynamic Modulus (E*) and Repeated Load Triaxial (RLT) testing, the state of the art test methods for evaluating Hot Mix Asphalt (HMA) materials and providing input for AASHTO MEPDG pavement designs. EMC SQUARED Stabilized Aggregate materials exhibit flexible, or elastic behavior, and modulus values most similar to HMA materials. Consequently, those test methods are equally appropriate for evaluation of these stabilized aggregate materials and for pavement design purposes. The study found that the Dynamic Modulus property of the stabilized aggregate after one week of curing was in the range of 450,000 to 500,000 psi and that it was a very stable material that could be expected to resist permanent deformation effectively and without excessive stiffening and risk of shrinkage cracking. Dr. Sebaaly states "The combination of the elastic behavior of the EMC SQUARED stabilized aggregate material with its good level of long-term modulus makes it an appropriate choice for pavements serving heavy loads at slower speeds (worst case conditions) as well as for pavements subjected to standard loading conditions." Unlike HMA materials, which are weakened by increasing temperatures and slower loading conditions due to their highly viscoelastic nature, the study found that changes in loading frequency and temperature, from below freezing to 130°F temperature, had minimal impact on the modulus of the EMC SQUARED Stabilized Aggregate. The EMC SQUARED Stabilized Aggregate can therefore be represented by an average constant Dynamic Modulus property of 475,000 psi (versus the Master Curve required for HMA).

The resistance of the EMC SQUARED Stabilized Aggregate material to permanent deformation was evaluated in RLT testing with a finding that under a wide range of loading conditions no permanent deformation is anticipated. Furthermore, even in the worst case conditions for a flexible pavement layer, which are slow moving loads in hot environments, the behavior of the stabilized aggregate "...makes it a good candidate for pavements loaded under such severe conditions." according to Dr. Sebaaly.

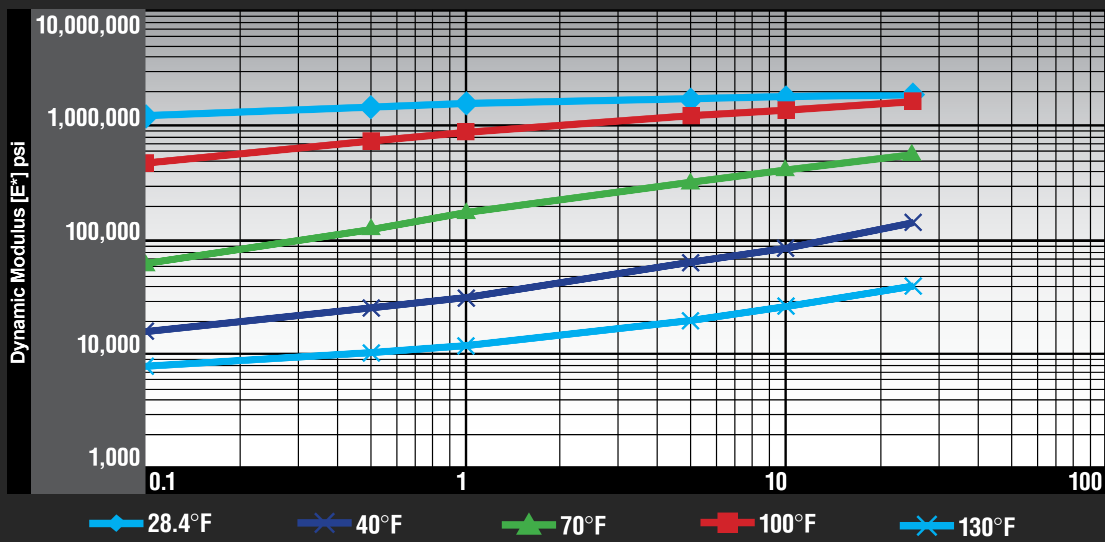
As an example of a severe service application, it should be noted that the EMC SQUARED Stabilized Aggregate materials for this laboratory evaluation were sampled during the construction of military heavy haul road projects designed by the U.S. Army Corps of Engineers (USACE). This high-strength stabilized aggregate material was plant-mixed and placed by asphalt paving machines as a surface course, or running surface, to be used by convoys of military battle tanks and other tracked military equipment as well as heavy haul trucks weighing over 120 tons when fully loaded. The EMC SQUARED Stabilizer product, manufactured by Soil Stabilization Products Company (SSPCo), was specified by USACE for stabilization of subgrade soils as well as stabilization of aggregate surface course materials for over 100 miles of heavy haul road construction projects. Of additional interest, the stabilization of subgrade soils eliminated the need to manufacture and transport over 1 million tons of crushed aggregate subbase material that otherwise would have been required for these projects.

