Lime Treatment Tradeoffs

Conventional Wisdom Has Its Limitations

Abstract: A decision to use lime in the treatment of soils to increase their strength or decrease their swell potential is not a routine procedure which can be left to conventional wisdom. An informed decision must be based upon current data and guidelines for use, much of which has only been developed within the last decade and is not yet widely disseminated. This paper reviews current data on the effects of lime treatment, including decreases in density and increases in permeability, and the effects of leaching on engineering properties. Plasticity issues and sulfate swell are also discussed. Some warning signs of situations in which lime treatment is contraindicated are assembled. An alternative treatment is discussed.

GENERAL BACKGROUND

Lime treatment has been utilized for several decades for chemical modification of clay soils. More specifically, it has been used (1) to increase their strength and (2) to decrease their plasticity index (soil swell potential). The increases in strength have been used to justify decreases in pavement structural section. The reductions in plasticity index (PI) have been used to extend the life expectancy of structures built over expansive clay soils. Obviously, considerable cost savings can accrue from the permanent modification of either of these engineering characteristics, and, in some geographical regions, the use of lime has become so routine and commonplace that few decision makers take the time to inform themselves sufficiently of the accumulating background of facts upon which their decision to use lime ought to be based. Effectively, they are allowing conventional wisdom, based upon data and guidelines which may be decades old, to make their decision for them - sometimes to their detriment. Mistakes in application of lime treatment can greatly exceed any and all expected cost savings when failures of lime treated subgrades necessitate the removal and replacement of the far more expensive asphalt, concrete and aggregate base course layers overlaying the lime treated soils.

Current facts are, of course, available in specialized research literature, but they are also available in Handbook For Stabilization Of Pavement Subgrades & Base Courses With Lime,[1] the instructional handbook sponsored by the National Lime Association, though its focus is appropriately upon how beneficial changes are accomplished with lime rather than upon the myriad ways that a complex system can experience problems. The quotations below, grouped into three subject areas, are taken directly from the handbook to illustrate the current background of facts which conventional wisdom seemingly ignores.

Maximum Density

"These moisture-density changes reflect the new nature of the soil and are evidence of the physical property changes occurring in the soil upon lime treatment. For a specific compactive effort, lime-treated soil has a lower density and a higher optimum moisture content than does the untreated soil. 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 2-4 percent, Little et al. (1987). 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."*[2]

In commenting that the lime treated soil has a "new nature," the handbook is noting that the lime treated soil has a different cluster of engineering characteristics than before treatment. It is not just stronger and less plastic when initially treated, it is also less dense and responds differently to moisture. Lime acts to reduce the maximum compacted density below that which

[1] Little, Dallas N., Handbook for Stabilization of Pavement Subgrades and Base Courses with Lime, Kendall/Hunt Publishing Company, Dubuque, IA, 1995.

[2] Op. Cit., page 78.

Stabilization Products LLC
Ph: (209) 383-3296 or (800) 523-9992
E-mail: info@stabilizationproducts.net
Website: http://www.stabilizationproducts.net

Canadian Sales:
Milieu Road Technologies, Ltd.
(780) 875-9159

the same soil would have if it had been compacted without the addition of lime. Parenthetically, it should be noted that other researchers (Fahoum & Aggour, 1995) have found reduction 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. The most extreme changes were observed in clay specimens treated with 8 percent lime, but the degree of change was very similar when adding 5 percent lime. Interestingly, reduction in maximum dry density still ranged from 7.4 to 9.2 percent when lime was added at a rate of two percent to the medium plasticity and highly expansive soils.[3] These reductions in maximum dry density are significant and clearly not desirable, particularly if the leaching action of water flow through the expanded soil structure reverses the initial improvements in strength and plasticity.

Permeability

> *"...Townsend and Klyn (1966) found significant permeability increases upon lime treatment of soils and related this increase in permeability to the increase in pore volume due to flocculation. Ranganatham (1961) found a 10-fold increase in permeability in lime-treated expansive clays. Other researchers... McCallister and Petry (1990) found that the permeabilities of three expansive North Central Texas soils were from 7 to 300 times higher after lime treatment than for the natural clays without lime stabilization."* [4]

In other words, lime treated soils are generally more permeable to water than they were before lime treatment, and some expansive clays have been found to be an incredible 300 times more permeable after lime treatment. These major increases in permeability are not surprising when viewed in context with the dramatic reduction in maximum density and increase in pore and void space resulting from a soil structure which has been expanded in volume by lime treatment.

