EVALUATION OF CONSOLID SOIL STABILIZATION SYSTEM

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Executive Summary

Increasingly, life cycle costs are being evaluated for infrastructure investments. Highways and roads provide a superior economic benefit, but also have both high initial cost and potentially high maintenance costs, though these costs range considerably with variabilities in weather exposure and conditions, road construction materials, and usage/traffic volume. It is therefore important from an engineering standpoint to carefully investigate materials and methods to improve roadway performance and longevity.

Madrid Engineering is a geotechnical engineering consultancy based in central Florida. We work for many municipalities and governmental agencies, including the City of Tampa, City of Lakeland, Florida Department of Transportation, the US Environmental Protection Agency, etc., with much of our work in the area of roadway and pavement evaluation and design. We were recently presented the opportunity to evaluate the CONSOLID system, a two-part product consisting of a dry material (SOLIDRY) and a liquid polymer concentrate (CONSOLID 444). When mixed with *in situ* soils, imported soil/rock, or a combination thereof, the manufacturers reported significant increase in strength and (perhaps more significantly) a decrease in both capillarity and permeability.

We mixed this product with a range of soil/rock typically sourced in Florida and used in roadway construction, including sand, clayey sand, and limerock. We ran compaction tests and the Limerock Bearing Ratio (LBR) test which is comparable and similar to the California Bearing Ratio (CBR). CONSOLID material was added at a dry weight basis of 1, 2 and 3%. Test results showed an increase in the maximum LBR value of 2 to 4 times the initial strength; we further noted that the samples were more difficult to extrude from the test molds and held together until broken apart. The optimum moisture content increased approximately 1% higher than untreated samples. It is our opinion that CONSOLID meets or exceeds published strength data for these common soils, and can be used in multiple pavement applications including roadways, airports, sea ports, railroads, and numerous other applications.

Introduction

Paved roadways are an expensive, major component of infrastructure in developing and developed countries, contributing to economic well-being by allowing goods and services to be moved faster and with more consistency than unpaved systems. Maintenance of roadways is an ongoing expense and part of the lifecycle costs of this infrastructure. Any technology that can reduce initial cost or lower long term maintenance provides benefit to the owner/user. Particularly with flexible (asphaltic) pavement, the author has observed that the main maintenance issues often do not involve the asphaltic wearing surface, but rather are due to failure of the underlying natural soils, subbase, and base materials. We have further observed that the main cause of base/subbase group failures is that water gets into these groups – via rain, lateral flow, and capillary action - and the base materials lose their strength over time. As the base/subbase loses strength, cracks reflect into the asphalt which further aggravates the weakness by providing additional flow paths for water to get into the base/subbase.

CONSOLID is a two-part system to stabilize soils that has been used across the world to increase the strength of road base materials; reduce the permeability of these materials; and decrease the capillary action of these materials. These materials apparently combine to increase the bearing capability of the road and to reduce the influence of water on the base, and in doing so also increasing the reliability of the base.

Madrid Engineering Group, Inc. (MEG) has laboratory facilities accredited by the Construction Materials Engineering Council (CMEC), the leading body regulating soils testing laboratories in the United States. Accreditation means that our laboratory personnel, equipment and procedures have been show to provide quality control resulting in accurate and repeatable test results, making MEG an excellent candidate to complete an independent evaluation of the CONSOLID system. We asked for and received samples for testing the system from the manufacturer, CONSOLID LTMD.

Madrid Engineering performed a laboratory testing program of the CONSOLID product used for *in situ* road base stabilization, among other applications. We were provided with a two-part system including SOLIDRY and CONSOLID 444 concentrate from the manufacturer. We were also provided a dosage guideline for mixing CONSOLID system with soils. To simulate typical Florida conditions, we performed the Limerock Bearing Ratio (LBR) test in lieu of the more widely used California Bearing Ratio (CBR)[1], and we completed index testing for sand and clayey sand samples obtained from local (central Florida) sources.

Laboratory Testing Procedure

The following procedures were followed in our laboratory testing program.

1. Perform the Limerock Bearing Ratio (LBR) test for the untreated soil sample in accordance with the standard Florida test Method (refer to FM 5-515 testing standards for details). The optimum moisture content corresponding to the

[1] The CBR value is approximately 80% of the LBR value; tests are similar involving measuring the penetration resistance of a piston plunged into the compacted soil sample.

highest dry density was determined. The target moisture content for the treated samples was estimated based on this moisture content.