WESTERN REGIONAL SUPERPAVE CENTER

The engineering evaluation of the stabilized aggregate materials was conducted under the direction of Peter Sebaaly, Ph.D., P.E., Director of the Western Regional Superpave Center, one of five centers established by the Federal Highway Administration (FHWA) to support the implementation of the Superpave Technology for hot mix asphalt materials. Dr. Sebaaly is also the Director of the Nevada Technology Transfer Center (funded by FHWA and Nevada DOT), and Professor of Civil Engineering in the Civil and Environmental Engineering Department at University of Nevada Reno where the Pavement/Materials Program and materials testing laboratory are located.

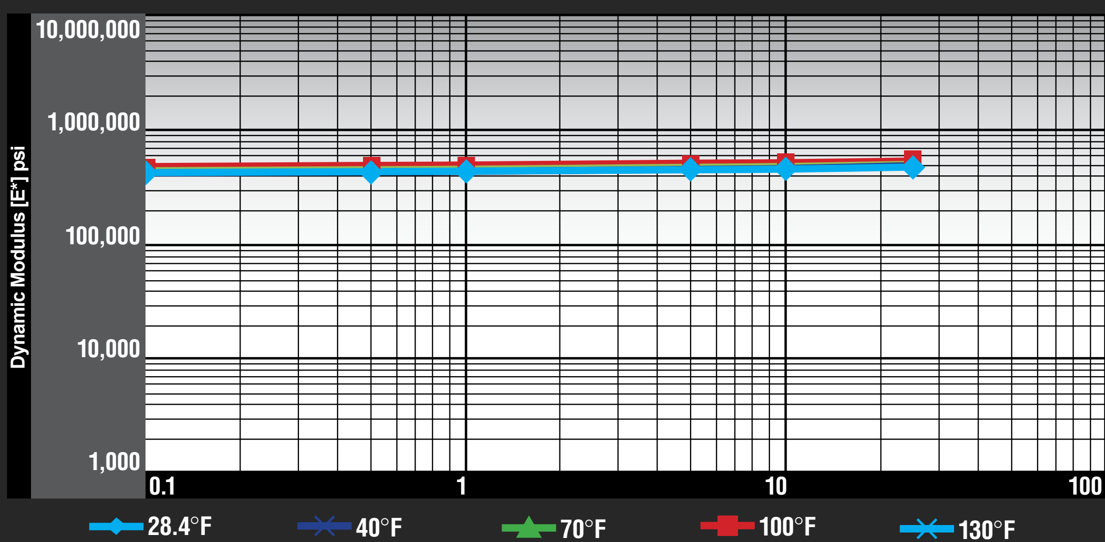
*"...**changes in loading frequency and temperature,** from below freezing to 130⁰F temperature, **had minimal impact on** the modulus of the **EMC SQUARED Stabilized Aggregate...**"*

HOT MIX ASPHALT



Typical Dynamic Modulus Data for HMA Mixture

EMC SQUARED



Dynamic Modulus of EMC SQUARED Stabilized Aggregate Cured for 168 Hours @ 104^{0}F

