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Subgrade Modification – A Practitioner's Experience With Sustainable Materials

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ABSTRACT

Weak subgrade soils have been modified in one form or another for centuries. This paper focuses on experiences with lime and fly ash as modifiers and stabilizers in Illinois. Modifiers have been used to change the properties of soils for many years. The choice of using a soil modifier depends on the properties that are in need of modifying and to what extent the property is to be modified. Commonly used modifiers have changed over the years from bitumen to modifiers producing pozzolanic reactions. The choice to modify the insitu soils can reduce the demand on the high quality aggregate sources.

A recent roadway project in Kane County, Illinois is showcased to illustrate the cost differences between aggregate base course and lime modified subgrade. An Illinois Department of Transportation project in Grundy County, Illinois is highlighted to discuss the need for proper testing prior to using these stabilizers in the field to ensure satisfactory results.

INTRODUCTION

Stabilization by mixing has been used as a tool for creating a uniform base on which to build a pavement since the 1920's [Rodriguez, Castillo and Sowers, 1988]. While the equipment and the chemicals have changed, the principals remain the same. The mixing of soils, no matter if it was just with other soils with more desirable properties or with chemicals such as cement, lime or fly ash, the intent has always been to improve the properties of the insitu soils.

The word lime can mean a variety of products such as quicklime (calcium oxide – CaO), hydrated lime (calcium hydroxide – $Ca[OH]_2$), lime slurry, which is a suspension of hydrated lime in water and can be made from either hydrated lime or quicklime or lime kiln dust [National Lime Association, 2004]. Fly ash, on the other hand, is a by-product of coal manufacturing. Besides the chemical makeup of these materials, the differences of their reactions set them apart from each other. Lime typically needs a minimum amount of clay to react with to result in the desired strength gain. Fly ash does not need the clay but the amount of fly ash needed to achieve the same result can be as high as 3 to 4 times that of lime. Because fly ash does not need the clay to react, it is better suited for more granular soils.

This paper first gives a historical review of engineering practice in subgrade soil modification. Two case histories are described in some detail on the successful use of lime and fly ash as modifiers in highway projects sponsored by IDOT District 3 office located in Ottawa, Illinois. Another case history shows the cost benefits possible with the use of lime modification. The use of subgrade modifiers can save the aggregate deposits for future use in Portland Cement Concrete, PCC, pavement and Hot Mix Asphalt, HMA, pavement.

Each year there seems to be a shortage of fly ash. This may be simply rumors to create an atmosphere accepting of higher prices or there may be truly a shortage of the material resulting from the multiple uses of fly ash. It is more likely this presumed shortage is a local problem with local suppliers not able to meet demand. As long as we have coal combustion power plants there will be a source of fly ash. The paper finally gives concluding remarks on how to perform necessary tests on determining the type of stabilizer to use and the importance of providing adequate monitoring during construction.

HISTORICAL REVIEW OF PRACTICE

The practice of soil modification within the boundaries of the Illinois Department of Transportation (IDOT) District No. 3 has been primarily with by-product lime and hydrated lime. Quicklime can be very harsh to workers skin and respiratory systems and contractors routinely shy away from it. The main problem with the use lime slurry has often been the uneven distribution on the job site.

The use of hydrated lime peaked for District 3 during the construction of the subgrade of Interstate 39 (I-39) in the 1980's and early 1990's. The surficial soils on this alignment were primarily cohesive in nature with areas of silt and fine sand. At the time, the practice was to construct fill sections with a local cohesive material with clay content greater than 15% and with a plasticity index (PI) greater than 12. The cut sections meeting these criteria were disked and dried and ultimately lime modified to a depth of 30.5 cm (12 in.) along with the constructed fill sections. Soils with less clay content were often replaced with aggregate and geosynthetics. Some areas were treated to depths as deep as 61.0 cm (24 in.).

While the standard subgrade treatment was lime modification, the field work routinely encounter soils that were non-reactive with lime and were undercut. The typical undercut at that time was to remove 45.7 cm (18 in.) of subgrade soil, place a geotextile type fabric and backfill with 30.5 cm (12 in.) of crushed limestone meeting IDOT's CA-7 gradation and 15.2 cm (6 in.) of crushed limestone meeting IDOT's CA-6 dense graded base gradation. Silts and sands with less than 12% clay showed poor performance after treatment with lime. This threshold was elevated to 15% to ensure there was enough clay content in the soil to be modified.

