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Fly Ash as a Soil Amendment in the Northern Red River Valley

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FLY ASH AS A SOIL AMENDMENT IN THE NORTHERN RED RIVER VALLEY

A Senior Design
Presented to
The Department of Geological Engineering

In Partial Fulfillment
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Bachelor of Science in Geological Engineering

By
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EXECUTIVE SUMMARY

Combustion of coal occurs worldwide to produce energy for numerous residential and industrial processes. During coal combustion, byproducts including fly ash, bottom ash and slag are formed (Lafarge, 2004). By standard regulations, power plants in the United States and many other countries must effectively capture and dispose of these byproducts. Over 118 million tons of combustion byproducts are produced and captured each year in the United States alone. Disposal of this extraordinary amount of waste is difficult and costly. Finding ways to turn this waste into a resource has been necessary, and at times, profitable.

The past fifty years has witnessed great advancement in the understanding of coal byproducts and their potential for use in a variety of settings. One common application incorporates fly ash into the construction of road surfaces. Fly ash can be used in combination with, or in place of, other aggregates to strengthen road-base soils (Parsons and Kneebone, 2004). The proportional amount of fly ash that should be used in such an application depends on many factors including, but not limited to, climate, soil properties, groundwater conditions, and construction strength requirements.

Based on a pilot study completed as a senior design project, the objective of this report is to design a testing methodology and schedule to determine optimal parameters for fly ash addition to strengthen road-base soils in the Northern Red River Valley. The project has been designed with the assistance of Lafarge, International. The expected outcome will be a procedure and set of testing results that can be used by others to determine optimum fly ash proportions for specific soil types. Also included are the results of the pilot study for one typical soil collected from Casselton, North Dakota. The development of the procedure is expected to provide the basis of a thesis for a graduate student pursuing a Master's of Science degree in Geological Engineering.

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ACKNOWLEDGMENTS

Special thanks to Dr. Scott Korom, Hank Hauge and Lafarge International, and Gregg Johnson, Keith Johnson and other employees at Midwest Testing, for providing resources, assistance and mentorship during my senior design project.

INTRODUCTION

A description of fly ash origin and properties, fly ash soil stabilization uses, and objectives of the design project herein are given below.

Background

Fly ash is a fine-grained dust captured from power plant emissions by precipitator reactors. Fly ash is composed primarily of non-combustible silicon compounds (glass) melted during coal combustion (Lafarge, 2004). Fly ash has pozzolanic properties. This means that fly ash is capable of reacting chemically with calcium oxide, or lime (CaO), at ordinary temperatures to form cementitious compounds (Das, 1995). This cementing ability makes fly ash useful in strengthening and stabilization applications.

In road construction, lime, cement and soil base material are mixed together with water or other fluids, allowed to cure and harden, and compacted to form a road sub-base (Yoder, 1992). The addition of lime and cement to the soil base enhances the road-base load-bearing strength. By increasing strength, the necessary number of pavement layers, the necessary thicknesses of pavement layers, and any seasonal road restrictions decrease. Strength development is highly dependent on curing time, temperature, and amount of compaction of the mixture (Little et al., 2001), but in general, pavement life is enhanced and expanded. Fly ash can be added in a similar manner in addition to or in place of lime and cement (Yoder, 1992). In addition to the previously mentioned benefits, fly ash addition can effectively improve soil properties by increasing stiffness, strength, freeze-thaw durability, and control of soil compressibility and moisture. Also, fly ash addition decreases permeability, plasticity, and swelling of soils (Little et al., 2001).

Unfortunately, fly ash addition is only beneficial to a point. After a critical fly ash to soil mixture ratio is reached, excess addition of fly ash makes soil material brittle, weak, and unsatisfactory for road-base design (Lafarge, 2004). The critical ratio depends on the temperature, the moisture content, and the compositions of the fly ash and soil that compose the mixture. Understanding these restrictions is vital when using fly ash as a soil amendment for road base surfaces.

Two varieties of fly ash exist for use; they are Class F (non-self-cementing) ash and Class C (self-cementing) ash. Class F fly ash is produced from the combustion of bituminous, anthracite, and some lignite coals. It is pozzolanic, but not self-cementing. To produce cementitous properties, an activation agent like lime or Portland cement must be added (Little et al., 2001).

Class C fly ash was not discovered until the 1970's with the passage of the Clean Air Act (Little et al., 2001). To meet regulation standards, utility companies began to burn low-sulfur sub-bituminous coals. The new type of ash that formed was self-cementing, and was designated as Class C coal fly ash (Little et al., 2001). Class C ash is self-cementing because calcium oxide (CaO), a basic activation agent used for non-self-cementing ash mixtures, is present naturally in concentrations ranging from 20-30%. However, most of the calcium oxide in Class C fly ash is complexly combined with pozzolans and only a small percentage is unreacted and available to assist in cementation processes (Little et al., 2001).

Both types of ash are acceptable for use in road-base stabilization projects (Lafarge, 2002). When choosing a fly ash source, it is essential to select a company that produces material that meets all state and national regulations. The North Dakota

Department of Transportation (NDDOT) (See Appendix A), the Minnesota Department of Transportation (MNDOT) and the Environmental Protection Agency (EPA) have regulations on the types and qualities of fly ash that are acceptable in road design (AASHTO, 1990) in the Northern Red River Valley.

Objectives

The pilot test study and the proposed thesis work herein utilize regional Class F fly ash from the Coal Creek Power Plant in central North Dakota (Appendix B). The purpose of this design project is to outline a practical method that others can use to determine critical mixture ratios for any soil in the Northern Red River Valley. A pilot study was completed with mixtures of fly ash and a local valley soil at various moisture contents, using standard engineering strength tests, to better understand fly ash addition effects and properties. The tests included the Triaxial Cell test and the California Bearing Ratio test. The knowledge gained from the pilot test has been used to outline the standard procedure herein. The standard procedure, timeline schedule, and budget analysis have been developed to provide the basis of a thesis for a graduate student pursuing a Master's Degree of Science in Geological Engineering.

PILOT STUDY METHODOLOGY

The procedure outlined below was used to assist in the determination of fly ash to soil ratio methodology and uses a combination of four different elements: the Standard Proctor Test, the Atterberg Limit Tests, the Triaxial Test and the California Bearing Ratio. These four tests were chosen because they are easily accessible, commonly used in road construction, and meet the NDDOT testing standards. In the subsequent paragraphs, a description of each of the tests is given. The complete laboratory testing procedures can be found in Appendix C.

The Standard Proctor Test and the Atterberg Limit Tests are used to classify the soil sample or soil/fly ash mixture and determine its optimum moisture content and maximum dry unit weight (Das, 2002). The Triaxial Test and the California Bearing Ratio are used to determine the strength and stiffness properties of the samples.

Before beginning the tests, it was necessary to determine the number of samples that would be investigated. Two variables had the largest effect on sample results: the fly ash percentage and the moisture content of the sample. Previous testing (Kumar et. al, 2004) showed that fly ash additions of $\leq 20\%$ improved soil qualities, but additions $>20\%$ did not improve soil quality, and at in some instances, were detrimental. The number of tests and variations completed for the pilot study also depended on how much time and money were available. Lafarge, International covered the costs of all testing procedures and materials. The amount of time available for the pilot study was two months. Unfortunately, the pilot test was completed during the winter, and the amount of the soil sample, which had been collected from Casselton, ND, during warmer temperatures, was limited.