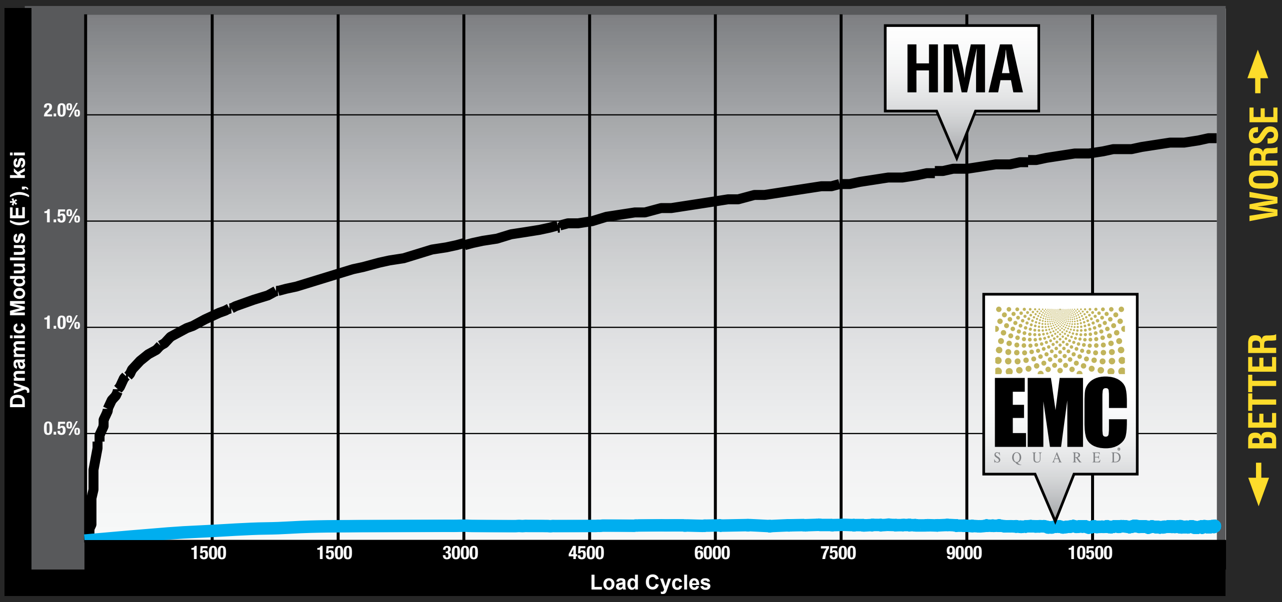
This laboratory evaluation under the direction of Dr. Sebaaly included both Dynamic Modulus (E*) and Repeated Load Triaxial (RLT) testing (included on page 3), the state of the art test methods for evaluating Hot Mix Asphalt (HMA) materials and providing input for AASHTO MEPDG pavement designs. EMC SQUARED® Stabilized Aggregate materials exhibit flexible, or elastic behavior, and modulus values most similar to HMA materials. Consequently, those test methods are equally appropriate for evaluation of these stabilized aggregate materials and for pavement design purposes. The study found that the Dynamic Modulus property of the stabilized aggregate after one week of curing was in the range of 450,000 to 500,000 psi and that it was a very stable material that could be expected to resist permanent deformation very effectively and without excessive stiffening and risk of shrinkage cracking. Dr. Sebaaly states "The combination of the elastic behavior of the EMC SQUARED stabilized aggregate material with its good level of long-term modulus makes it an appropriate choice for pavements serving heavy loads at slower speeds (worst case conditions) as well as for pavements subjected to standard loading conditions." Unlike HMA materials, which are weakened by increasing temperatures and slower loading conditions due to their highly viscoelastic nature, the study found that changes in loading frequency and temperature, from below freezing to 130°F temperature, had minimal impact on the modulus of the EMC SQUARED Stabilized Aggregate, and that the EMC SQUARED Stabilized Aggregate can therefore be represented by an average constant Dynamic Modulus property of 475,000 psi (versus the Master Curve required for HMA to address the fact that the strength of HMA is reduced as temperature or loading increases).

Comparison of Typical Permanent Deformation Characteristics

HOT MIX ASPHALT (HMA) MIXTURE

with

EMC SQUARED® STABILIZED AGGREGATE

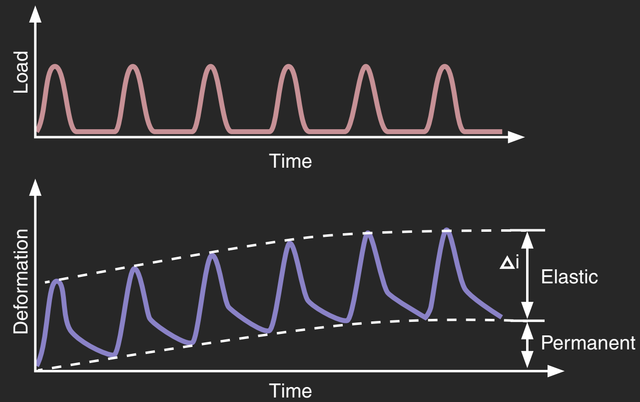


compared with EMC SQUARED Stabilized Aggregate Cured for 72 hrs at 104°F.

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.