The use of aggregate to replace weak soils is very popular in urban settings. The use of fine grain pozzolanic materials to stabilize soils can become quite dusty with only moderate wind speeds. The aggregate used for this purpose can be of low quality. However, what is delivered may be of the best quality because that is what the nearby quarry has. Geosynthetics are popular because their use may reduce the aggregate thickness needed; however in frost susceptible soils it has been IDOTs policy to remove the soil down to the theoretical frost line.

Prior to treatment, the subgrade soils were brought up to grade in approximately 20.3-cm (8-in.) thick compacted lifts. The moisture content was not to exceed 110% of optimum moisture content and the density was to be 95% of the standard Proctor density. There has been some discussion as to why the top lifts were compacted prior to tilling together with lime. This is to ensure that there is enough pre-treated material within the prescribed depth of treatment. This also goes toward the goal of uniformity. There is no practical way to get a subgrade to be of all the same material with the same strength or modulus but specifications require controlling the moisture content and compacting the material to achieve a uniform subgrade.

Large tillers were used to incorporate lime with subgrade materials as evenly and thoroughly as possible. In some instances, the tillers made multiple passes to blend the material together. At the time, the treatment depths were 30.5 cm (12 in.), 45.7 cm (18 in.) and 61.0 cm (24 in.) depending on the depth of weak material. The equipment effectively treated to a maximum depth of 35.6 cm (14 in.), therefore, to reach the depths desired in the plans, such as the 61.0 cm (24 in.), the top 25.4 cm (10 in.) of soil was removed and the lower 35.6 cm (14 in.) was treated. The material previously removed was returned to its original location and treated with lime in the same manner as the previous lift.

Today's practice has not changed much from that of 20 years ago but the modifying agents have. Industry commonly uses lime, fly ash and cement as modifiers and stabilizers. In choosing the proper agent, one must ask what is to be accomplished by modifying or stabilizing the soil. Is it lowering the liquid limit of expansive clays, producing an improved subgrade for pavement design or simply producing a working platform to pave on considered as the objective?

Modification and stabilization of subgrade soils has been tied to increasing the stability of the subgrade. The level of improvement has been checked by nuclear density gauges, dynamic cone penetrometers and proof rolling. Typically, it is a combination of two or more of these methods. By specification, IDOT runs nuclear density tests and dynamic cone penetrometer (DCP) tests for acceptance. Proof rolling is used in IDOT District 3 to locate areas in question to test with the DCP.

The success of a soil modification project is dependent on the insitu soils and the modifying materials available. Another factor greatly affecting the results of the project is the level of experience of the designer, inspector and contractor. The designer needs actively decide whether to modify the insitu soils, replace the soils with better soils or replace with aggregate. This decision should be made after comparing the costs and supplies of local materials verses that which would have to be shipped in. The benefits of a particular material may out way the cost. These decisions should not be taken lightly. When the materials decisions have been made the designer should insert the proper specifications and quantities into the plan documents. The proper application rates of the modifying agent and water need to be stated in the plans. These rates may be altered in the field by the inspector who has experience in doing so.

It is desirable for all parties to have similar expectations of the end result. The designer wants a subgrade strong enough to build the pavement upon. The contractor wants the subgrade to be strong enough to hold up to the construction traffic and the inspector should ensure the owner of the project is getting what they are paying for.

CASE HISTORIES

Anderson Road Extension. Looking at this project and where it is located one would assume the pavement structure would rest on an aggregate base. It is located relatively close to an aggregate source which would mean costs should be low.

During the subsurface investigation and the subsequent reporting of the findings the use of an aggregate base was questioned. It was questioned because the majority of the pavement is to rest above an approved embankment material. The embankment material is restricted to soils with a laboratory Standard Dry Density greater than 1450 kg/cu m (90 lb/cu ft) when determined in accordance with AASHTO T99. The organic content of this material shall be less than 10% determined in accordance with AASHTO T194 (wet combustion). The capping material is further restricted to soils with a grain size distribution having less than 35% passing the number 75 micron (#200) sieve. The capping material shall also have a plasticity index, PI, of greater than 11 and a liquid limit, LL less than 45.

These restrictions along with proper construction methods of placement and compaction typically results in a stable embankment to place an aggregate base on as well as a subgrade material that is typically suitable for lime modification. The untreated embankment will typically have an Immediate Bearing Value, IBV, greater than 4. The IBV is analogous to an unsoaked California Bearing Ration, CBR. The standard base course thickness or depth of subgrade modification is typically 300 mm (12 inches). This is typically satisfactory for embankments with IBV's greater than 3. The resulting IBV after a successful soil modification is typically greater than 11.