2. Determine the moisture to add to obtain various moisture contents above and below the optimum moisture content. Allow the samples to equilibrate the moisture for a 24 hour holding period.
3. Just prior to compacting into the LBR mold, mix the SOLIDRY with the soil sample thoroughly at the proportion listed in the provided dosage table for 1%, 2% and 3%, respectively;
4. Prepare CONSOLID Lab Solution by diluting the CONSOLID 444 CONCENTRATE with distilled water;
5. Mix the CONSOLID Lab Solution with the soil mix prepared by step 2 thoroughly at the proportion listed in the referenced dosage table for 1%, 2% and 3%, respectively;
6. Perform LBR test for the treated soil samples for 1%, 2% and 3%, respectively.

Please note that in order to save sample and time, in some cases we only prepared the treated samples at or near the optimum moisture content assuming the LBR will have the highest value at/near the optimum moisture content. Therefore, the maximum LBR might be higher than what was obtained in this experiment, if a different moisture content produced a higher LBR value.

Test Results and Observations

CONSOLID did have a positive effect on the soil samples. The following table summarizes our results:

Material (USCS)	**Untreated**	**Treated with CONSOLID**		
		1%	**2%**	**3%**
Clean Sand (SP - less than 4% fines)	16	31	43	45
Clayey Sand (SC – appx. 20% fines)	46	76	120	160
SC + Limerock (50/50% mix)	103	193	226	330+

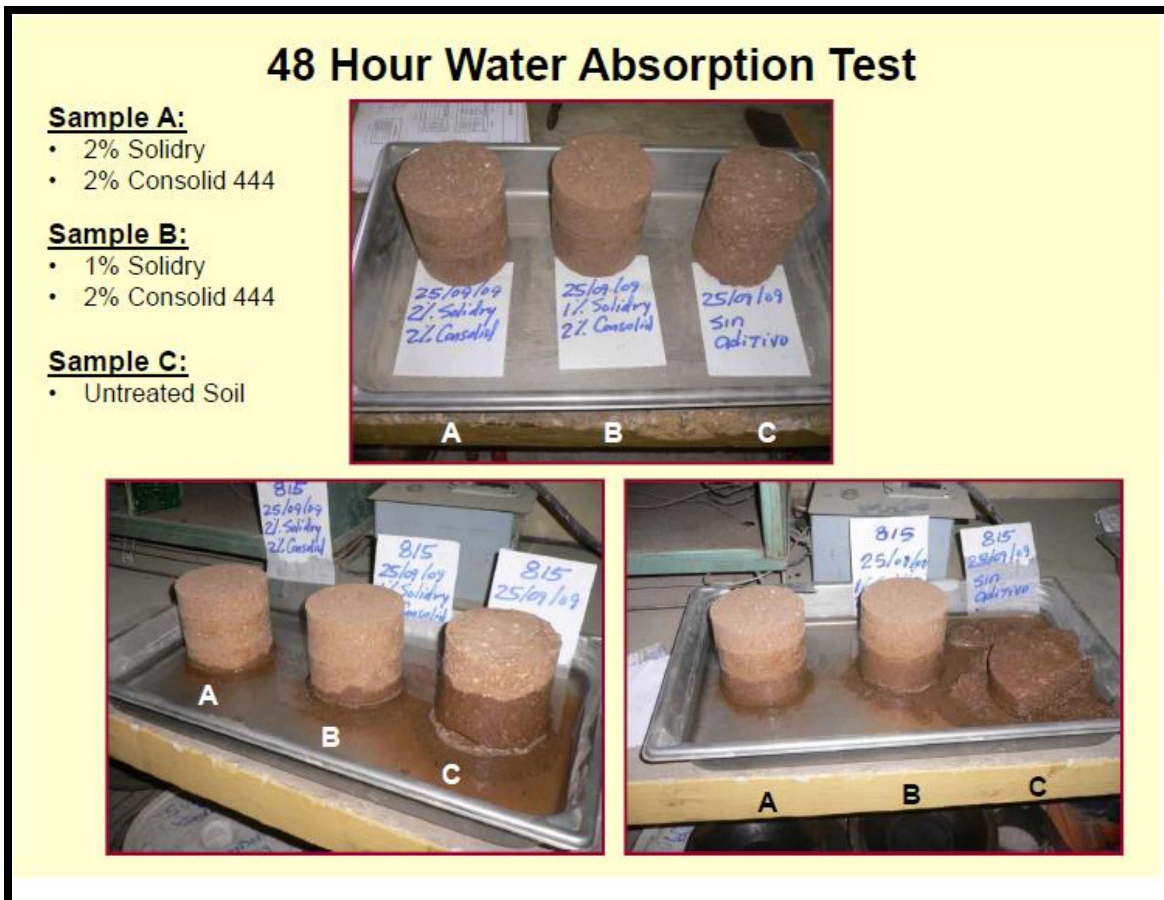
Samples mixed with CONSOLID materials had significantly higher bearing strength than those without the mixture. Additionally, we noted that samples with CONSOLID did not exhibit tension cracks around the piston after completing the tests, except the sample with clean sand and 1% CONSOLID. The samples held together and were difficult to extract from the mold without a hammer and chisel. The moisture of the samples, even after soaking in water for 48 hours prior to penetration testing, was uniform except at the very top and bottom of the samples as expected, indicating that the permeability of the samples were much lower with CONSOLID than without. Finally, the test with clayey sand/limerock mix and 3% CONSOLID was so hard that it caused a shear pin to break in the compression machine, effectively shutting down the test at a LBR of 330.