Repeated Load Triaxial Setup



Loading and Response

Aggregate Materials Treated with EMC SQUARED® Stabilizer Average 1.7 times stronger than Typical Hot Mix Asphalt at 70°F

7.5 times stronger than Typical Hot Mix Asphalt at 100°F

23.7 times stronger than Typical Hot Mix Asphalt at 130°F

Typical Hot Mix Asphalt		EMC SQUARED System	
19,000 psi	130°F	451,000 psi	23.7 Times Stronger
62,000 psi	100°F	462,000 psi	7.5 Times Stronger
277,000 psi	70°F	483,000 psi	1.7 Times Stronger
1,092,000 psi	40°F	508,000 psi	
DYNAMIC MODULUS [E*]	TEMPERATURE	DYNAMIC MODULUS [E*]	

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.

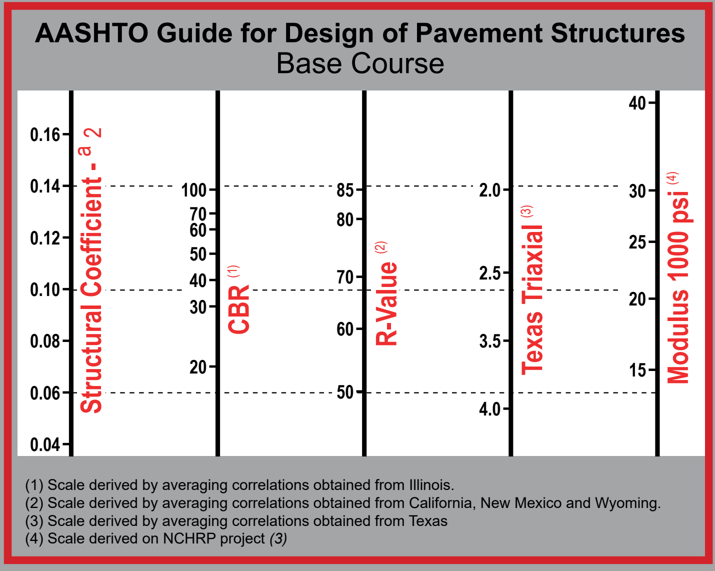
Dynamic modulus is the main input required for design of Hot Mix Asphalt (HMA) pavements using the nationally recognized AASHTO Mechanistic-Emperical Pavement Design Guide (MEPDG). HMA pavement materials are viscoelastic in nature and their dynamic modulus values vary dramatically in response to changes in loading rate and temperature. For example, HMA materials exhibit much lower dynamic modulus values (significant strength loss) as pavement temperatures increase. In contrast, dynamic modulus testing shows that EMC SQUARED Stabilized Aggregate materials retain a relatively consistent dynamic modulus (consistent strength) through the full range of loading rates and temperature changes, indicating elastic rather than undesirable viscoelastic behavior.

Field Testing – Falling Weight Deflectometer Testing (FWD)

One of the many benefits of conducting Resilient Modulus testing in the materials laboratory is that laboratory test results and design assumptions can be verified in the field with Falling Weight Deflectometer (FWD) testing as part of the road construction process. Knowing that typical subbase aggregate materials have modulus values in the range of 15,000 psi, and that higher quality aggregate base course materials are commonly in the range of 25,000 to 50,000 psi, the standard modulus of these conventional road construction materials can be used by the design engineer as the base line for evaluating the equivalency of stabilized soil layers of similar thickness.

<u>Fort Bliss Army Base – Texas/New Mexico</u>

The photo at right shows a FWD testing appartus evaluating the strength of a stabilized heavy haul road at Fort Bliss after several months in service under heavy haul trucks and tracked military equipment. The FWD equipment is capable of simultaneously providing Resilient Modulus measurement of both the Stabilized Aggregate Surface Course layer and the Stabilized Soil Subgrade layer below in a non-destructive manner (no coring or extraction of sample materials from the constructed road is required) while testing the performance of many miles of road in a single day. The analysis of the FWD field testing data for this stabilized road project resulted in an average layer moduli for the stabilized soil subgrade layer of 40,000 psi[1], equivalent to the strength of crushed aggregate base course materials. Using the comparative chart provided by the American Association of State Highway Transportation Officials (AASHTO) for correlation with other standard index tests for additional perspective, the FWD testing demonstrated that the stabilized subgrade soil was significantly stronger than 30,000 psi, the Resilient Modulus value that correlates with a CBR of 100, an R-Value of 85, a Texas Triaxial of 2.0 and a Structural Coefficient of 0.14. These test values from this group of five standard highway industry test methods are all representative of good quality crushed aggregate base course materials. The higher moduli of the native soil materials stabilized with the EMC SQUARED® Stabilizer treatment (40,000 psi) at Fort Bliss demonstrates in materials engineering measurements the effectiveness of this advanced broad spectrum stabilization technology. The FWD test results validated the project engineer's decision to approve a cost-saving design using an EMC SQUARED System product to replace twelve-inches of aggregate subbase with twelve inches of stabilized soil. The resulting savings funded the construction of over twenty additional miles of stabilized heavy haul roads.