The area to the west of the project is urbanized with the town of Elburn, Illinois. The area to the immediate east is agricultural farm land. Because the prevailing winds flow easterly and the property to the east is not urbanized the use of the lime modification has been proposed. Lime modification was accepted and will be put in the plans because of the cost savings.

Approximately 25,084 sq m (30,000 sq yd) of subgrade will be affected by this decision. The engineers cost estimate for this project is $266,500 for the 300 mm (12 inch) thick aggregate subgrade, $323,767 for 200 mm (8 inch) thick aggregate subgrade with geogrid and $184,500 for 300 mm (12 inch) deep lime modification. The cost difference and the land use of the area persuaded the county engineers to put lime modification in the plans for this project. The side benefit of this is that approximately 20,000 ton of high quality aggregate may be used in the pavement. The use of high quality aggregates and binding agents, cement for Portland Cement Concrete, PCC, pavements and polymer asphalts for Hot Mix Asphalt, HMA, pavements allows the engineers to possible thin up the pavement and or give extend the life of the pavement in life cycle analyses.

Illinois Route 53. A project that didn't reach the results expected from that typically achieved from lime modification was Illinois Route 53, through Gardner, Illinois where the road crosses a railroad track at the south edge of town. This project involved removing the existing structure and building a new bridge with approximately 91.4 cm (3 ft) additional clearance. To do so, the profile grade was raised and the slopes were widened. Four soil samples were obtained from two test pits excavated from the proposed borrow pit, tested and approved for use with 4% lime for modification at subgrade level. This 4% design value was obtained by running an immediate bearing value (IBV) test, which is analogous to running an unsoaked California Bearing Ratio (CBR) test. The IBV tests gave values between 10.0 and 12.0, which met IDOT's strength acceptance criteria for lime modified soils (Illinois Department of Transportation, 1999).

The new profile grade line went from the original ground to approximately 914.4 cm (30 ft) above original ground at the new structure. The HMA pavement was placed late in the fall of 2000 and in early spring of 2001, several locations heaved as much as 7.6 cm (3 in.). Capillary action could bring moisture up to this height above the water table. The height of capillary rise is a function of suction potential influenced by the soil type or grain size and the depth to ground water table. Another source of moisture in the soil is from above through the pavement. This is quite possible as the late winter days brought snow in the night and thawed during the day with temperatures in Fahrenheit at mid to upper 30's (slightly above 0 degrees Celsius).

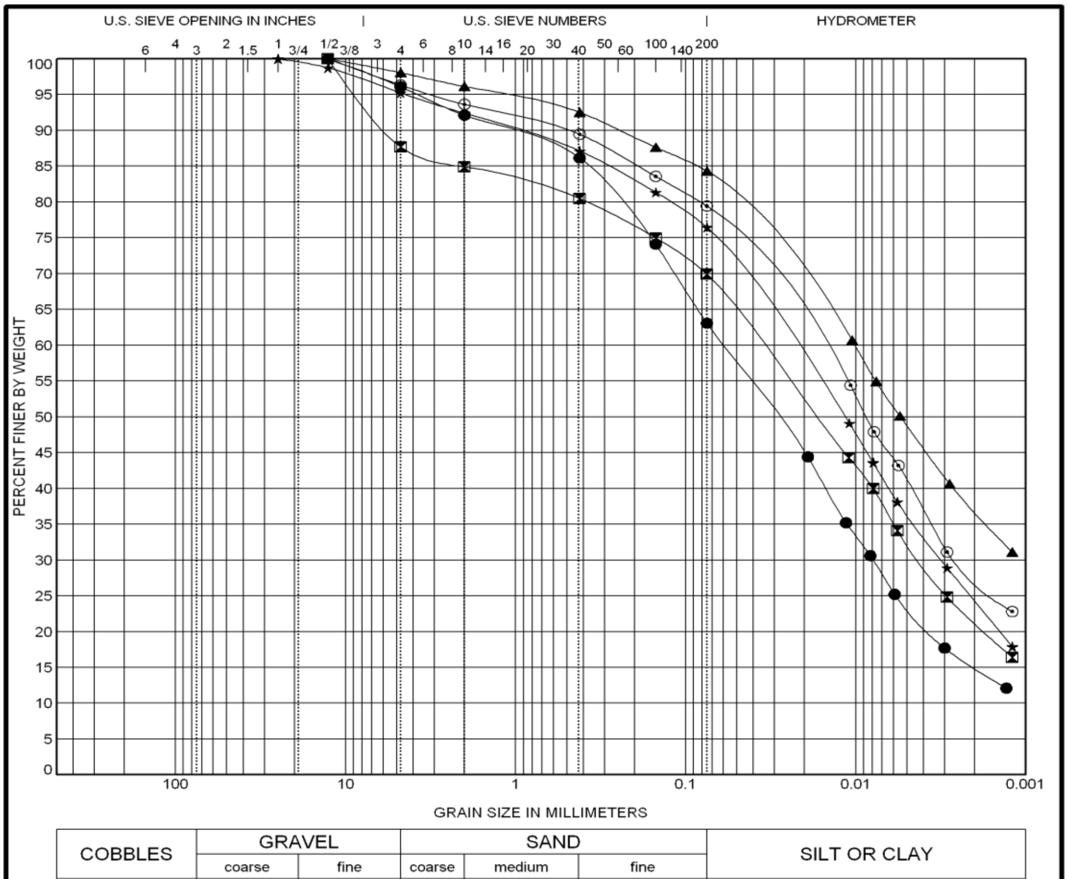
The soils approved for use from the borrow pit were not considered frost susceptible in that they did not meet IDOT's definition of frost susceptible. However, the soil found in the subgrade was not texturally the same as that tested prior to construction. The material found under the pavement was 71.1% silt and fine sand with a plasticity index of 11 and field moisture of 38%. It is possible and quite probable the silt content was increased with the chemical reaction that took place during the curing of the lime modified mixture. This subgrade was reported as being extremely difficult to drive forming pins into and it did not deflect during the paving operations. The excessive moisture and resulting instability came after the bituminous surface layer was paved.