Leaching

> *"A comprehensive leachate study of lime-stabilized soils was conducted by McCallister and Petry (1990). In this study seven labs prepared lime treated clay samples from three different expansive soils in the North Central Texas area. "*
>
> *"The major findings of the study were that:*
>
> 1. *The magnitude of the changes in physical and chemical property of the lime-treated soils subjected to leaching is highly dependent upon the lime content of the mixture,*
> 2. *Soils stabilized with 6 to 7 percent lime demonstrated the least physical property and chemical property changes. In fact, the physical changes of the lime-treated soils at this relatively high treatment level were usually negligible and*
> 3. *Greater changes occurred at the lower stabilization rate of 3 to 4 percent lime. These changes were significant and often substantial."* [5]
>
> *"Soils stabilized with low lime percentages often may not develop the pozzolanic reaction or at least the full complement of pozzolanic reactivity necessary to produce extensive permanent changes and resist moisture or leachate damage."*[6]

In other words, lime treatment can leach out (losing the beneficial effects of the treatment in that process) though it is less likely to do so if the treatment rate is at 6 to 7 percent

[3] Fahoum, K. and Aggour, M.S., "Range of Properties for Lime Stabilized Clay Soils," Paper Submitted for Presentation and Publication in 1995 Annual Meeting of Transportation Research Board, Washington, DC.
[4] Little, D., page 93.
[5] Op. Cit., page 122.
[6] Ibid

lime. The danger of those "significant and often substantial" changes referenced in the handbook is precisely the factor which the decision maker ought to be weighing in making a stabilization decision. Though the increase in strength often found at the lower treatment rates seems to be a cost effective investment, that increase can be lost through leaching and the resulting weakened material can be less dense and more permeable than before treatment.

CHANGES IN ENGINEERING CHARACTERISTICS

Given the risks to highway stability attached to potential leaching of a lime treatment, the following quotes are provided directly from pages 40-43 of the 1990 McCallister and Petry[7] study referenced earlier in the Handbook For Stabilization Of Pavement Subgrades And Base Courses With Lime, in which seven materials testing laboratories participated in a cooperative study involving three different expansive clay soils subjected to lime treatment at a number of application rates.

Permeability

"For all three soil sites, the permeabilities of the lime-treated clay increased with the addition of as little as 1 percent lime. The amount of increase ranged from a 7-fold increase to a maximum 342-fold increase. ...At very low or very high lime contents, the increase in permeability was less pronounced. However, even at very high lime contents permeability was still much greater than that of the natural soil."

Atterberg Limits

"After leaching, plastic limit (PL) and liquid limit (LL) values decreased, whereas PI values increased. Maximum increase in postleach PI value appeared in samples with 1 to 3 percent lime, for those leached 45 days and compacted at OMC. Samples leached 90 days had even larger increases in PI value."

Swelling Pressure

"Tests indicated increases in swell pressure after leaching at all lime contents. These increases ranged from as little as 13 percent to as high as 98 percent. The maximum increase in swell pressure occurred in samples treated with lime contents of 3 to 6 percent."

Free Swell

"Maximum increases in postleach free swell occurred in samples tested with 3 to 4 percent lime, with increases ranging from 115 to 340 percent."

Unconfined Compressive Strength

"Unconfined compressive strength tests run on samples leached 45 and 90 days indicated that materials with very low lime content had considerable loss in strength during leaching. The maximum loss was a decrease of 76 percent for Site 1 material with 1 percent lime."

Physical Property Changes

"In all physical property tests conducted, postleach testing revealed that there were detrimental effects on the stabilizing attributes of lime-treated clays. The samples treated with lime contents of 1 to 4 percent displayed the largest detrimental changes during leaching. However, in all physical property tests conducted, there was a minimum lime content beyond which leaching was not significantly detrimental. This optimal lime content varied slightly between property tests. For Atterberg limits and linear shrinkage, the optimal lime content was found to be between 5 and 6 percent; for swelling properties, it varied between 6 and 8 percent; and for strength, it was found to be 7 to 8 percent."