[1]FWD testing by Fugro Consultants and data analysis by Peter Sebaaly, Ph.D., P.E., Director of the Western Regional Superpave Center, Professor, Civil and Environmental Engineering Department, University of Nevada Reno.

Field Testing – Falling Weight Deflectometer Testing (FWD)

Mountrail County – North Dakota

In contrast to the haul road project at Fort Bliss, which is close to the southern border of the United States, a county road project in the Bakken Field in northwestern North Dakota also used FWD testing to verify the performance of the subgrade stabilization treatment. It too validates the assumptions used by the design engineer that were based upon Resilient Modulus testing as the input for the AASHTO 2002 Mechanistic-Empirical (M-E) Pavement Design Method conducted prior to design and construction. FWD testing was conducted by American Engineering Testing, Inc. prior to placement of the asphalt pavement. The modulus of stabilized subgrade was 16,400 psi, which was higher than the design assumption, which was 12,000 psi, based upon the laboratory test results for the stabilized soil specimens cured for only 7 days. Interestingly, the poor quality local subbase aggregate tested at only 8,600 psi, supporting the design engineer's choice to replace fourteen-inches of this subbase aggregate material with twelve-inches of EMC SQUARED® stabilized subgrade soil. In addition to eliminating the costly aggregate subbase materials, the M-E Pavement Design also allowed the project engineer to reduce the thickness of the asphalt pavement, saving the county major money on two road construction projects totalling 15 miles in length. The FWD test results confirmed the stabilized road was superior in performance to the conventional design. While the County subjected their other roads to load restrictions during the spring freeze-thaw season, they did not subject these two roads with EMC SQUARED Stabilized Subgrades to spring load restrictions in spite of their use by high frequency traffic of heavily loaded oilfield service trucks.

City of Clovis – California

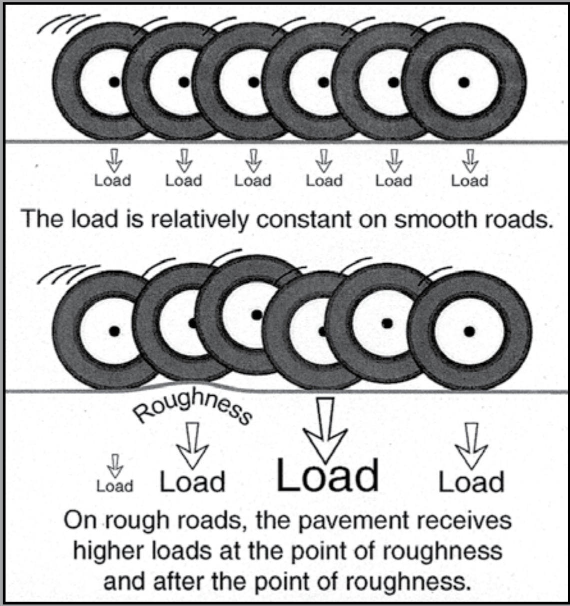
The geotechnical engineering consultant providing design and construction management services for a one mile long segment of an expressway project for the City of Clovis used Resilient Modulus testing as the design input for their M-E Pavement Design and as a quality control test for the stabilized materials during construction. FWD Testing after the project was completed verified that the stabilized base course and stabilized subgrade of the constructed road project exceeded the design assumptions and provided a road structural section that was 60% stronger than the recently completed section of adjacent expressway that had been built using conventional Caltrans Design that required a thicker asphalt surface course and a thicker base course constructed with imported aggregate base materials. Based upon the Resilient Modulus input, the M-E Pavement Design method allowed the design engineer the option to reduce the required layer thickness of asphalt pavement and to eliminate the need to import 640 truck and trailer loads of aggregate base material by stabilizing four-inches of recycled asphalt pavement (RAP) millings and twelve-inches of native soil. Both recycled asphalt and the native soils were treated with the same EMC SQUARED System stabilizer product. Submitting a report on the project to the California Department of Transportation (Caltrans) for a potential innovation award, the City reported a twenty-five percent costs savings on the overall project, and a reduction in project-related air pollution of 15% by the elimination of the trucking haul for the 16,000 tons of imported crushed aggregate that otherwise would have been required to build the road. The City also cited the benefits of improved safety, traffic congestion relief, and the protection of the connecting road systems.

