SUMMARY OF RESEARCH REPORT 3929-1

A review of research performed at the Texas Transportation Institute (TTI)

EMC
SQUARED

Advanced Stabilization Technology

An Effective Solution

Reduces Moisture Susceptibility of Aggregates and Soil Materials and Is an Effective Alternative to Lime for Treatment of Expansive Clay Soils

The benefits of stabilizing problem soils and aggregate base materials (flexible base) are well established. However, the limitations in performance and cost-effectiveness of conventional chemical treatments (i.e., cement, lime and fly ash) are equally real. For example, aggregate base materials treated with 6 percent cement have failed under asphalt pavements on Texas Department of Transportation (TxDOT) projects and other sites with similar problems due to their inability to resist moisture infiltration. Moreover, all three of these conventional calcium based stabilizers have proven ineffective with the sulfate rich expansive clay soils well known in Texas and several other states. Another restriction for conventional stabilization efforts is that cement, fly ash and lime are often unavailable for stabilization projects due to limitations in supply. Advanced stabilization product technology is available to address many of these requirements at far lower installed cost than the conventional calcium based chemical products.

...aggregate base materials treated with 6 percent cement have failed under asphalt pavements ... due to their inability to resist moisture infiltration.

It is well known that moisture infiltration reduces the strength and stiffness of most aggregate base materials and subgrade soils. The failure of cement treated base materials, designed relying upon the old standardized index tests which provide no direct measure of moisture susceptibility, were a fairly clear indication that advances in both testing and product technology would be needed to more effectively address the problem. However, a testing methodology has been developed which provides a long needed performance based test method for identifying moisture susceptible aggregate base materials and for evaluating the effectiveness of stabilization treatments. The research conducted by the Texas Transportation Institute with sponsorship fromTxDOT and the U.S. Department of Transportation, Federal Highway Administration (FHWA), was focused on using electrical properties for the classification of strength properties of base course aggregates. The Minnesota Department of Transportation's (Mn/DOT's) Minnesota Road Research Project (Mn/ROAD) is now utilizing this testing methodology in their program, and it is being incorporated in the National Cooperative Highway Research Program's (NCHRP's) study, "Performance Related Tests of Aggregates for Use in Unbound Pavement Layers." Further information on the resulting Suction and Dielectric test methodology is provided in the paper entitled, "Use of Tube Suction Test for Evaluation of Aggregate Base Materials in Frost/Moisture Susceptible Environment" (Syed, et. al, 2000). This paper addresses laboratory testing conducted at the Texas Transportation Institute as a followup study to three earlier field projects where aggregate base materials were treated with an EMC SQUARED® System treatment from Stabilization Products LLC. The document entitled "Treatment of Moisture and Frost Susceptibility," is available here – http://stabilizationproducts.net/docs/18587.pdf .

...a testing methodology has been developed which provides a long needed performance based test method for identifying moisture susceptible aggregate base materials...

The Suction and Dielectric Test method provides the advanced testing needed to more directly measure the moisture sensitivity of earth materials...

The Suction and Dielectric Test method provides the advanced testing needed to more directly measure the moisture sensitivity of aggregate and soil materials (and frost susceptibility in cold climate areas subject to freeze-thaw cycles). This new window into the engineering characteristics and performance of earth materials confirms the unique capabilities of the EMC SQUARED and EMS® Concentrated Liquid Stabilizers to treat these problems, previously reported in field test results and actual installation experience (Transportation Research Record 1589, 1997), and illuminates and explains much of that success. This advanced treatment system is effective with a wide range of aggregate base course materials as well as clay and silt soils.

IN SEARCH OF...
Moisture Resistant Stabilization

Cement and lime have long been in use, with varying degrees of effectiveness, for improvement of aggregate and soil as load bearing structures and earthworks. The high costs of these calcium based stabilizing agents has inhibited wider use of stabilization in most areas. Fly ash is also utilized on a limited basis, most often in combination with cement or lime, in order to attain the required engineering values. As with all methods of chemical and mechanical soil stabilization, they are not appropriate and cost-effective for all applications. Costly sulfate swell problems basically eliminate cement, lime and fly ash as treatments for high sulfate expansive clay soils.