1 Photo of Sample with 2% CONSOLID after LBR Penetration

Conclusions

Based on this testing program, CONSOLID material provides a significant cementitious strength gain, increasing the LBR value by 2 to 4 times the initial strength. We further note that although the samples are significantly stronger, they do not appear to be brittle, which is a problem with soil cement that makes it somewhat incompatible with flexible pavement (asphalt). We believe that this significant strength gain can combine with relative ease of construction and speed of construction to reduce cost of a road.

This testing did not include an experimental evaluation of capillary action or measurement of the permeability of the samples. Anecdotal evidence, however, of the moisture distribution of the samples (after soaking and testing) does indicate that the permeability is lower, particularly in the sand-only sample. The manufacturer also claims that capillarity is reduced and provided us with a slide presentation of a very important experiment (photo below), in which samples with varying amounts of CONSOLID are placed side-by-side in a pan of water, and capillary action can be seen over time with a wetting front advancing up the samples (see below). The result of capillary action on untreated soil was disintegration of the sample, while the majority of the samples with CONSOLID remained unchanged, i.e., reduced capillarity is strongly evident.



2 CONSOLID Capillarity Test at 0, 24 and 48 hours

Throughout Florida, in coastal communities, and in areas with high rainfall or poor drainage, we have observed that roads can be adversely affected by water. Rainwater can infiltrate and saturate the road base through rainfall, entering through cracks in the asphalt' laterally along the sides of the roadway and in the median; and from capillary action above the water table or raising of the water table into the base group of the road. With CONSOLID, the reduced permeability of the base material and the reduced capillarity of the base materials can be a very important factor to hold the moisture constant within the base, thereby decreasing the potential for changes in material characteristics over time. If the road base is, for instance the same strength 20 years from the time it was constructed, it can continue to provide excellent service with little to no maintenance.

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About the Author – Larry Madrid is a professional geotechnical engineer based in central Florida with over 35 years of experience. He has been president of Madrid Engineering Group, Inc. for 23 years, during which time the company has successfully completed over 8000 projects. Mr. Madrid is a Diplomate of Geotechnical Engineering with the Academy of GeoProfessionals, and is a Fellow of the American Society of Civil Engineers (ASCE). He is also a life member of the Society of Hispanic Professional Engineers (SHPE), and a member of Florida Engineering Society (FES) where he is vice president of the Geotechnical and Materials Engineering Council (GMEC), the leading organization of geotechnical engineers in the state. He obtained both his bachelor and master of science degrees in civil engineering (geotechnical specialty program) at Colorado State University; has authored numerous technical papers, and is a regular speaker on technical issues in civil engineering and sustainability. He has worked on two successful patents claims, for PhosFilter (a phosphorus reduction technology) and for Greenstar Panels, a residential and commercial insulation system. Mr. Madrid is an expert in soft soils and sediments, and developed PhosphoCrete as a soil admixture to strengthen waste phosphatic clay, a very soft mine waste product. He has completed research on diverse topics including pozzolanic reactions in spent oil shale, consolidation of waste phosphatic clay, pavement base evaluation using phosphogypsum mixtures, and the influence of hydraulic gradient on sinkhole formation.

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