FWD TESTING VERIFIES THAT USE OF RESILIENT MODULUS INPUT FOR M-E PAVEMENT DESIGN CAN REDUCE STRUCTURAL SECTION LAYER THICKNESS REQUIREMENTS AND REDUCE COSTS FOR ROAD OWNERS WHILE CONSTRUCTING BETTER PERFORMING ROADS.

International Roughness Index (IRI) – The Ultimate Test of Subgrade Stabilization

Tests conducted in material testing laboratories are known as accelerated tests. They attempt in a matter of days or weeks to predict the performance of road construction materials in the actual service environment over periods of many years. Falling Weight Deflectometer (FWD) testing that is conducted in the field during and after construction is superior to laboratory testing as the FWD test measures the modulus of the materials at multiple locations in the completed road construction project, rather than evaluating a few small laboratory specimens in a laboratory testing apparatus. What both laboratory testing and FWD testing lack is the ability to evaluate the performance of the full scale road networks on a continuing basis over the life of the pavement project. The National Cooperative Highway Research Program (NCHRP) began the development a test method that could evaluate the performance of road systems over a period of years and that effort was continued by the World Bank in the 1980's. They developed a standardized international method to measure the rate at which a pavement develops roughness. 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 and roughness severity. Known as the International Roughness Index (IRI), this test method became the generally accepted index for predicting the limits of the remaining service life of a specific section of highway pavement. IRI measurement has been in nationwide use since 1990 when the Federal Highway Administration (FHWA) mandated implementation of annual IRI evaluation of highways by all state highway agencies. IRI testing of highway pavements is conducted with equipment known as Profilers or Profilometers.

The goal of subgrade stabilization in highway construction, besides providing an all-weather working platform for the contractor during the construction phase, is to maintain pavement smoothness by protecting against differential settlements. In areas where pavements historically developed roughness at a rapid rate, soil stabilization treatments were often specified by highway design engineers as a measure to prolong pavement smoothness and good ride quality. Given the close relationship of subgrade stabilization and pavement smoothness, IRI measurement became the ultimate test for the effectiveness of various soil stabilization treatments. IRI testing can determine on a project specific basis whether a particular soil stabilization treatment was effective in prolonging pavement smoothness over time, or whether the stabilization product applied was actually counterproductive and accelerated the rate at which the pavement experienced increased roughness.



How Pavement Roughness Generates Dynamic Loads

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 and roughness severity.

After 18 Years – Surface Condition and IRI Rating

Use and Performance of Advanced Soil Stabilization

Synthesis Summary of Projects in Dallas, Texas — ARA Report No. 003563-1*

Project Identification	Surface Condition Category	IRI Category
Interstate Highway 30 (TxDOT - Dallas Fort Worth Turnpike)	Excellent	Good
SH 161 (NTTA - President George Bush Turnpike, DNT-346)	Excellent	Good
SH 190 (NTTA - President George Bush Turnpike, DNT-323)	Excellent	Good
Interstate Highway 635 Frontage Road (TxDOT - LBJ Freeway)	Excellent	Good
Luna Road (TxDOT)	Good	Good

For the past thirty years, road and highway projects constructed with EMC SQUARED® System stabilizers have demonstrated the capability of this advanced stabilization product technology to build roads that are strong, durable and uniquely smooth running. The five projects listed above included four Dallas Area freeways and a major arterial expressway. A later review study confirmed the contribution of the EMC SQUARED System product technology to the construction of smooth running highways. The study incorporated the most up to date IRI data collected by the two public agencies responsible for the construction and maintenance of these highway projects, the Texas Department of Transportation (TxDOT) and the North Texas Tollway Authority (NTTA).