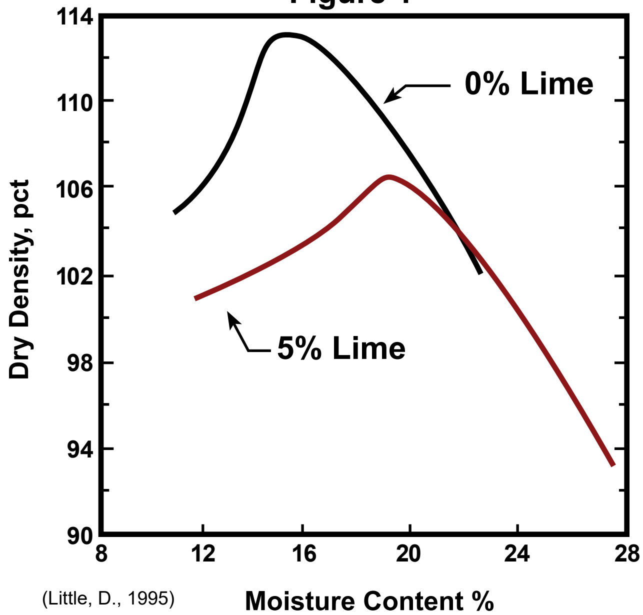
The limited ability of heavily cement treated aggregate base materials to resist weakening by moisture infiltration has led to pavement failures in warm as well as cold climate areas and brought the use of calcium based stabilizers into question for these applications as well. Additionally, when used in applications where the treated materials remain susceptible to moisture infiltration, lime and cement products are prone to leaching, a phenomenon which reverses the stabilizing influence of the chemical treatment. While higher additive rates may help solve these problems, the increased cost may rule out use of stabilization treatment entirely when calcium based chemicals are the only stabilization technology under consideration.

The moisture susceptibility of cement and lime treated materials is less surprising when the effect of these chemicals on the optimum moisture content, density and permeability of aggregate and soil materials is understood. Cement and lime treated soils require more water than untreated soils to reach their optimum moisture content for compaction. Cement and lime generally reduce the maximum dry density. The Handbook for Stabilization of Pavement Subgrades and Base Courses with Lime, sponsored by the National Lime Association, states, "The reduction in maximum dry density is typically from 48 to 80 Kg/m3 (3-5 pounds per cubic foot) with a typical increase in optimum moisture content of 3-4 percent, Little et al. (1987)."

The limited ability of heavily cement treated aggregate base materials to resist weakening by moisture infiltration has lead to pavement failures...

"However, in highly plastic clays, substantially greater increases in optimum moisture may be realized...If a mixture is allowed to cure and gain strength prior to compaction, further reduction in maximum dry density and an additional optimum moisture content increase may be noted." (Little, D, 1995) It should be noted that other researchers (Fahoum and Aggour, 1995) have found reductions in maximum dry density as great as 13 percent and increases in optimum moisture content as great as 14.6 percent with the addition of lime to medium plasticity soils, and reductions in maximum dry density as great as 15 percent and increases in optimum moisture content as great as 29 percent with the addition of lime to highly expansive soils.

Figure 1



Shift In Density and Optimum Moisture Content Resulting from Lime Treatment

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Lime treatment can also significantly increase the permeability of treated soil materials, exposing the treated soil to a higher rate of moisture infiltration. This is a trade-off for stabilization benefits, a trade-off which can reverse those benefits over time, due to the susceptibility of the material to leaching of the chemical treatment by water infiltration. For example, the average of the optimum moisture content for the two lime treated clay soils in the Texas Transportation Institute research summarized in Table 1 was approximately 16% higher than the untreated soils and approximately 25% higher than the soils treated with the EMC SQUARED System Stabilizers. The additional moisture content contributes to a less dense, weaker structure which must undergo a certain degree of shrinkage and potential cracking as water evaporates out of the expanded and more permeable structure created by lime treatment.

PROJECT	EMC SQUARED System	LIME Treatment
SH 161	14.4%	20.2%
IH 635	15.4%	17.1%

(Rajendran & Litton, 1997)

Table 1
Optimum Moisture Content

In the same testing series (Table 2), the lime treated soils averaged approximately 9% lower density than the EMC SQUARED System treated soils and were more permeable to water.