After viewing all limiting factors, only two variations of the design were completed. A control sample containing 100% soil was processed at its optimum moisture content and a sample of 90 % soil, 8 % Class F fly ash, and 2% Portland cement (added as activation agent) was processed at its optimum moisture content. The percentage of fly ash and Portland cement used in the project were determined from previous laboratory and field tests (Kumar et. al, 2004). The pilot test was conducted in the laboratories of Midwest Testing, Inc., in Fargo, N.D.

The control samples containing 100% soil were tested immediately. Samples containing fly ash were compacted immediately after mixing, placed in plastic wrap to reduce moisture loss, and then allowed to cure and harden for 168 hrs (7 days). This time period allowed the mixture to gain strength and produce more practical results. Testing outcomes are found in the Pilot Study Results section.

Standard Proctor Test

For construction roadways, it is necessary to compact an in-situ soil to improve its strength characteristics and find its maximum dry unit weight ($\gamma_{d\ max}$) and optimum moisture content (w%). Proctor developed a laboratory compaction test procedure that can be used to determine the maximum dry unit weight ($\gamma_{d\ max}$) of compaction of a soil. The test values can be related to field compaction cases (Das, 2002).

The maximum dry unit weight ($\gamma_{d\ max}$) is the maximum amount of soil particles that can be compacted into a standard volume (Das, 2002). Though not visible to the naked eye, soil particles have sharp, angular edges. These sharp edges prevent close packing of soil particles. When water is initially added to these particles, a thin film covers their surfaces and allows them to slide past each other, leading to tighter packing. As water is continually added, void pore spaces are filled between the soil particles, decreasing the compaction ability of the soil. The water content where the maximum compaction ($\gamma_{d\ max}$) occurs is called the optimum moisture content (w %).

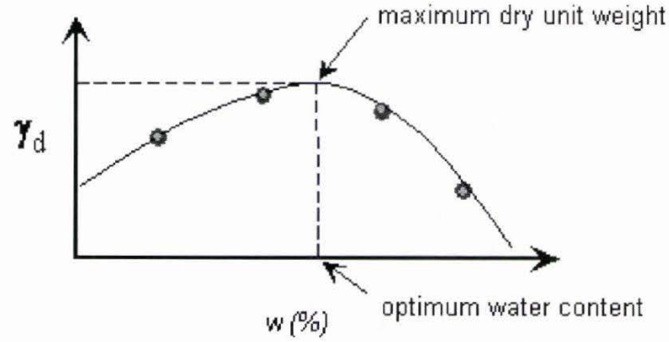


FIGURE 1: Maximum Dry Unit Weight vs. Optimum Water Content— Standard Proctor Test

Road designers try to compact soils to 90-95% of the maximum dry unit weight (Das, 2002).

Once the maximum dry unit weight and optimum moisture content of the soil and fly ash/soil mixtures were determined, they were used in the Triaxial Test and California Bearing Ratio sample evaluations.

Atterberg Limit Tests

When any soil analysis is conducted, soil classification is necessary. Without knowledge of soil type, any testing completed cannot be compared to future analyses. The pilot study used the Unified Classification System (UCS) to describe its soil type and fly ash/soil mixture type. The American Association of State Highway and Transportation Officials (AASHTO) Classification system is also available for specific situations that would not incorporate the Unified Classification System. Both schemes use the Atterberg Limit Tests for classification.

When a cohesive soil is mixed with an excessive amount of water, it will be in a somewhat liquid state and flow like a viscous liquid (Das, 2002). However, when this viscous soil is dried, it will gradually lose moisture and pass into a plastic state. With further moisture reduction, the soil will pass into a semisolid and then a solid state (Das, 2002). Figure 2 shows a graphical representation of these changes.

The moisture content (%) at which a cohesive soil will pass from a liquid state to a plastic state is called the *liquid limit* of the soil. Similarly, the moisture contents (%) at which the soil changes from a plastic to a semisolid state and from a semisolid state to a solid state are referred to as the *plastic limit* and the *shrinkage limit* of the soil, respectively. The liquid, plastic, and shrinkage limits are referred to as the Atterberg limits (Das, 2002).

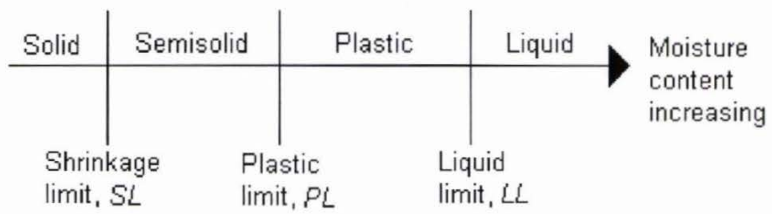


FIGURE 2: Atterburg Limits

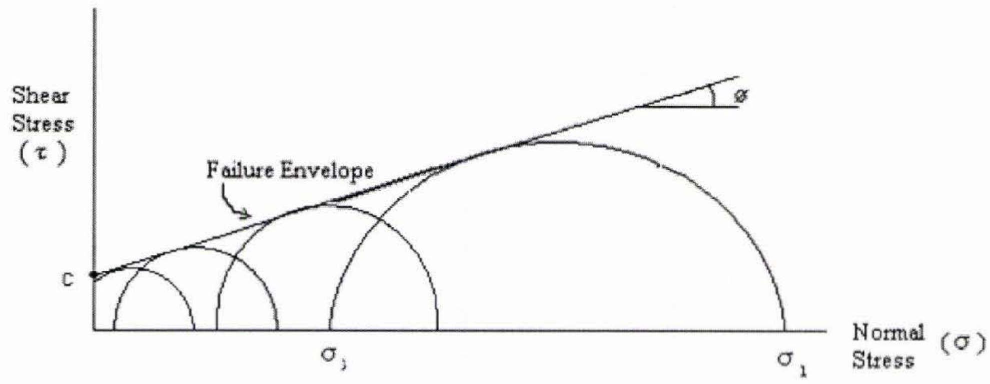
Liquid and plastic limits were determined for the control (100% soil) and the fly ash/soil samples.

Triaxial Test

According to Das (1995) and Bowles (1992), the triaxial compression test is used to classify strength and failure parameters of soils and rocks. The triaxial test can be used on sand and clay soils. In the procedure, a sample of soil is inserted into and confined by a cylindrical rubber membrane. The sample and the rubber membrane are placed inside a cylindrical chamber, which is usually made of Lucite. Inside the chamber, an all-around confining pressure (σ_3) is applied to the sample. The confining pressure is induced by a chamber fluid, usually water or glycerin. An axial stress (σ_1) is then applied to the sample. Axial stress is increased until the sample experiences failure or reaches a preset maximum limit. By changing the amount of confining pressure on a single type of soil sample, it is possible to calculate the average failure criterion of the sample (Mohr-Coulomb failure criterion). The combinations of axial and confining stresses that induce failure are plotted as Mohr's circles on a normal stress vs. shear stress diagram. Then, a common tangent line is drawn to define the failure envelope of the sample. At failure,

$$\sigma_1 = \sigma_3 * \tan^2 (45+\phi/2) + 2c*\tan (45+\phi/2)$$

where σ_1 is the axial stress applied to the soil sample, σ_3 is the confining stress applied to the soil sample, ø is the angle of internal friction (obtained from Mohr's circle, Figure 3) and c is the value of cohesion (obtained from Mohr's circle).



c = 0 for normal consolidated clays

FIGURE 3: Mohr-Coulomb Failure
Diagram

For clay soils such as those found in the Northern Red River Valley, three varieties of tests can be conducted with triaxial equipment: the consolidated-drained test, the consolidated-undrained test, and the unconsolidated-undrained test. The differences in the tests exist from internal pressures formed by fluid present inside soil pores. Unless a soil sample has been oven dried above 100°C, fluid is present in the voids of the soil. As soil is compressed in the triaxial testing equipment, pore pressure from fluid inside the soil voids pushes back, increasing the stress on the soil particles, and reducing the cohesive strength of the soil.