[7] McCallister, Larry and Petry, Thomas, "Physical Property Changes in a Lime-Treated Expansive Clay Caused by Leaching," Transportation Research Record, 1295, Transportation Research Board, Washinton, DC., 1990.

Lime Treatment Tradeoffs

Conventional Wisdom Has Its Limitations

The conclusion seems clear. In the pursuit of a treatment to reduce the plasticity and expansive characteristics of clay soils, the negative impacts of lime treatment on other engineering properties are being widely ignored, particularly when application rates less than 6 or 7 percent are specified. There is serious risk that a lime-treated soil will ultimately have less desirable engineering properties than the soil would have if left untreated. Lime is acknowledged to reduce the maximum compacted density below that of the same soil compacted without addition of lime. As density decreases, pore and void space increase, so it logically follows that the lime treated soil also becomes more permeable to water than the untreated soil. This logic and the facts of research are widely ignored, yet they are fundamental to informed decision making.

No engineer would intentionally apply a treatment that will make a highway subgrade soil 5 to 100 times (or more) as permeable and susceptible to water intrusion and the destructive effects of moisture flow without other permanent counterbalancing measures. Unfortunately, if lime fails to initially react a particular clay soil, or if water flow leaches the lime out of the structure and reverses the effect of the chemical treatment, the net effect is an expansive clay "sponge." At this point, the soil has less desirable engineering properties than the original "problem soil" that the treatment was expected to improve. The risk inherent in lime treatment is that a routine application will ultimately weaken a highway structural section rather than improve it. In these cases, the "no treatment" option would have been much the better design decision.

A research project conducted by Texas Department of Transportation and the U.S. Army Corps of Engineers staff (Kota, Hazlett and Perrin, 1996) details projects in which cement as well as lime treatments were applied to highway subgrade soils with disastrous results, eventuating in repair costs far exceeding any possible savings that might have been realized from these in situ soil treatments. While these particular problems were the result of lime and cement treatment of sulfate rich clay soils, (a subject which is further addressed below), the researchers made some very interesting observations and suggestions which bear upon the overall subject being addressed in this paper. They observed a section of highway built on a lime treated subgrade with severe heaving distress observed within six months of construction where the previous pavement had been constructed on the same natural subgrade and lasted for over 40 years.[8] On another construction project they observed significant pavement cracking and heaving in the pavement overlaying cement and lime treated subgrades just months after construction. A year and a half after construction, sulfate-swell damage continued along the sections overlaying the calcium based treatments while the section overlaying the untreated clay remained in excellent condition.[9]

The risks of poorly matched applications of lime are well documented. This particular case, mentioned above, is instructive: an untreated soil providing competent highway support over a 40 year period, while lime treatment of the same soil created an almost immediate failure. The "do nothing" option was far better than a mismatched application of a calcium based stabilizer. While this subgrade soil might have been beneficially improved with another form of soil treatment in regards to its strength, density and moisture resistance, a mismatched attempt to treat non-destructive levels of subgrade soil plasticity led to an inevitable premature failure of the entire highway structural section.

Unless compatibility and treatment rate issues for a particular soil are carefully evaluated prior to a lime treatment project, the results of current research indicate that alternative approaches should be selected. Either methods other than in situ soil stabilization should be used, or concentrated liquid stabilizers should be selected which reduce optimum moisture content and permeability while increasing maximum dry density and improving the flexural and bearing strength values of aggregate and soil materials. The reductions in density and increases in permeability associated with lime treatment

[9] Op. Cit., pp. 13-14.

clearly are not acceptable risks if performance of the treatment with a particular soil is not assured.

DISCUSSION OF SOIL PLASTICITY ISSUES

Lime use has traditionally been applied to reduce the plasticity, or volume change characteristics of expansive clay soils. The presence of highly expansive clay soils, subject to wide fluctuations in moisture content and resulting shrink-swell phenomenon, has clearly been proven to be extremely destructive to pavements and other structures. Damage costs in the United States alone which are directly attributable to expansive clay soil problems exceed $9 billion annually (Civil Engineering magazine 8/97).