PROJECT	EMC SQUARED System	LIME Treatment
SH 161	113 lbs/cf	104 lbs/cf
IH 635	117 lbs/cf	107 lbs/cf

(Rajendran & Litton, 1997)

Table 2
Dry Density at Optimum Moisture

PROCEDURAL NOTE: Figures and Tables in this technical bulletin reflect averages of measures taken on multi-specimen testing groups.

Given the high water content required for application of lime, cement and fly ash treatments and the low density of the compacted materials, it is no wonder that these calcium based stabilizers are at their weakest when criteria such as permeability and moisture resistance are incorporated in testing programs. As addressed in "Handbook for Stabilization of Pavement Subgrades and Base Courses with Lime" (Little, D., 1995), a publication sponsored by the National Lime Association, permeability increases significantly upon lime treatment as the result of pore volume increases due to flocculation. Researchers found that the permeabilities of expansive clay soils were 7 to 300 times more permeable after lime treatment. Further perspective on lime treatment is provided in "Lime Treatment Tradeoffs," an article also available on the SP LLC website. http://stabilizationproducts.net/docs/18392.pdf

With advancements in stabilization now available, highway engineers and contractors no longer need assume that shrinkage cracking is an inevitable side effect of treating aggregate base course materials and subgrade soils with chemical stabilizers. It is true that shrinkage cracking is a natural and unavoidable problem which accompanies cement and lime treatment. Expensive bituminous curing membranes are specified to limit the extent of the cracking, but reflective cracking of overlying asphalt pavements is a not unexpected occurrence above cement and lime treated base materials.

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In contrast, materials treated with the EMC SQUARED System are compacted in place at higher density, at far lower moisture content, and without any built-in chemical reactions which cause shrinkage cracking.

While cement has often been the product of choice on highway projects for treatment of aggregate base course materials, lime has been the dominant product in use for treatment of highly expansive clay soils. The potential effectiveness of lime treatment can be negated in the presence of what are termed "nonreactive clays" (where pozzolanic and cementing reactions are inhibited), or clays that have more than one percent organic content. The limitations of lime in treatment of low PI and silty soils are well known, and its costly failure to treat sulfate rich clay soils has been well documented. Sulfate swell is activated by the addition of lime and other calcium based stabilizers, and the resulting expansion causes heaving, cracking and buckling of pavements.

The State of Texas is one of a number of states where expansive clay problems are further exacerbated in some areas by high sulfate content; and, the Department of Transportation (TxDOT) has had its share of experience with sulfate swell damage to highways. On TxDOT SH 161 (7% lime treatment), heaving was observed within six months of construction. The highway section was then reconstructed with a double application of lime, but once again heaving was observed, this time within two months of reconstruction. In another TxDOT project, SH 118, heaving occurred in both lime and cement treated sections within several months of construction. On TxDOT IH 635, the sulfate induced heaving from the lime treated subgrade was so pronounced that the pavement was providing poor rideability and some of the heaves were cracking the pavement.

The photos below show the laboratory results of swell tests conducted with expansive clay soils from both TxDOT SH 161 and TxDOT IH 635 highway projects. In both cases, the calcium-based lime treatments reacted deleteriously with the natural sulfate content of the clay soils. As indicated in the photos, the sulfate swell reaction generated by the lime treatment was far more severe than the swell exhibited by the untreated or "raw" expansive clay soil.

Figure 2 - Photograph Showing Comparisons of Swell (Lime vs Raw) - SH 161

Figure 3 - Photograph Showing Comparisons of Swell (Lime vs Raw) - IH 635

The sulfate content of the SH 161 and IH 635 soils are provided in Table 3 above. (Rajendran and Lytton, 1997)

PROJECT	ELECTRICAL CONDUCTIVITY	SULFATE CONTENT (ppm)
SH 161	2.52	5337
	2.28	3826
IH 635	1.74	2641
	0.90	2631
	1.65	1766

Table 3 Sulfate Content

According to information released by TxDOT on the sulfate swell problem, appropriate application of alternate stabilizers could save the State of Texas $23 million a year in repair costs. Fortunately, state funded research has demonstrated in a laboratory research program using the soils from the IH 635 and the SH 161 projects that advanced stabilization technology is available at far lower cost to effectively treat these "problem soils."