The consolidated-drained test allows for complete drainage of pore water. While the chamber pressure is applied, water drainage is allowed and no pore water pressure develops. After the chamber pressure is applied, the axial stress is applied very slowly. Water drainage is also allowed in this stage, and no pore water pressure develops. The consolidated-undrained test allows drainage while the chamber pressure is applied, but prevents drainage while axial pressure is applied. The effective stress (σ'_1) used in the Mohr-Coulomb Failure Criterion is equal to the total applied stress minus the pore water pressure induced by axial stress. In the unconsolidated-undrained test, drainage is prevented during chamber pressure application and axial stress application. For this test, the effective stress (σ'_1) used in the Mohr-Coulomb Failure Criterion is equal to the total applied stress minus the pore water pressure induced by the chamber pressure and axial stress.

All three tests have important applications, but it was determined that the unconsolidated-undrained test was most realistic for design of road-base surfaces.

Underneath road coarse surfaces, it is unlikely that pore water can escape easily. Realistically, pore water would be trapped in the cement-like mixture of soil and fly ash.

Engineers at Midwest Testing, Inc., determined preferable confining pressures. Triaxial tests were run for control samples and fly ash/soil mixture samples at confining pressures of 1, 10 and 20 psi.

California Bearing Ratio

The laboratory CBR test (AASHTO, 1990) measures the shearing resistance of a soil under controlled moisture and density conditions. The test yields a bearing ratio number that is applicable for the state of soil as tested. The CBR is obtained as the ratio of the unit stress required to affect a certain depth of penetration of the piston, with an area of 3.0 in^2 (1935 mm^2), into a compacted specimen of soil at known water content and density to the standard unit stress required to obtain the same depth of penetration on a standard sample of crushed stone.

TABLE 1: California Bearing Ratio Classification Scheme (Bowles, 1992)

CBR	General Rating	Uses
0-3	Very poor	Sub-grade
3-7	Poor to fair	Sub-grade
7-20	Fair	Sub-base
20-50	Good	Base of sub-base
>50	Excellent	Base

Typical CBR ratings

CBR tests can be used in the laboratory or in the field. The pilot soil testing was conducted in the laboratory; cold weather would not permit otherwise. Test samples were prepared and cured for 168 hours (7 days). After the curing period, they were hydrated for 96 hours (4 days).

PILOT STUDY RESULTS

All components of the pilot study were tested in the Midwest Testing, Inc. laboratories in March 2005, with a representative Northern Red River Valley Soil. The soil was collected from a location in Casselton, ND. Soil sample volume was limited, and unfortunately, only two variations of the design were completed. A control sample containing 100% soil was processed at its optimum moisture content and a sample of 90% soil, 8% Class F fly ash, and 2% Portland cement (added as activation agent) was processed at its optimum moisture content. Complete results are located in Appendix D.

The Standard Proctor Test was completed on both samples to find corresponding optimum moisture contents. The results are shown in Figure 4. The optimum moisture content and the maximum dry density correspond to the maximum value of the lower curve on each graph. The straight line, labeled as Zero-Air-Voids, is the hypothetical combination of unit weight and moisture content that would occur if all of the void spaces in the sample were filled. The optimum moisture content of the control sample was 23.6 % and the maximum dry unit weight (γ_{dmax}) of the control sample was 99.0 lb/ft^3. The optimum moisture content of the fly ash/soil mixture was 21.7 % and the maximum dry unit weight (γ_{dmax}) was 100.2 lb/ft^3. The fly ash addition increased the maximum dry unit weight by 1.2 % and decreased the optimum moisture content by 8.1%.

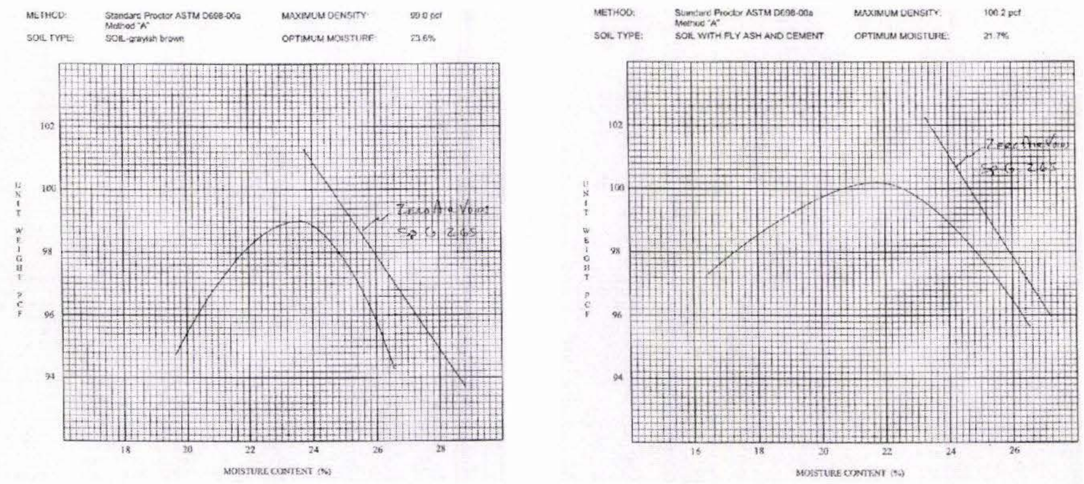


Figure 4: Standard Proctor Results for Casselton Soils
with control soil (left) and fly ash mixture (right)

The Atterberg limits of the two sample variations were calculated using the Liquid and Plastic limit tests. For the control sample (100% soil):

- $LL = 45$
- $PL = 27$
- $PI = LL - PL = 18$

According to the Unified Classification System, the sample is identified as **ML** – Silt.

For the fly ash mixture:

- $LL = 54$
- $PL = 33$
- $PI = LL - PL = 21$

According to the Unified Classification System, this mixture is identified as **MH** – Elastic silt. The addition of fly ash and cement increased the liquid limit by 20.0% and plastic limit by 22.2%. The raised liquid limit and plastic limit indicate that fly ash addition decreased the ability of a soil to flow as a viscous liquid. Fly ash addition stabilized and cemented the soil, making it less susceptible to moisture fluctuations.

The unconsolidated-undrained triaxial test was conducted with three samples of the control and three samples of the fly ash mixture. The control specimens were tested immediately. The fly ash specimens were covered in plastic to reduce moisture loss and shelved for 168 hrs (7 days) before testing to allow curing and hardening. As mentioned previously, the control and fly ash samples were tested at three different confining pressures; 1 psi, 10 psi, and 20 psi.