Experiments with limiting moisture fluctuations of expansive clay soils (e.g., essentially maintaining moisture content in a state of equilibrium) have been relatively successful as evidenced by the growing use of geomembrane products to encapsulate expansive clay subgrade soils.[10] This approach completely avoids any form of chemical treatment to radically alter soil chemistry and instead addresses the causative agent, the moisture flow and moisture fluctuation through a soil which leads to destructive levels of volume change in highly expansive soils. Soils which are not effectively encapsulated or treated for their moisture susceptibility are constantly subject to atmospheric effects and other environmental factors such as wet/dry cycles, hot/cold cycles, and freeze/thaw cycles which dramatically change their engineering properties and stability values.

Untreated clay soils that have limited degrees of volume change are regularly utilized for pavement subgrades as evidenced by construction specifications in states like Texas where problems with highly expansive clay soils are widespread. The Texas Department of Transportation classifies moderately expansive clays with plasticity indices of less than 25 as suitable for highway subgrade construction. This ongoing use of moderately expansive subgrade soils indicates that plasticity and limited volume changes are not unmanageable elements in a highway structural section.

Rather than eliminating soil chemistry characteristics tied to volume change through chemical treatment, other alternatives are being successfully applied. As indicated above, this requires selection of soils with limited volume change characteristics or else use of methods which encapsulate or in some other manner limit moisture fluctuations in highly expansive soils. As research efforts continue to assist materials and design professionals to better discriminate specific soils which are not appropriate for, or not cost-effectively improved by lime treatment, investigation of alternative approaches becomes increasingly important. Soil problems remain which are not effectively addressed by lime, and in some cases are not addressed by any calcium based-treatment. Treatment methods which address moisture susceptibility, moisture flow and moisture fluctuation will be called upon to address these specialized problems and be increasingly utilized as more cost-effective solutions to improve stability of all types of expansive clay soils.

WARNING SIGNS THAT LIME TREATMENT IS CONTRAINDICATED

There are significant limitations on the range of soils for which lime treatment is effective. Soil chemistry and composition make many soils non-reactive to lime. According to the Handbook For Stabilization Of Pavement Subgrades And Base Courses With Lime (pp. 49-54), poor lime reactivity is indicated by factors relating to clay content, organic content, gradation and soil pH values. At no time is lime recommended as a treatment for soils without some degree of clay content and it is suggested that suitable soils should have clay content of 7 percent or more, plasticity indices greater than 10, more than 25 percent material passing the number 200 sieve, organic content of 1 percent or less, and pH values of 7 or greater.

[10] Steinberg, Malcom, Geomembranes and the Control of Expansive Soils in Construction, McGraw Hill, Inc., 1998.

As construction projects of major areas and road projects of any length often consist of a mix of three or more distinct soil types, it is highly likely that one or more portions of a project will not benefit from and will possibly be weakened by lime treatment of non-reactive soils. Soil composition varies widely between soil horizon layers and within very limited areas of local topography. Expansive soils can often be interspersed with non-plastic soils, all within a single subgrade stabilization project. Given the potential negative tradeoffs, of all these factors relating to soil classification which affect the performance of lime deserve careful evaluation in preparation for responsible application of lime treatment.

SULFATE SWELL

Sulfate-induced heaves have been a recognized problem in the United States since first reported in 1986 by Mitchell in an article titled *"Practical Problems from Surprising Soil Behavior."*[11] Damage from deleterious lime-soil-sulfate reactions have also subsequently been reported in Australia and Europe.[12] Sulfate induced heaves are not unique to lime treatment. Other calcium-based chemical treatments such as cement and fly ash have been found to cause sulfate-swell reactions equally destructive to pavements.

Sulfate swell has been identified as a problem in many areas. When clay soils are high in sulfates, the calcium in lime, cement or fly ash may react with sulfates to form expandable minerals such as ettringite, which can double in volume when exposed to moisture. This expansion causes powerful heaving phenomena in treated subgrades which buckle, deform and crack pavements. In 1988, Hunter reported sulfate induced heaves in a Las Vegas roadway as high as 300 mm and pavement fractures as wide as 150 mm on the surface and reported roadway repair costs of $2.7 million, based on a mistaken effort to save $0.3 million during initial construction.[13] In 1992, Perrin observed three projects with sulfate swell damage in Texas with heaves often ranging between 300 mm to 600 mm (approximately 12 to 24 inches). Given the severity of this level of damage to the pavement, the findings published by the Texas Department of Transportation's Research Technology Transfer Office do not seem unrealistic.[14] In the March-April 1997 edition of TR NEWS, a Transportation Research Board publication addressing benefits of transportation research, an article by Jones and Lee indicates that the Texas Department of Transportation estimates that with use of a test kit to identify sulfate rich soils and availability of an effective non-calcium based stabilizer, the department could save the state $23 million a year in repair costs.[15]