TEXAS TRANSPORTATION INSTITUTE CONFIRMS

Superior Solution Available Now

Researchers at the Texas Transportation Institute, in a study funded by TxDOT to address the sulfate swell problem, concluded that the EMC SQUARED System product technology from Stabilization Products LLC, provides an effective alternative to lime treatment. This study, recently completed at Texas Transportation Institute, verified that the EMC SQUARED System was "superior to lime in terms of strength, stiffness, permeability and swell resistance" and recommended its use at the two TxDOT sites in place of lime and "at all other sites where soils that are high in soluble sulfates are encountered." (Rajendran, D & Lytton, R, 1997)

"...superior to lime in terms of strength, stiffness, permeability and swell resistance..."

THE EMC SQUARED SYSTEM

It is important to note that the EMC SQUARED System provides a distinct alternative to lime. While lime products are highly alkaline (extremely high pH) chemicals supplied in bulk quantities as powder or slurry additives, EMC SQUARED System products are neutral and supplied as concentrated liquids (Concentrated Liquid Stabilizers or CLS products) which are diluted with water prior to application at the project locations. Lime treatment attempts to create a high pH environment in the soil mixture in order to increase its stability. The neutral pH EMC SQUARED System treatments improve the stability of aggregate and soil materials without radically changing their pH characteristics. Although lime treatment will generally increase the strength and stiffness of clay soils, it typically also reduces their maximum dry density and increases their Optimum Moisture Content and permeabilty. EMC SQUARED System treatments generally increase strength and stiffness in soil materials, but affect all these other engineering properties in a direction opposite to that of lime.

EMC SQUARED System products also provide a distinct alternative in regard to protection of workers, construction equipment and the environment. No special protective clothing or equipment is required for their handling. The products are non-toxic, non-hazardous, non-reactive, non-flammable, and non-corrosive. Laboratory analyses, including testing funded by the US EPA, have verified that EMC SQUARED System products have no detectable levels of ingredients of environmental concern and that they are appropriate for use even in sensitive wetland areas.

STRENGTH AND STIFFNESS

The results of the Triaxial Testing conducted at the Texas Transporation institute are provide below in Tables 4 and 5. The comparison with lime treatment for these particular soils indicates that the EMC SQUARED System Dual Component Treatment clearly provides superior performance.

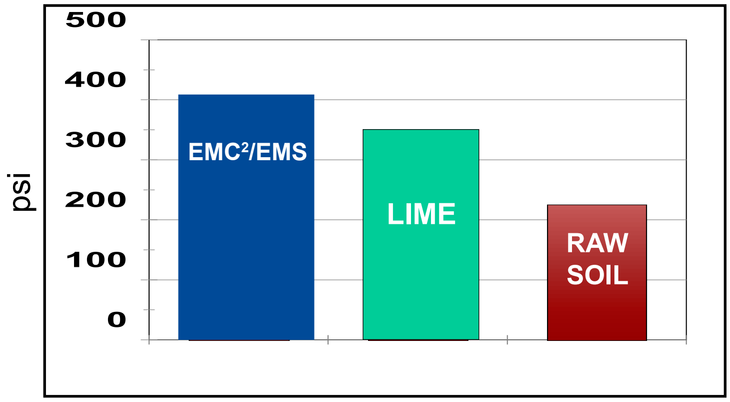
Table 4
STRENGTH AND STIFFNESS MEASUREMENTS - IH 635

TxDOT IH635 TREATMENT	STRENGTH psi (kPa)	STIFFNESS psi (kPa)
EMC SQUARED & EMS	412.56 (2,844.51)	2,324.8 (16,029.01)
LIME	353.61 (2,438.06)	1,228.96 (8,473.39)
NOT TREATED	217.39 (1,498.86)	833.33 (5,745.61)

Table 5
STRENGTH AND STIFFNESS MEASUREMENTS - SH 161

TxDOT SH161 TREATMENT	STRENGTH psi (kPa)	STIFFNESS psi (kPa)
EMC SQUARED & EMS	399.04 (2,751.29)	5,000.00 (34,473.79)
LIME	341.55 (2,354.91)	3,166.67 (21,833.43)
NOT TREATED	232.56 (1,603.45)	588.24 (4,055.78)