The top diagram in Figure 5 displays results for the control samples, while the bottom diagram displays results for the fly ash samples. The confining pressures and maximum axial pressures that occurred for each of the three different samples defined the circles on the graph. The tangential line to each circle represents the Mohr-Coulomb failure envelope of the samples.

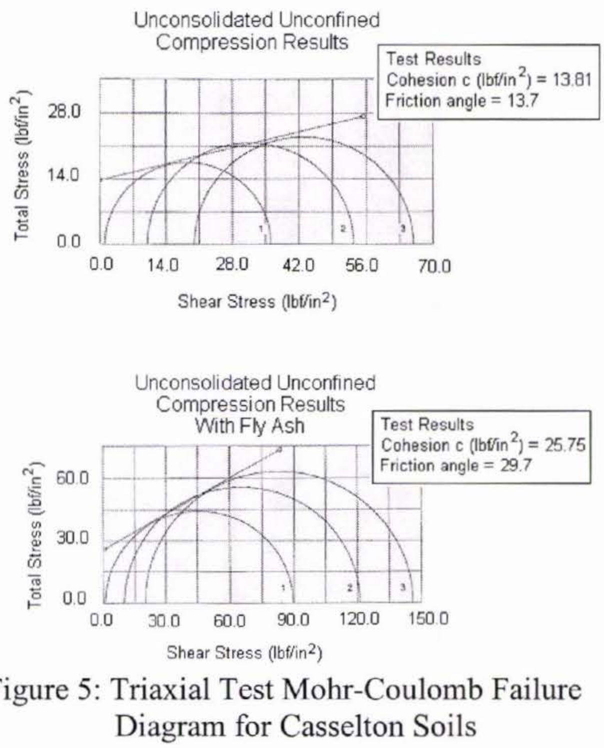


Figure 5: Triaxial Test Mohr-Coulomb Failure Diagram for Casselton Soils

In general, samples with fly ash were able to withstand much larger pressure additions than control samples. The fly ash samples were stronger and could resist loads more effectively. Fly ash was effective as a strengthening agent.

The California Bearing Ratio was tested on control and fly ash samples at three different compaction levels. A standard compaction hammer was used at 25, 40, and 56 blows per layer.

The more compacted samples withstood more load bearing than the less compacted samples. Fly ash addition was extremely beneficial to load capabilities. The fly ash samples needed much larger pressure additions to exact the same amount of compaction as the control sample tests. The strength of the samples was greatly increased by ash addition. The fly ash addition turned a poor to fair soil into an excellent soil by the CBR classification scheme.

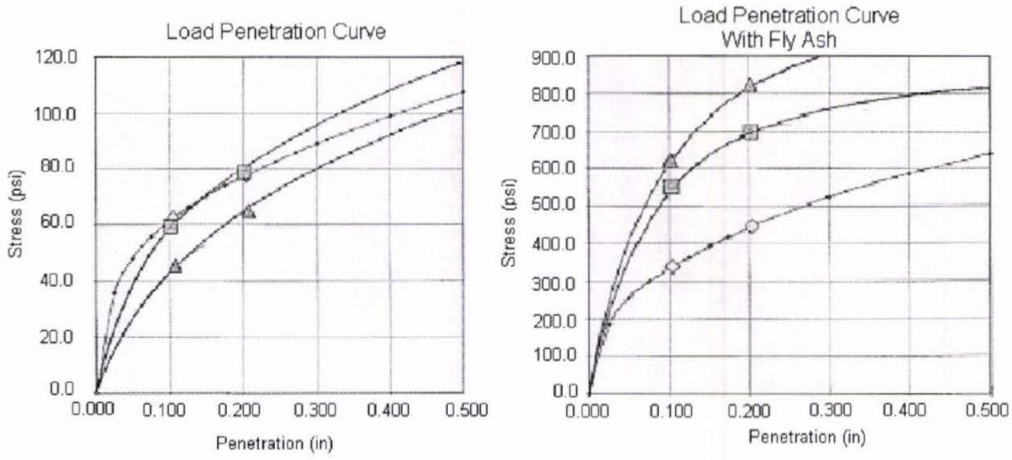


Figure 6: Load Penetration Curves for Casselton Soils

Again, since soil sample volume was limited, it was only possible to test one fly ash mixture. While the results of the pilot study showed that fly ash addition does increase the strength and stiffness of a sample, the objective of the design was not met. Testing could not be conducted at various fly ash percentages to find the optimum fly ash content of the Casselton soil.

STUDY DESIGN

Based on a completed pilot study, the goal of this project will be to test the design methodology above and determine optimal parameters for fly ash addition to strengthen road-base soils in the Northern Red River Valley. The procedure and results may be used by others to determine optimum fly ash proportions for specific soil types. This project will be the basis of a thesis for a graduate student pursuing a Master's of Science degree in Geological Engineering.

Task List

Task 1: Determine location sites for soil samples to be tested with design. Soil survey maps of North Dakota Red River Valley (Appendix E) categorize soil types by their formation. Labels include Soils of the Glacial Till Plains, Soils of the Outwash, Interbeach, Delta, and Valley Areas, Soils of the Glacial Lake Plain, Soils of the Flood Plains and Low Terraces, and Soil on Breaks and Bottom Plains. This broad classification scheme will be more acceptable than classification by UCS system. It is not feasible to collect each UCS sample variety. Samples will be collected from Cass County, Traill County, Grand Forks County, Walsh County and Pembina County, or as decided later.

Task 2 Sample soil collection with the assistance of Midwest Testing, Inc. 15 lb of each soil type (from soil survey) in each county listed above will be collected. A total of 25 samples will be collected.

Task 3 Control (100% soil) Proctor test for each sample. This will determine the maximum dry unit weight and optimum moisture content to be used for the other tests.

Task 4 Atterberg Limit Testing on each control sample. Liquid limit, plastic limit and UCS system soil classification will be performed.

Task 5 Unconsolidated-undrained triaxial cell testing for each control sample. Samples will be prepared at optimum moisture content and tested immediately.

Task 6 California Bearing Ratio Test determination for each control sample. Samples will be prepared at optimum moisture content, hydrated for 96 hours (4 days) and tested.

Task 7 Sample preparation of 90% soil, 8% fly ash and 2% Portland cement for each soil variety.

Task 8 Proctor test will be conducted for the mixture to determine the maximum dry unit weight and optimum moisture content for each soil sample mixture.

Task 9 Atterberg Limit Testing on each sample mixture. Liquid limit, plastic limit, and UCS system classification will be performed.

Task 10 Unconsolidated-undrained triaxial cell testing for each sample. Samples will be prepared and compacted at optimum moisture content, shelved for seven days, and tested.

Task 11 California Bearing Ratio Test determination for each sample. Sample will be prepared at optimum moisture content, shelved for seven days, then hydrated for 96 hours (4 days) and tested.

Task 12 Sample preparation of 80% soil, 16% fly ash and 4% Portland cement for each soil variety. *

Task 13 Proctor test will be conducted for the mixture to determine the maximum dry unit weight and optimum moisture content for each soil sample mixture.

Task 14 Atterberg Limit Testing on each sample mixture. Liquid limit, plastic limit, and UCS system classification will be performed.