Regarding the concept that double applications of lime might provide successful treatment of sulfate-rich clay soils, Kota, Hazlett and Perrin summarized their findings as follows:

> *"The authors would like to make it clear that one may easily be mislead by interpretations such as adding more and more lime until the concentration of soluble sulfates in the treated soil is brought down to levels below a problematic level. In a recent application of this concept, it was found that heaves are still developing even after treating the soil twice with 7 percent lime each time (total of 14 percent). It was found that the level of soluble sulfate, though reduced in concentration, was significant even after double treatment with lime and it may be possible that this concept may suggest one more application of lime (making it a final total of 21 percent lime!). It is to be understood that eliminating more and more soluble sulfates by reacting with lime*

11 Mitchell, J.K., "Practical Problems from Surprising Soil Behavior," Journal of the Geotechnical Engineering Division, ASCE, Vol. 112, No. 3, 1986, pp. 259-289.

12 Kota, Prakash, et. al., p. 2.

13 Hunter, D., "Lime-Induced Heave in Sulfate-Bearing Clay Soils," Journal of Geotechnical Engineering, ASCE, Vol. 114, No. 2, February 1988, pp. 150-167.

14 Perrin, L., "Expansion of Lime Treated Clays Containing Sulfates," Paper presented at the 7th International Conference on Expansive Soils, Vol. 1, Dallas, Texas, August 3-5, 1992, pp. 409-414.

15 Jones and Lee, TR NEWS, Transportation Research Board, Washington, DC, March-April, 1997, p. 17.

> *means forming that much ettringite which is the culprit in the heaving problem. Moreover, as explained before, tests to measure soluble sulfate levels do not measure all the sulfates present in the soil and there could still be additional sulfates that could be solubilized by a fresh supply of moisture in subsequent rains or from oxidation of pyrites in the soil. Similarly, more sulfates may get into the pavement through washing from the surrounding soil and from capillarity from the untreated soil below the treated layer. Additional supply of sulfates could definitely be considered a problem if the native material has high concentrations of sulfates. It is not clear whether excess lime supplied after the first application of lime may benefit the layer by forming a pozzolanic compound or may get leached down to react with fresh untreated soil to form ettringite under the stabilized layer. Though the later reaction may not cause any expansion in the stabilized layer, the problem of heaving is now transferred to a new layer at lower depth."*[16]

> *"It has to be realized that since the problem starts with damage from the bottom layer of the pavement, the remedies involve removing all the top layers which is equivalent to tearing up the whole pavement and constructing a new pavement altogether. Double application of lime for soils with high level of soluble sulfates may prove to be detrimental if not done properly."*

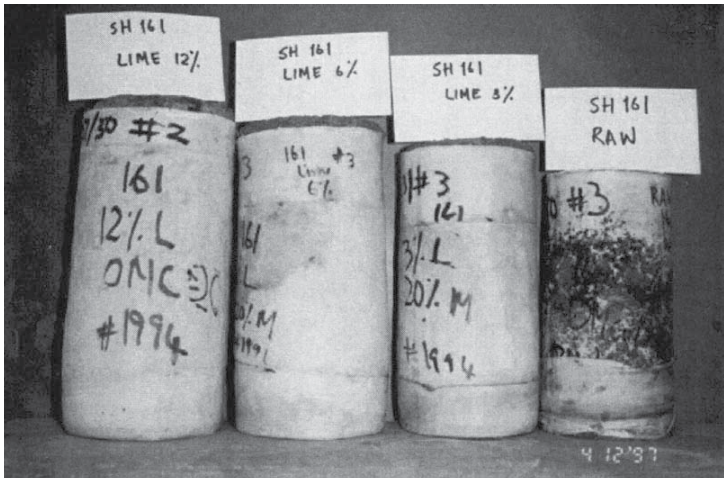
In addition to the performance problems and risks attached to double application of lime which are described above, the high costs of double application of lime will often favor excavation of the problem soil and importation of select fill or aggregate base course materials. In the language of the Jones and Lee article cited above, if the cost-savings normally expected of in-situ soils stabilization are to be realized with sulfate-rich clay soils, application of *"an effective non-calcium based stabilizer"* will be required.