Figure 4
Comparative Strength
(Average of IH 635 and SH 161)



MOISTURE SUSCEPTIBILITY TESTING

Electrical Property Measurements

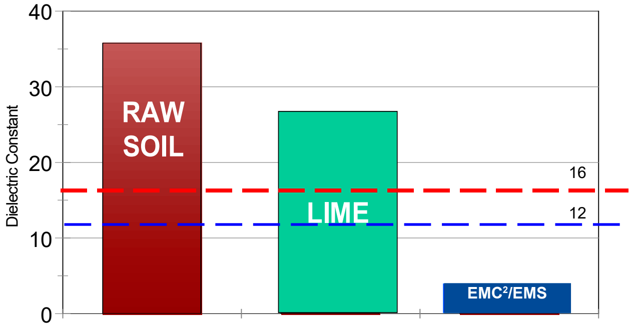
Just as Suction and Dielectric measurements were taken of stabilized aggregates and untreated aggregates to determine their moisture susceptibility, Texas Transportation Institute researchers subjected both untreated or "raw" soil specimens and stabilized specimens to electric property measurement. One hundred milliSiemens per centimeter was set as 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 in Table 6 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.

Table 6
Electrical Conductivity - SH 161
(EMC SQUARED/EMS Treated)

E.C. (mS/cm)	E.C. + Water(mS/cm)
53.75	34.50

As indicated below in Figure 5, the dielectric measurements for the EMC SQUARED System treated specimens were well below 12, the value established by researchers as 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 16, 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. Notice also in Figure 5 that the untreated or raw 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.

Figure 5
Dielectric Constant - SH 161



PERMEABILITY MEASUREMENTS

The Suction and Dielectric measurements address the affinity or susceptibility of an earth material to soak up moisture from soils below and to infiltration by rain water. Permeability is a measure of the velocity of water, subject to a certain head of pressure (modeling a situation in which water would be flooding and deeply ponded on the soil surface). While properly designed road structures are rarely, if ever, immersed under water or subject to water applied at high positive pore pressures, materials testing science is limited in its ability to predict water flow through soil materials that are not already saturated. Consequently, permeability or hydraulic conductivity testing is often utilized to compare the moisture barrier aspects of untreated and chemically treated soils. While a treated subgrade or base course may successfully resist moisture infiltration and perform year round in an unsaturated condition, capable of maintaining an optimum state of strength and flexural stiffness (leading one to question the utility of testing based upon the assumption of saturation), testing science protocols still suggest that permeability testing can provide valuable, if indirect, information that can be an indicator of performance in load bearing or structural fill applications.

> *...permeability of less than one thousandth of an inch per month...*

The Texas Transportation Institute permeability test data on the soils treated with the EMC SQUARED/EMS Dual Component Treatment indicate that the treated soil specimens function as extremely low permeability barriers to moisture flow. The treated SH 161 soils had a permeability of less than one thousandth of an inch per month, or 8.9 x 10^{-10} cm/sec., approximately 111 times more impermeable to water than the US EPA's minimum standard for landfill clay liners. Research indicates that a soil with this degree of impermeability is highly resistant to hydraulic flow. In fact, flow through a material of permeability 1 x 10^{-8} cm/sec or less is primarily by molecular diffusion. Such an impermeable material becomes a diffusion barrier as well as a hydraulic barrier.

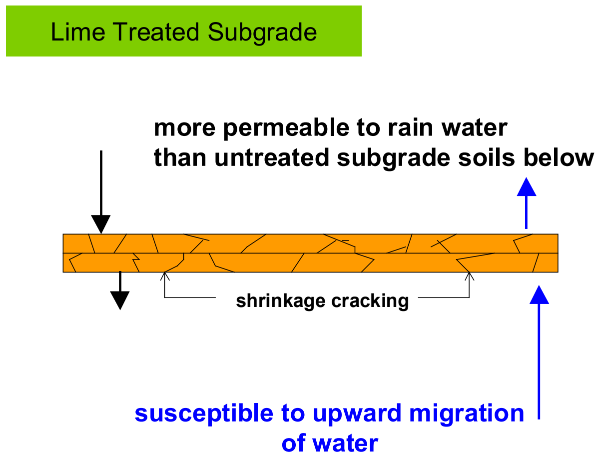
Conclusions and Recommendations

As previously quoted from the Texas Transportation Institute report, the EMC SQUARED System provides an effective alternative treatment to lime for these sulfate bearing highly expansive clay soils. The EMC SQUARED System treatment was found superior to lime in strength, stiffness, swell resistance and permeability and was recommended for the SH 161 and IH 635 projects and for any other projects where sulfate problems are identified.