Task 15 Unconsolidated-undrained triaxial cell testing for each sample. Samples will be prepared and compacted at optimum moisture content, shelved for seven days, and tested.

Task 16 California Bearing Ratio Test determination for each sample. Sample will be prepared at optimum moisture content, shelved for seven days, then hydrated for 96 hours (4 days) and tested.

Task 17 Preparation of results and master thesis.

*Based upon results, it may be necessary to repeat method with more soil/fly ash/ Portland cement ratios.

Schedule

Task	Output	QTY	Year 1				Year 2			
Objective: to assess fly ash addition in typical valley soils.		MONTHS	JUL-05	OCT-05	JAN-06	APR-06	JUL-06	OCT-06	JAN-07	APR-07
Task 1 – Determine soil location pick-up sites	25 sites identified	3	■							
Task 2 – Collect 15 lb samples of soil from each site.	25 soil samples collected	3	■							
Task 3 – Proctor testing on control samples	Testing completion	3		■						
Task 4 – Atterberg Limit testing on control samples	Testing completion	3		■						
Task 5 – Triaxial Cell testing on control samples	Testing completion	3		■						
Task 6 – CBR testing on control samples	Testing completion	3		■						
Task 7 – Sample preparation – 90% soil, 8% ash, 2% cement	25 samples prepared	6			■	■				
Task 8 – Proctor testing on soil mixture (Task 7)	Testing completion	6			■	■				
Task 9 – Atterberg Limit testing on soil mixture (Task 7)	Testing completion	6			■	■				
Task 10 – Triaxial Cell testing on soil mixture (Task 7)	Testing completion	6			■	■				
Task 11 – CBR testing on soil mixture (Task 7)	Testing completion	6			■	■				
Task 12 – Sample preparation- 80% soil, 16% ash, 4% cement	25 samples prepared	6					■	■		
Task 13 – Proctor testing on soil mixture (Task 12)	Testing completion	6					■	■		
Task 14 – Atterberg Limit testing on soil mixture (Task 12)	Testing completion	6					■	■		
Task 15 – Triaxial Cell testing on soil mixture (Task 12)	Testing completion	6					■	■		
Task 16 – CBR testing on soil mixture (Task 12)	Testing completion	6					■	■		
Task 17 – Preparation of results and master's thesis	Documented results	6							■	■

*The output and quantities shown on this table reflect the entire master's thesis project. 25 samples will be tested and analyzed from the North Dakota side of the Northern Red River Valley.

Proposed Budget

DESCRIPTION	GRANT FUNDS REQUESTED YEARS 1 - 2
Salary Wages	40,000.00
Fringe Benefits	+ 5,360.00
Total Personnel	= 45,360.00
Travel	682.00
Communications	100.00
Office	0.00
Supplies	50.00
Fees	+ 0.00
Total Operating	= 832.00
Total Direct Cost	46,192.00
Indirect Cost	+ 18,292.00
Total Cost	64,484.00

Budget comments: Salaries will be $16,000/yr for the graduate student for two years and $4,000/yr for the graduate advisor. The graduate student will collect samples, test samples, and provide a written report of results. The graduate advisor will oversee the work and assist graduate student in duties. Fringe benefits are 27% for the director and 10% for the graduate student. Supplies and materials needed include field books, sample bags, storage containers, writing utensils, and miscellaneous supplies. Travel will occur at a rate of $0.341/mile. The federally approved indirect cost rate is 39.6% for the University of North Dakota.

FUTURE RESEARCH

Other possibilities exist for future research in fly ash amendment issues. Any fly ash used in road base design in northern areas, like the Red River Valley, will be exposed to multiple freeze-thaw cycles. Studies like that by Fleming et al. (1995) have attempted to evaluate the effects of varying thermal gradients from climatic freeze-thaw cycles.

In the test by Fleming et al. (1995), compacted pure fly ash samples were subjected to cyclical freezing and thawing in a freeze-thaw permeameter designed and built by the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, N.H. The freezing process was conducted by the circulation of a solution of ethylene glycol and water around the fly ash samples. The freeze-thaw rates and temperature gradient parameters were set at values which are considered standard in northern climates, and were frozen for 10 hours in each cycle to allow ample time to attain equilibrium conditions. The study found that the strength, or amount of effective stress that the fly ash can resist before failure, decreased with increasing freeze/thaw cycles. Similar research could be worthwhile for this design aspect.

It is also important to research the possible negative effects of fly ash addition. In areas where large amounts of sulfur are present in groundwater, a secondary mineral, called ettringite, can form as fly ash cures and hardens (Lafarge, 2004). This mineral turns amended areas into powder, making them completely unstable for road-base design, and leading to damage costs and possible lawsuits.

APPENDIX A

STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION
NORTH DAKOTA DEPARTMENT OF TRANSPORTATION

STANDARD SPECIFICATIONS FOR ROAD AND BRIDGE CONSTRUCTION NORTH DAKOTA DEPARTMENT OF TRANSPORTATION (ND DOT, 2002)

234.04 CONSTRUCTION REQUIREMENTS

The roadbed shall be shaped to the cross section shown on the Plans. The roadbed material shall be scarified or disked to a depth of 6 inches, 12 inches, 18 inches, 24 inches, or more as required. Any work that the Engineer requires to be done below a 24-inch depth will be paid according to Section 104.03D. The bottom 6 inches of the scarified or disked depth shall remain on the roadway, mixed with lime or lime-fly ash, and recompacted as directed by the Engineer. Section 104.03B will not apply to lime or lime-fly ash. Any wet or unstable materials below the scarified section shall be corrected as determined by the Engineer.

A. **Spreading.** The lime or lime-fly ash shall be spread by dry application or slurry at the rates shown on the Plans. The lime and fly ash may be applied together or separately, provided the lime is applied before the fly ash. Both lime and fly ash shall be distributed uniformly without loss of material by wind or other causes. Lime or fly ash shall not be applied by dry application when the wind is 15 mph or greater.

   Slurry shall be used in areas adjacent to residential or other developed areas so the lime or lime-fly ash does not damage, discomfort, or be an inconvenience to public or private property. The lime or lime-fly ash shall be premixed with water in approved agitation equipment in proportions so that the "Dry-Solids Content" is at least 30% by weight. Lime or lime-fly ash and water may be similarly proportioned in distributing equipment, provided the equipment contains approved metering devices which accurately meter the quantity of water, lime, or lime-fly ash into the distribution tank to provide positive controls for proper proportioning of the mixture.

   All distributing equipment shall provide continuous and adequate agitation until the slurry is applied to the roadbed. The slurry shall be applied through pressurized distributing spray bars. Adequate means of accurately determining distribution of lime or lime-fly ash on each area shall be provided. Each distributing unit shall be provided with a metering device which accurately determines the "Dry-Solids Content" applied to any area, based on the percentage of lime or lime-fly ash in the slurry. The application of lime or lime-fly ash may also be controlled by weight or by measuring and converting to weight each load or partial load applied, and basing the dry-solids content on the percentage of lime or lime-fly ash in the slurry.

   The total application of lime or lime-fly ash ordered shall be attained by successive passes of the distribution equipment over a measure area.

   The slurry may be applied directly to the scarified or disked subgrade, provided no loss of lime or lime-fly ash slurry is evident and uniform distribution into the soil can be made.