ALTERNATIVE TREATMENT

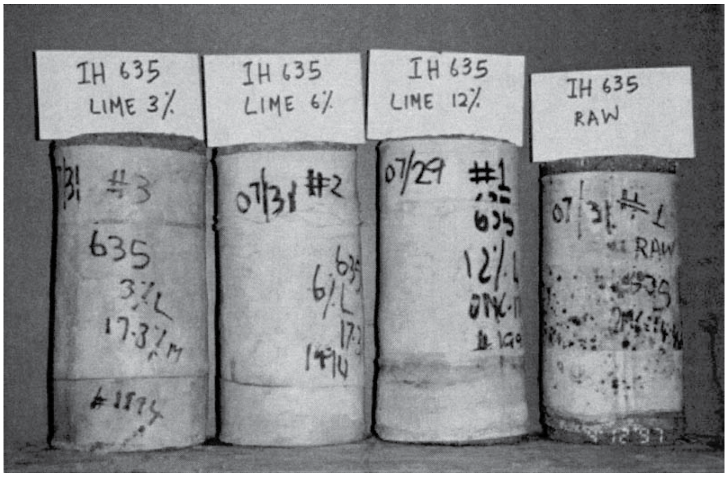
In addition to funding the research which constituted Kota and Hazlett's contribution to the data of their 1995 paper, the Texas Department of Transportation funded a laboratory study to identify non-calcium stabilizer treatments that could be applied successfully to the sulfate-rich expansive clay soils in their Dallas District and other areas in the state where destructive levels of sulfate have been observed. This research study (Rajendran and Lytton, 1997)[17] further addresses cases of sulfate-swell damage to Texas highways. The report also identifies effective alternative stabilization product technology. The study verified that the EMC SQUARED System was *"superior to lime in terms of strength, stiffness, permeability and swell resistance,"* and recommended it for two Texas Department of Transportation freeway projects in place of lime, and "at all other sites where soils high in soluable sulfates are encountered."

[16] Kota, Prakash, et. al., pp. 14-16.

[17] Rajendran, Deepa and Lytton, Robert L., "Reduction of Sulfate Swell in Expansive Clay Subgrades in the Dallas District," Texas Transportation Institute in cooperation with the Texas Department of Transportation, Report # TX-98/3929-1, 1997.



Photograph Showing Comparisons of Swell (Lime vs Raw) - SH161



Photograph Showing Comparisons of Swell (Lime vs Raw) - IH635

The photos above show the laboratory results of swell tests conducted with expansive clay soils from both TxDOT SH161 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. EMC SQUARED System treatments have subsequently been applied for subgrade stabilization on both SH 161 and IH 635 highway projects.

As the earlier summary of the research work indicates, the EMC SQUARED System outperformed lime in treatment of these two sulfate-rich, highly expansive clay soils. Further information on this research and an additional testing series conducted at the Texas Transportation Institute (which further demonstrates the ability of EMC SQUARED System treatments to reduce moisture susceptibility and moisture flow through compacted earth materials), is available upon request.

SUMMARY

Lime treatment has demonstrated effectiveness at high application rates when applied to clay soils that are reactive to lime treatment and that are absent of sulfates at levels which would make them prone to sulfate-swell. However, for projects that involve soils not appropriate for lime treatment, or for which the high application rates necessary for effective lime treatment are not affordable or cost-effective, the EMC SQUARED System stabilizers may be used for in-situ treatments, subject to project specific engineering evaluation and soil specific performance evaluation in materials testing laboratories or field tests.

Stabilization Products LLC
Ph: (209) 383-3296 or (800) 523-9992
E-mail: info@stabilizationproducts.net
Website: http://www.stabilizationproducts.net

Canadian Sales:
Milieu Road Technologies, Ltd.
(780) 875-9159