THE BIGGER PICTURE

Moving beyond the news that effective stabilization treatment has been confirmed for sulfate bearing expansive clay soils, the Texas Transportation Institute research illuminates a far greater advance in material treatment technology that expands the benefits of base course treatment and subgrade treatment beyond the highway structural section itself. As addressed earlier, the calcium based stabilizers (cement, fly ash and lime) are relatively ineffective when it comes to addressing moisture flow through the treated aggregate and soil mixture. It is generally understood that many untreated aggregate base materials and most cohesive and silty subgrade soils are moisture susceptible and subject to loss of flexural stiffness as they become saturated. What is not generally understood is that addition of the conventional calcium based stabilizers can change the physical properties of the material into a lower density structure with greater pore and void space and reduced effectiveness as a barrier to moisture flow.

Figure 6

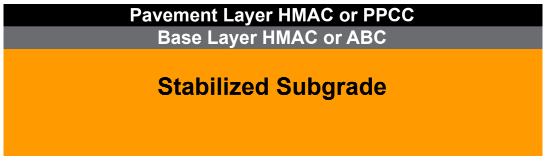


While attention is normally focused on the high compressive strengths of the treated materials (and the resulting problems in the highway structure from excessively rigid base and subgrade layers and their susceptibility to cracking and reflective damage of overlying pavement layers), the fact that moisture problems remain after the calcium based treatment is applied is often surprising even to people in the highway industry. As addressed in the handbook sponsored by the National Lime Association, research has verified the tendency to increased permeability resulting from lime treatment. They also discuss the reality that leaching and reversal of stabilization benefits is often a problem in the presence of moisture flow, or in applications when a less than optimum rate of lime for that earth material has been applied.

The potential loss of stability due to reversal of a calcium based treatment is of concern within the highway structural section as the base and pavement layers are normally designed based upon an assumption of some degree of flexural stiffness in the subgrade.

Figure 7

Conventional View of Highway Structural Section



The bigger picture includes more than the pavement structural section. Seasonal changes in the moisture content of native soil materials below the pavement and constructed subgrade can create conditions where flexural stiffness is lost and where plastic deformation and soil volume changes can occur. Differential settlement related to moisture driven soil problems under the pavement structural section weaken and deform transportation structures in both warm and cold climate regions at an unacceptably accelerated rate.