It is believed the inspector did not monitor the material being taken from the borrow pit and placed in the upper 61.0 cm (24 in.) of the embankment. The material was very close in color to what was approved but had higher silt content. Had this material been caught before it reached the subgrade and the proper material placed, the heaving problems may have never taken place. The properties of the soil samples collected and tested after the heaving problem are shown in Figure 1. It has been an unwritten policy to only lime modify soils with clay contents greater than 15% and preferably greater than or equal to 20%. As indicated in Figure 1, there is plenty of clay content to have reacted with the lime. The amount of water was monitored and the planned quantity was used. As mentioned earlier, it is possible and quite probable that the silt content was increased with the addition of the lime. Adding lime to clay will often lower the liquid limit and in turn, may lower the plastic index, PI of the soil. It is more likely the permeability of the treated soil may have increased with the addition of lime allowing for moisture to penetrate the soil-lime mixture. Figure 2 shows ice lenses in a sample taken from the problem subgrade of Illinois Route 53 project. These areas did not always go across the entire pavement and were in excess of 152.4 cm (5 ft) long. The remedy for this project was to install transverse under drains across the pavement to take as much moisture away from the subgrade as possible, mill the existing bituminous surface and repave. To date, this remedy has worked in that there is no heave problem.

Fly ash has been primarily used as a drying agent in IDOT District 3. In addition, it was also used in winter months to generate heat to reduce the amount of frost during the process of building embankments. In this case, the fly ash was mixed with non-frozen but relatively wet soil in an open field area, collected and deposited on site with scrapers. During the night time, the area was covered with plastic to retain the heat. Each morning, the plastic was removed and the same process of mixing and placing continued. Only two percent (2%) fly ash was used in this process. Typically, the fly ash amounts used are near 10% but the desired result in this case was to dry the soil and create heat and not to provide a large strength gain.

Use of Fly Ash. In areas where it is readily available, fly ash is being used to modify silts and sandy soils. The IDOT specifications currently restrict the type of fly ash used in soil modification to be class C. Other types have been used as an embankment material but are not approved as a modifier.

In one instance, when very fine sand was encountered in the subgrade of a subdivision street in Coal City, Illinois, the stability of these soils was in question well before the concrete trucks were getting stuck. This brought it to the attention of the owners of the concrete company and construction companies involved in the project as they could no longer reach the areas they desired to work in. The subgrade was basically fine sand found just below the topsoil. The topsoil was removed from the subgrade but the depth of the sand was too great



Specimen Identification			Classification	LL	PL	PI	Cc	Cu
●	1	1.00	A-6 (6) LOAM	39.4	28.3	11.1		
⧗	1.1	1.00	A-6 (9) CLAY LOAM	38.6	24.5	14.1		
▲	1.1	2.50	A-6 (12) CLAY	33.1	17.6	15.5		
★	1.2	1.00	A-6 (12) SILTY CLAY LOAM	38.5	23.1	15.4		
⊙	1.2	2.10	A-6 (7) SILTY CLAY LOAM	28.1	16.7	11.4		