B. **Mixing.** The lime or lime-fly ash shall be thoroughly mixed with the material to be processed with enough water added to the mixture to maintain not less than optimum moisture content. Mixing shall be accomplished by the use of a rotary mixer. It shall be mixed so that 100% of the material passes a one inch sieve. It the material does not readily mix with the lime or lime-fly ash, it shall be thoroughly mixed, brought to the proper moisture content, and left to cure 24 to 48 hours.

C. **Compacting and Finishing.** Compaction shall begin immediately after the material has been spread to the specified section. The stabilized subgrade shall be compacted to the density specified in the Plans.

If 6 inches are scarified of disked, the 6 inches shall be compacted until a uniform specified density is obtained. If more than 6 inches are scarified or disked, the top 12 inches shall be compacted until a uniform specified density is obtained.

Subgrade material that can not be compacted to the required stability shall be removed and replaced with approve material. Rocks, roots and any other material that may interfere with compaction and shaping to grade and cross section shall be removed and disposed of under Section 203.02D. It the required stability cannot be achieve through manipulation and drying after the subgrade is scarified to the required depth, the Engineer will determine what further subgrade work is necessary.

When imprints from equipment are left in the finished surface, the surface shall be lightly scarified and recompacted. The moisture content of the surface material must be maintained at its specified optimum during all finishing operations.

The Engineer may suspend the work if instability of the subgrade is cause by frost or excess moisture. A suspension for these reasons shall not constitute a basis for a claim for payment of any contractor losses.

Mixing shall not be performed after October 1 and shall not be resumed in the spring until the ground is frost free.

D. **Curing.** The completed surface of the treated subgrade shall be kept in a continuously moist condition until an application of bitumen is applied to the surface as a protective cover to prevent moisture loss.

Liquid asphalt for curing shall be applied according to Section 401.

812.01 WATER

Water used in mixing or curing concrete, cement-treated bases, lime-treated bases, and fly ash treated bases shall be clean and free of oil, acid, alkali, organic matter, and other substances damaging to the finished product. Water will be tested according to AASHTO T-26. Water known to be of potable quality may be used without testing. Where the source of water is relatively shallow, the intake shall be enclosed to exclude silt, mud. Grass. Or other foreign materials.

When water used for mixing with Portland Cement has a pH value less that 4.5 or more than 8.5, the water shall be tested by casting and testing mortar cubes according to AASHTO T-106. The 7-day compressive strengths shall equal at least 90% of the companion test specimens made using distilled water.

The water must also meet the autoclave expansion and time of setting tests criteria given in AASHTO T-26.

820.01 GENERAL

Fly ash shall meet the following for the specific type of work:

Type of Work	Specification
Portland Cement Concrete	AASHTO M-295
Lime Fly Ash Treated Subgrade	ASTM C-593
Econocrete	AASHTO M-295
Aggregate Base	ASTM C-593

Sampling and testing all fly ash shall be at the contractor's expense.

The requirement for loss on ignition in AASHTO M-295 (table 1 chemical requirements) is modified for 5.0% to 2.0% max. Also the optional requirements in Table 2 are required.

Fly ash shall be from an electrical generating plant using a single coal source. Fly ash produced at plants where the limestone injection process is used for controlling air pollutants will be considered unacceptable for use in Portland Cement Concrete. The Contractor shall provide weather-tight storage facilities for the fly ash either at the source or on the Project site.

APPENDIX B

PROOF OF COMPLIANCE FOR FLY ASH RESTRICTION
IN CASSELTON SOIL TESTS

HEADWATERS RESOURCES

Adding Value to Energy ™

ASTM C618-03 / AASHTO M 295-00 Testing of Coal Creek Fly Ash

Type of sample:	3200-ton Rail	**Report Date:**	December 29, 2004
Date of sample:	10/28-11/1/04	**MTRF I.D.**	2379CC

Chemical Analysis		**ASTM / AASHTO Limits** Class F	Class C	**ASTM Test Method**
Silicon Dioxide (SiO_2)	48.69 %			
Aluminum Oxide (Al_2O_3)	15.09 %			
Iron Oxide (Fe_2O_3)	6.93 %			
Sum of Constituents	70.71 %	70.0% min	50.0% min	D4326
Sulfur Trioxide (SO_3)	0.98 %	5.0% max	5.0 % max	D4326
Calcium Oxide (CaO)	17.12 %			D4326
Moisture Content	0.09 %	3.0% max	3.0% max	C311
Loss on Ignition	0.05 %	6.0% max	6.0% max	C311
(AASHTO M 295-00 req.)		5.0% max	5.0% max	
Available Alkalies, as Na_2O **	1.10 %			C311
(AASHTO M 295-00 req.)		1.5% max	1.5% max	
Physical Analysis				
Fineness, % retained on #325	23.95 %	34% max	34% max	C311, C430
Strength Activity Index – 7 or 28 day requirement				C311, C109
7 day, % of control	85 %	75% min	75% min	
28 day, % of control	96 %	75% min	75% min	
Water Requirement, % control	94 %	105% max	105% max	
Autoclave Soundness	0.36 %	0.8% max	0.8% max	C311, C151
True Particle Density	2.65			

*** Supplementary Optional Chemical Requirement (Available Alkali) was removed by ASTM C618-01*

ISG Resources, Inc. certifies that, to the best of its knowledge, the test data listed herein was generated by applicable ASTM methods and meets the requirements of ASTM C618-03 for Class F fly ash.

Bobby Bergman

Bobby Bergman
MTRF Manager

AASHTO R18

Materials Testing & Research Facility
2650 Highway 113 S.W.
Taylorsville, Georgia 30178
P: 770.684.0102
F: 770.684.5114
www.headwaters.com

July 31, 2003

Strata Concrete, Inc.
PO Box 13500
1625 N. 36th Street
Grand Forks, ND 58203

ATTENTION: Mr. Ed Fellner

TO WHOM IT MAY CONCERN:

This is to certify that the Type I/II Portland Cement produced by Lafarge North America, Richmond, British Columbia, Canada meets all ASTM C-150 Type I/II specifications and AASHTO M-85 Type I specifications.

The Lafarge North America manufacturing facility located at Richmond, British Columbia, Canada is I.S.O. 9001:2000 certified and operates in compliance of applicable industry standards.