Figure 8

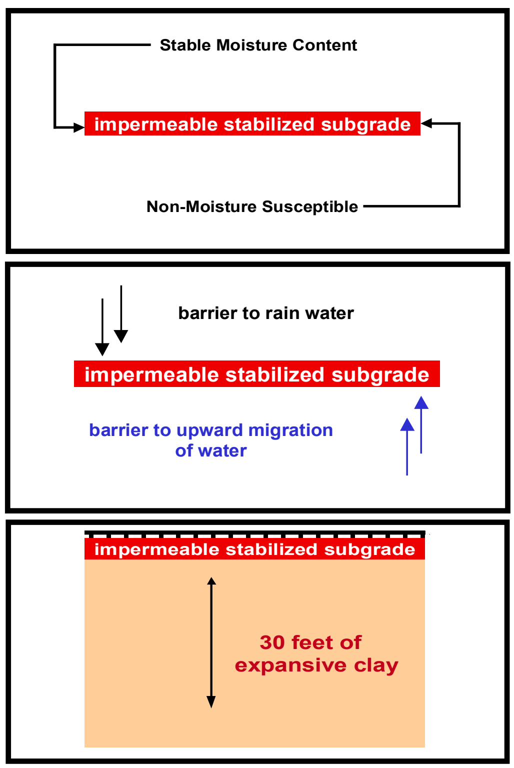
Actual Pavement Environment

Conventional calcium based aggregate and soil treatments unfortunately do little to modify the environmental factors which deform the pavement structures. A lime treated subgrade, for instance, which is more permeable to water than the native soils below, will not provide a barrier to rain water and surface moisture sources, nor to eventual upward migration of water under repetitive traffic loading and the pumping action generated in the native subgrade when saturation weakens its support characteristics. If and when the native subgrade soils begin to deform or swell in localized areas, or desiccate and shrink during drought conditions, rigid cement and lime treated base layers and subgrades are then highly susceptible to cracking, a phenomenon which increases water flow and which promotes reflective cracking in the pavement surface course layer. Moisture driven problems deep below the pavement structural section are causative factors in premature pavement failures.

The Texas Transportation Institute research program verified that the EMC SQUARED System application was effective in treatment of moisture related problems as well as providing significant improvements in strength and stiffness. As stated earlier, that part of the testing which focused on the EMC SQUARED System treatment established that it was superior to lime "in strength, stiffness, swell resistance and permeability." Translating the laboratory findings to the actual highway service environment, the report went on to state, "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...". This statement points out the fundamental advance in stabilization technology which is achieved when upward and downward flow of water is controlled by a stiffened layer within the structural section that provides an effective barrier to moisture flow.

As visualized in the three panels of Figure 9 below, the highly impermeable EMC SQUARED System treated clay is non-moisture susceptible, implying that it not only sheds water, but also that it has lost its tendency to soak up water. The stabilized layer is therefore better able to retain dry strength values and capable of maintaining a stable, or equilibrium moisture distribution within the layer. By shedding rain water away from the native subgrade soils and by not soaking water up from these untreated soils, this stable layer is also able to positively influence an equilibrium moisture distribution in the native subgrade soils below the constructed pavement structural section.

Figure 9



EQUILIBRIUM MOISTURE DISTRIBUTION IN NATIVE SOIL SUBGRADES

The Transport and Road Research Laboratory (TRRL) in the United Kingdom, a world class research organization similar to the Texas Transportation Institute, studied the issue of how pavements affect the moisture distribution in soils below pavements. They studied airport pavements in temperate, tropical, semitropical and arid zone areas. The research indicated that pavements constructed within 10 meters (32.8 feet) of the water table were effective in maintaining equilibrium moisture conditions under the pavement structure. Their work also confirmed the importance of constructing impermeable shoulders adjacent to the pavements in order to maintain this condition. In areas where the water table was deeper, generally in very arid areas, they found that the moisture distribution under pavements fluctuated more widely, similar to the moisture distribution in uncovered soils. It is reported that in these situations the moisture distribution appeared to be controlled by the atmospheric humidity. (Croney and Croney, 1997)

The EMC SQUARED System is leading that revolution. No other stabilization product technology can match the EMC SQUARED System in providing the combination of flexural stiffness, strength, low permeability and ability to treat moisture and frost susceptibility in one low cost package.

As addressed earlier, lime treatment has proven relatively ineffective in treatment of the moisture and frost susceptibility of aggregate and soil. While this calcium based treatment is often capable of significant alteration of physical properties, the resulting rigid layers generally have an expanded structure with more pore and void space and greater permeability than the native soils below. These so-called stabilized subgrades have proven susceptible to leaching of the stabilizing agents. They have not functioned well as barriers to rainwater penetration into the subgrade nor to the upward migration of water into the pavement structural section from the native soil subgrade. The limitations of calcium based treatments have been most apparent in highway and building structures constructed in areas with deep underlying deposits of expansive clays. Highways, for instance, still suffer from differential settlement or "roughness" and a need for frequent repairs and asphalt "leveling courses" in spite of the application of conventional lime treatments.