As of 2018, these five projects had all been in service for approximately 18 years. All five projects presented the challenge of constructing pavements over famously problematic expansive soils with a history of cracking, buckling up and heaving asphalt and concrete pavements constructed on top of them. Two of the four freeway projects were the subject of the Tx-98/3929-1 Research Study that recommended the use of EMC SQUARED System products for subgrade stabilization. Lime treatment, the traditional chemical stabilizer used throughout Texas was found to be ineffective, and in fact counterproductive, when applied to these Dallas Area soils. The study was tasked with identifying an effective alternative to lime treatment. The study found that EMC SQUARED System products were superior to lime in strength, stiffness, swell resistance and permeability and it recommended use of EMC SQUARED System products for all projects with similar problem soils.

The four freeway projects that were subsequently constructed in Year 2000 and evaluated in 2018, as shown above, were all constructed on top of highly problematic soils. They were constructed with proper drainage conditions. The alignment of the fifth project, a major six-lane arterial (Luna Road) located in the Trinity River Watershed, required construction of a tall embankment running through two lakes. The design consultant (HDR Engineering) protected the stability of the clay embankment soils by including a 12-inch thick EMC SQUARED System moisture barrier layer within the lower portion of the embankment just above the water level of the lakes.

These freeway and highway projects have now been in service under very heavy traffic volume for more than twenty years since their construction. As shown above, results from ARA Report No. 003563-1 confirm that the pavements constructed on top of subgrades stabilized with the EMC SQUARED System treatments remain in Excellent condition overall. The International Roughness Index (IRI) test results demonstrate that the stabilized subgrades are performing very well. The ARA Report validates the findings of Dr. Robert Lytton at the Texas Transportation Institute (TTI) in his Tx-98/3929-1 Research Study recommending the EMC SQUARED System stabilizer products for effective treatment of these highly problematic soils.

* Harold L. Von Quintus, P.E., Applied Research Associates, Inc.

Recommended Laboratory Test and Design Methods

The laboratory and field test results reported on the previous pages are specific to the aggregate or soil material sampled for testing and to the independent materials testing laboratory that conducted the testing. Field test sections or laboratory testing are therefore recommended to determine the suitability of each aggregate or soil material in regards to their performance as a stabilized material for a project specific application. Index test methods such as the California Bearing Ratio (CBR), R-Value and Texas Triaxial are among the laboratory tests that have historically been used to evaluate the strength and stability of untreated aggregate, recycled pavement materials, and soils. When it comes to evaluation of aggregate and soil materials treated with EMC SQUARED System stabiilizer products, the recommended laboratory test is the Resilient Modulus test (AASHTO T 274), as standardized by the American Association of State Highway and Transportation Officials (AASHTO). Resilient Modulus testing evaluates the response of base course materials and subgrade soils to dynamic loading (representing repeated passes of cars and loaded trucks over a pavement structural section). It is a laboratory testing procedure that more realistically characterizes the engineering properties of road building materials than earlier generation test methods, and it provides a means to determine the equivalency of various materials in regards to their ability to support dynamic or repetitive loading. While local materials testing laboratories may not yet have Resilient Modulus testing equipment available in house, stabilized specimens can be prepared in the local laboratory and shipped out to materials testing laboratories currently providing Resilient Modulus testing services. Dynamic Modulus Testing may also be appropriate for evaluating the performance of stabilized aggregate and recycled pavement materials used as surface course pavement layers.

The Federal Highway Administration (FHWA) has promoted national standardization through AASHTO, and these standards are typically used on federally aided highway projects. Starting in 1996, AASHTO sponsored the development of what is now known as the AASHTO 2002 Mechanistic-Empirical (M-E) Design Guide, based upon an extended nationwide field-testing study and the use of Resilient Modulus and Dynamic Modulus laboratory testing. M-E Pavement Design is far more sophisticated in regards to specific traffic loading, climatic conditions, design life and the ability to model real-world performance and changes in material properties. It facilitates better-informed decisions and takes advantage of new materials, products, and features. FHWA's long term goal is to have all state transportation agencies fully adopt the AASHTO 2002 procedures as part of a nationwide standardization of testing and design methods. Whenever possible, use of the M-E Pavement Design method is recommended in order to take the fullest advantage of the economical EMC SQUARED® System products to improve the strength and modulus of both base course materials and subgrade soils and potentially reduce the layer thickness requirements for pavements constructed with costly asphalt and concrete materials.

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