Specimen Identification			D100	D90	D50	D10	%Gravel	%Sand	%Silt	%Clay
●	1	1.00	12.7	1.149	0.029		3.9	33.0	48.1	15.0
⧗	1.1	1.00	12.7	5.717	0.017		12.3	17.8	48.6	21.3
▲	1.1	2.50	12.7	0.247	0.005		1.9	13.7	47.5	36.8
★	1.2	1.00	25	0.982	0.012		4.8	18.8	52.2	24.3
⊙	1.2	2.10	12.7	0.514	0.009		3.7	16.9	51.8	27.6

Illinois Department of Transportation
Division of Highways
Illinois Department of Transportation

GRAIN SIZE DISTRIBUTION- SCOUR
Route: FAP 846(IL53)
Section: (6)R,VBR FROST HEAVE
County: GRUNDY

GRAIN SIZE IL53.GPJ IL_DOT.GDT 9/29/08

Figure 1. Properties of soil samples collected from Illinois Route 53 near Gardner, Illinois.

Figure 2. Ice lenses in sample taken from problem subgrade of Illinois Route 53 near Gardner, Illinois.

to remove it all and the cost of aggregate was too great for the developer to add to the project. Fly ash was chosen because with the addition of water it has cementitious properties. The fly ash was locally available at a relative low cost when compared to the removal and replacement with aggregate. The immediate bearing values, IBV, as determined in the field with the DCP averaged 7.6-cm (3-in.) penetrations per blow into the loose fine sand. After modifying with fly ash, the IBV's averaged near 20. This is a significant increase in strength with only 11% fly ash mixed with soil.

Fly ash, unlike lime does not require clay for the modification to be successful and therefore lends itself to modification of silts and sandy soils. Fly ash may not provide the needed strength gain to be considered for stabilization of a soil, therefore, undercutting or other remedy may have to be incorporated if stabilization requirements are to be met. Lime modification and stabilization may be used with soils having clay contents greater than 20% and have been successfully used with soils having 15% clay content. Lime, fly ash and even cement have little long term effect on top soils.

CONCLUDING REMARKS

The decision to modify insitu soils should be based on the characteristics of the soils themselves. If the soils are suitable then and only then can soil modification or stabilization be considered an alternative to an aggregate subgrade. The cost savings associated with modifying the insitu soils will not be realized if the modification requires further remediation or removal and replacement with a crushed aggregate.

The preconstruction design should include sampling and testing the soils to determine their strength, insitu moisture content and soil classification based on a particle size analysis. This will determine the pavement design parameters, the level of frost susceptibility and whether or not the soil should be treated or removed and replaced with a better soil or aggregate. The desire to use aggregate is understandable. A clean crushed aggregate with little fines is not frost susceptible and provides a strong base, however the choice of using aggregate can be very costly not only in the immediate sense with the cost of the project but also in the long term sense. The use of high quality aggregate in the subgrade may be pulling the desired high quality material from the pavements of the future. Recycle PCC pavement or HMA pavement when available is a good source of aggregate subgrade or subbase material. The use of this material will also help ensure the availability of high quality aggregates for future pavements.

The decision to use a modifying agent isn't always easy. Laboratory testing should be performed to define the appropriate application rate of agent and water. This testing takes time and if the decision is being made during construction can delay the project. The particle size analysis of the soil is to be determined according to AASHTO T-88. A pre-agent Proctor test should be performed using AASHTO T-87 and T-99 (Method C) and a penetration test according to AASHTO T-193 immediately after compaction without soaking in water should be performed. The soil should be mixed with the desired percentage of agent and a post mixture Proctor and penetration test should be performed using the same test methods as before the mixture. The IBV calculations should be performed according to AASHTO T 193. If the desired IBV is obtained, the laboratory testing is deemed complete. If laboratory IBV is too high or too low, the percentage of agent used should be adjusted accordingly and the post mixture testing resumes as described above.

During construction the inspecting staff should be checking quantities for errors and ensuring the proper amounts of each ingredient is being used to produce the target strength, stability and density values. The inspectors should be collecting the truck tickets from each shipment of modifying agent and verifying weights if desired. The inspectors should routinely monitor the water meter at the source of water. The inspectors need to measure each area of treatment and determine the proper quantity of agent and water used as well as the design depth of treatment before going to the next area. Before completion, the particular construction parameters should be checked and confirmed whether on they meet specifications. For Illinois Department of Transportation, this includes density check with the nuclear gauge and stability check with the dynamic cone penetrometer. Most importantly, the inspector should use common sense. If the nuclear gauge says that the area has the required compaction, yet, the construction traffic is causing significant rutting and mobility challenges, there is a problem and needs to be addressed.

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