The failure of all calcium based treatments to provide effective encapsulation and protection of equilibrium moisture distribution in the native soils below highway pavements and building structures has led to increasing use of geomembrane liners, placed in both horizontal and vertical applications, to encapsulate expansive clay soils under structures in order to stop moisture fluctuations and the resulting changes in volume and flexural strength characteristics. These efforts to attack the causative agent of clay stability problems, moisture flow and moisture fluctuation, have generally been successful as reported in Geomembranes and the Control of Expansive Soils in Construction.[7] Geomembrane moisture barriers are increasingly gaining popularity as a replacement for chemical treatments which provide stiff construction platforms but lack effectiveness as moisture barriers. With the arrival of the EMC SQUARED System product technology, the best of both worlds can now be combined. The improvements in strength and flexural stiffness, common to conventional calcium based stabilizers, can be realized, while moisture barrier benefits previously limited to geomembrane installation can now be incorporated into the structural layers. The economic impact is doubly significant as EMC SQUARED System applications are far less expensive than either geomembrane installations or calcium based chemical treatments.

REVOLUTION IN MATERIALS TESTING AND TREATMENT TECHNOLOGY

The ability of a single low cost treatment system to treat the moisture susceptibility of aggregate and soil materials while also improving shear strength and bearing strength properites is a major advance over calcium based products, which have been with us for over a century and have proven to have limited value in addressing the moisture flow and moisture fluctuation problems. They also come with the extreme risk of shrinkage cracking and sulfate-induced heave. The ability to better understand and to better solve these problems is indeed a recent arrival, driven by new technology in materials testing science and in treatment technology. We can now better understand the nature of our historical problems and can understand the nature of the revolution which is underway.

The EMC SQUARED System is leading that revolution. No other stabilization product technology can match the EMC SQUARED System in providing the combination of flexural stiffness, strength, low permeability and ability to treat moisture and frost susceptibility in one low cost package. No other stabilization product technology has demonstrated a reliable track record in improvement of so broad a spectrum of soil and aggregate and recycled materials. This translates into greater assurance in field application that variations in soil types and aggregate materials can be accommodated and that money spent on stabilization treatment will contribute a positive benefit to the service life of the structure.

Taking another look at the bigger picture, it's time to move forward with this advance in stabilization technology. The future is no longer defined by the limitations of the past century during which costly calcium based treatments often proved problematic and of limited effectiveness. And, in terms of cost-effectiveness, it is clear that the EMC SQUARED System provides much more "bang for the buck."

Highway design engineers, geotechnical engineers and materials engineers have the tools now in hand. With the availability of performance based laboratory tests and advanced treatment technology, aggregate and soil problems can be properly diagnosed and effectively treated without creating negative side effects. We can now treat the problem and realize additional benefits - benefits that profoundly affect the full pavement structural section or earthwork structure. After all, a strengthened layer that provides a barrier to both moisture movement and atmospheric effects invites engineering review of environmental factors previously excluded by the narrow focus of calcium based chemical treatments.

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Note on Dr. Robert Lytton and the Texas Transportation Institute

Dr. Robert Lytton, the principal author of Report Tx-98/3929-12 which is extensively discussed here, is Research Engineer for TTI, holds the F.J. Benson Chair of the Department of Civil Engineering, and he is Director of the Center for Infrastructure Engineering at Texas A&M University. He was awarded the Year 2000 Transportation Research Board (TRB) Distinguished Lectureship. His contributions to highway engineering have been wide ranging. He has done pioneering work in prediction models for pavement response to loads, temperature and moisture. He has also made significant contributions in pavement rehabilitation and maintenance, expansive soils and foundation design, and related fields.

The Texas Transportation Institute (TTI), located on the campus of Texas A&M University in College Station, TX, is an official research agency of the Texas Department of Transportation (TxDOT) through TxDOT's Cooperative Research Program. TTI is now active in research on all modes of transportation receiving funding from such diverse sources as the Federal Highway Administration; U.S. Department of Transportation, Energy and Defense; departments of transportation of other states and nations; private industry; foundations; trade associations and technical societies. TTI is the largest university-based transportation research organization in the United States.

The Texas Transportation Institute research program verified that the EMC SQUARED System application was effective in treatment of moisture related problems as well as providing significant improvements in strength and stiffness. The testing which focused on the EMC SQUARED System treatment established that it was superior to lime "in strength, stiffness, swell resistance and permeability." Translating the laboratory findings to the actual highway service environment, the report went on to state, "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...". This statement points out the fundamental advance in stabilization technology which is achieved when upward and downward flow of water is controlled by a stiffened layer within the structural section that provides an effective barrier to moisture flow.

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