PROJECT: Grand Forks Air Force Base

CONTRACTOR: US Army Corps of Engineers

Henry Hauge
Technical Service Engineer
Lafarge North America

LAFARGE
NORTH AMERICA

Mill Test Report Number:	**R-1-AA-04-06**
YEAR:	**2004**
MONTH:	**JULY**
PLANT:	**Richmond**
CEMENT TYPE: low alkali	**Type I/II ASTM, Type I AASHTO,**
Data represents cement produced during:	**6/1 - 6/30**

PHYSICAL DATA		
Fineness by Air Permeability *(m2/kg; ASTM C204)*	357	
Fineness by 45 um (No. 325) Sieve	98.7	
Compressive Strength *(ASTM C109 / C109M)*	**Mpa**	**psi**
3-day	28.7	4160
7-day	37.8	5490
28-day	-	-
Previous Month 28-day Strength	46.2	6700
Time of Set, Vicat *(initial minutes; ASTM C191)*	83	
Air Content *(%, ASTM C185)*	4.1	
Autoclave Expansion *(%, ASTM C151)*	-0.01	

CHEMICAL ANALYSIS	**Percent**
Silica Dioxide *(%SiO2; ASTM C114)*	20.86
Aluminum Oxide *(%Al2O3; ASTM C114)*	4.71
Ferric Oxide *(%Fe2O3; ASTM C114)*	3.53
Calcium Oxide *(%CaO; ASTM C114)*	64.02
Magnesium Oxide *(%MgO; ASTM C114)*	0.92
Sulphur Trioxide *(%SO3; ASTM C114)*	2.62
Loss on Ignition *(%L.O.I.; ASTM C114)*	1.52
Potassium Oxide *(%K2O; ASTM C114)*	0.34
Insoluble Residue *(%, ASTM C114)*	0.03
Free Lime *(%f-CaO)*	1.06
Tricalcium Silicate *(%C3S; ASTM C150)*	58
Tricalcium Aluminate *(%C3A; ASTM C150)*	6.5
Total Alkali as Sodium Oxide *(%NaEq; ASTM C150)*	0.44

Certified by
N. Cooling
Quality Manager

This cement complies with current ASTM C 150, AASHTO M-85 and CSA /CAN A3000 - A5 specifications
This mill test represents testing data from a monthly average of cement produced on Cement Mill 3

LAFARGE CORP / Seattle Plant
5400 West Marginal Way,
Seattle, WA 98106
Tel 206-923-0098 Fax 206-923-0388

APPENDIX C

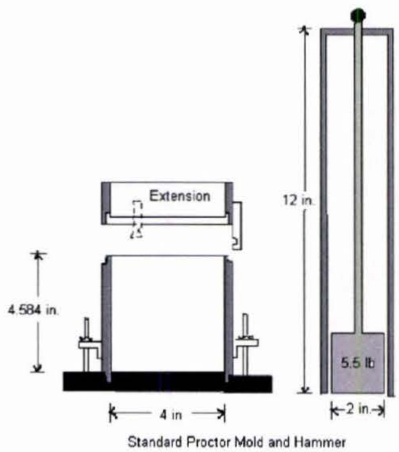
TESTING PROCEDURES

STANDARD PROCTOR COMPATION TEST

This test is based on the compaction of the soil fraction passing through No. 4 U.S. sieve.

Standard Proctor Test Equipment:

·Compaction sieve
·No. 4 U.S. sieve
·Standard proctor hammer (5.5 lb)
·Balance sensitive up to 0.01 lb
·Balance sensitive up to 0.1 g
·Large flat pan
·Jack
·Steel straight edge
·Moisture cans
·Drying oven
·Plastic squeeze bottle of water



Standard Proctor Mold and Hammer

Standard Proctor Test Procedure

1. Obtain about 10 lb of air-dry soil on which the compaction test is to be conducted. Break all the soil lumps.
2. Sieve the soil on a No. 4 U.S. sieve. Collect all of the minus-4 material in a large pan. This should be about 6 lb or more.
3. Add enough water to the minus-4 material and mix it in thoroughly to bring the moisture content up to about 5%.
4. Determine the weight of the proctor mold + base plate (not the extension), W_1 (lb).
5. Now attach the extension to the top of the mold.
6. Pour the moist soil into the mold in three equal layers. Each layer should be compacted uniformly by the standard proctor hammer 25 times before the next layer of loose soil is poured into the mold. *Note*: The layers of loose soil that are being poured into the mold should be such that, at the end of the

three-layer compaction, the soil should extend slightly above the top of the rim of the compaction mold.

7. Remove the top attachment from the mold. Be careful not to break off any of the compacted soil will be even with the top of the mold.
8. Using a straight edge, trim the excess soil above the mold. Now the top of the compacted soil will be even with the top of the mold.
9. Determine the weight of the mold + base plate +compacted moist soil in the mold, W_2 (lb).
10. Remove the base plate from the mold. Using a jack, extrude the compacted soil cylinder from the mold.
11. Take a moisture can and determine its mass, W_3 (g).
12. From the moist soil extruded in Step 10, collect a moisture sample in the moisture can (step 11) and determine the mass of the can + moist soil, W_4 (g).
13. Place the moisture can with the moist soil in the oven to dry to a constant weight.
14. Break the rest of the compacted soil (to No. 4 size) by hand and mix it with the leftover moist soil in the pan. Add more water and mix it to raise the moisture content by about 2%.
15. Repeat steps 6 through 12. In this process, the weight of the mold + base plate + moist soil (W_2) will first increase with the increase in moisture content and then decrease. Continue the test until at least two successive down readings are obtained.
16. The next day, determine the mass of the moisture cans + soil samples, W_5 (g) (from step 13)

Standard Proctor Test Calculations:

$$\gamma = \frac{\text{weight of compacted moist soil}}{\text{volume of mold}} = \frac{W_2 - W_1 \text{ (lb)}}{1/30 \text{ ft}^3}$$

$$w\,(\%) = (W_4 - W_5)/(W_5 - W_3) \times 100$$

$$\gamma_d = \gamma \,/\, (1 + (w(\%)\,/\,100)$$

Zero-Air-Void Unit Weight:

The maximum theoretical dry unit weight of a compacted soil at a given moisture content will occur when there is no air left in the void spaces of the compacted soil. This can be given by

$$\gamma_{d\,(theory-max)} = \gamma_{zav} = \gamma_w \,/\, ((w\,(\%)\,/\,100) + (1\,/\,G_s))$$

where γ_{zav} = zero-air-void unit weight

γ_w = unit weight of water
w = moisture content
G_s = specific gravity of soil solids

Graph

Plot a graph showing γ_d versus w (%) and determine the maximum dry unit weight of compaction [$\gamma_{d(max)}$]. Also determine the optimum moisture content, w_{opt}, which is the moisture content corresponding to $\gamma_{d(max)}$. On the same graph, plot γ_{zav} versus w (%).

<u>Note:</u> For a given soil, no portion of the experimental curve γ_d of w (%) versus should plot to the right of the zero-air-void curve.

LIQUID LIMIT TEST

Liquid Limit Test Equipment:

- ·Casagrande liquid limit device
- ·Grooving tool
- ·Moisture cans
- ·Porcelain evaporating dish
- ·Spatula
- ·Oven
- ·Balance sensitive up to 0.01 g
- ·Plastic squeeze bottle
- ·Paper towels

Casagrande Liquid Limit Device

Liquid Limit Test Procedure:

1. Determine the mass of three moisture cans (W_1).

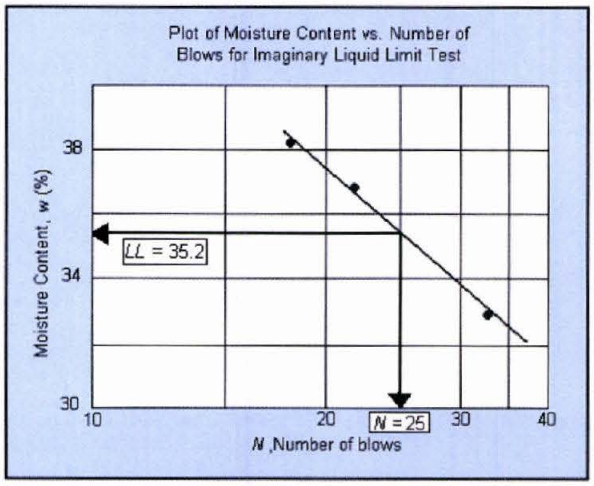
2. Put about 250 g of air-dry soil, passed through No. 40 sieve, into an evaporating dish. Add water from the plastic squeeze bottle and mix the soil to the form of a uniform paste.
3. Place a portion of the paste in the brass cup of the liquid limit device. Using the spatula, smooth the surface of the soil in the cup such that the maximum depth of the soil is about 8 mm.
4. Using the grooving tool, cut a groove along the centerline of the soil pat in the cup.
5. Turn the crank of the liquid limit device at the rate of about 2 revolutions per second. By this, the liquid limit will rise and drop through a vertical distance of 10 mm toward the center. Count the number of blows, N, for the groove in the soil to close through a distance of ½ in. (12.7 mm).
   If N = about 25 to 35, collect a moisture sample from the soil in the cup in a moisture can. Close the cover of the can, and determine the mass of the can plus the moist soil (W_2).
   Remove the rest of the soil paste from the cup to the evaporation dish. Use paper towels to thoroughly clean the cup.
   If the soil is too dry, N will be more than about 35. In that case, remove the soil with the spatula to the evaporation dish. Clean the liquid limit cup thoroughly with paper towels. Mix the soil in the evaporating dish with more water, and try again.
   If the soil is too wet, N will be less than about 25. In that case, remove the soil in the cup to the evaporation dish. Clean the liquid limit cup carefully with paper towels. Stir the soil paste with the spatula for some time to dry it up. The evaporating dish may be placed in the oven for a few minutes for drying also. Do not add dry soil the wet-soil paste to reduce the moisture content for bringing it to the proper consistency. Now try again in the liquid limit device to get the groove closure of ½ in. (12.7 mm) between 25 and 35 blows.
6. Add more water to the soil paste in the evaporating dish and mix thoroughly. Repeat Steps 3, 4 and 5 to get the correct closure at a blow count N = 20 to 25. Get a moisture sample from the cup.
7. Add more water to the soil paste in the dish and mix thoroughly. Repeat steps 3, 4 and 5 to get the correct closure at a blow count N = 15-20. Take a moisture sample from the cup.
8. Put the three moisture cans in the oven to dry to constant masses (W_3).

Liquid Limit Test Calculations:

To determine the moisture content for each of the three trials:

$$w\,(\%) = (W_2-W_3)/(W_3-W_1) * 100$$

A semi logarithmic graph will be made of moisture content vs. number of blows. This will approximate a straight line, which is called the flow curve. From the line, determine the moisture content corresponding to 25 blows. This is the liquid limit.



Imaginary Plot of Moisture Content vs. Number of Blows for Imaginary Liquid Limit Test

PLASTIC LIMIT TEST

Plastic Limit Test Equipment:

- ·Porcelain evaporating dish
- ·Spatula
- ·Plastic squeeze bottle with water
- ·Moisture can
- ·Ground glass plate
- ·Balance sensitive up to 0.01 g

Plastic Limit Test Procedure:

1. Put approximately 20 grams of a representative, air-dry soil sample, passed through a No. 40 sieve, into a porcelain evaporating dish.
2. Add water from the plastic squeeze bottle to the soil and mix thoroughly.
3. Determine the mass of a moisture can in grams and record it on the data sheet (W_1).
4. From the moist soil prepared in step 2, prepare several ellipsoidal-shaped soil masses by squeezing the soil with your fingers.

5. Take one of the ellipsoidal-shaped soil masses and roll it on a ground glass plate using the palm of your hand. The rolling should be done at the rate of about 80 strokes per minute. Note that one complete backward and one complete forward motion of the palm constitute a stroke.
6. When the thread is being rolled reaches 1/8 in. in diameter, break in up into several small pieces and squeeze into ellipsoidal shapes.
7. Repeat until thread crumbles at diameter of 1/8 in.
8. Collect the small crumbled pieces in the moisture can and put the covers on the can.
9. Repeat 2 more times.
10. Determine the masses of the moisture cans and wet soil (W_2).
11. Place in the oven. After 24 hrs, weigh to get W_3.

Plastic Limit Test Calculations:

To determine the moisture content for each of the three trials:

$$w\ (\%) = (W_2 - W_3)/(W_3 - W_1) * 100$$

To determine plastic limit:

$$PL = \text{mass of moisture/ mass of dry soil} = (W_2 - W_3)/(W_3 - W_1) * 100$$

To determine the plastic index:

$$PI = LL - PL$$

where LL = liquid limit
PL = plastic limit

UNCONSOLIDATED-UNDRAINED TRIAXIAL COMPRESSION TEST

Triaxial equipment varies widely between different testing locations. Below is a simple overview of the testing procedure.

Triaxial Test Equipment:

·Triaxial cell
·Strain-controlled compression machine
·Specimen trimmer
·Wire saw
·Vacuum source
·Oven

·Calipers
·Evaporation dish
·Rubber membrane
·Membrane stretcher

Unconsolidated-Undrained Test:

1. Prepare soil specimen as required by individual test.
2. Place the triaxial cell (with the specimen inside it) on the platform of the compression machine.
3. Make proper adjustments so that the piston of the triaxial cell just rests on the top platen of the specimen.
4. Fill the chamber of the triaxial cell with water. Apply a hydrostatic pressure to the specimen through the chamber fluid. *Note*: All drainage to and from the specimen should now be closed so that drainage from the specimen does not occur.
5. Check for proper contact between the piston and the top platen on the specimen. Zero the dial gauge of the proving ring and the gauge used for measurement of the vertical compression of the specimen. Set the compression machine for a strain rate of about 0.5% per minute, and turn the switch on.
6. Take initial proving ring dial reading for vertical compression intervals of 0.01 in. This interval can be increased to 0.02 in. or more later when the rate of increase of load on the specimen decreases. The proving ring reading will increase to a peak value and then may decrease or remain approximately constant. Take about four or five readings after the peak point.
7. After completion of the test, reverse the compression machine, lower the triaxial cell, and then turn off the machine. Release the chamber pressure and drain the water in the triaxial cell. Then remove the specimen and determine its moisture content.

Calculations and graphs are evaluated by a computer program connected to the triaxial machine.

CALIFORNIA BEARING RATIO TEST

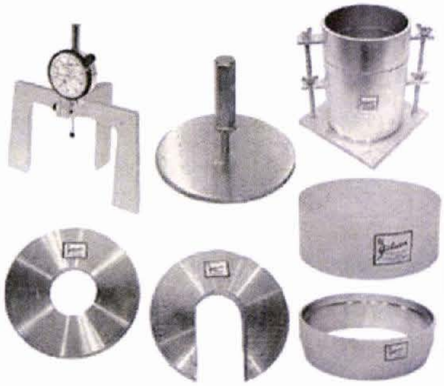
CBR Equipment
·Two-part mold
  ·Mold diameter - 6 in.
  ·Mold height – 5 in.
  ·Surge weight – 10 lb
·Hydration paper

·Compaction sieve
·No. 4 U.S. sieve
·Standard proctor hammer (5.5 lb)
·Balance sensitive up to 0.01 lb
·Balance sensitive up to 0.1 g
·Large flat pan
·Jack
·Steel straight edge
·Moisture cans
·Drying oven
·Plastic squeeze bottle of water

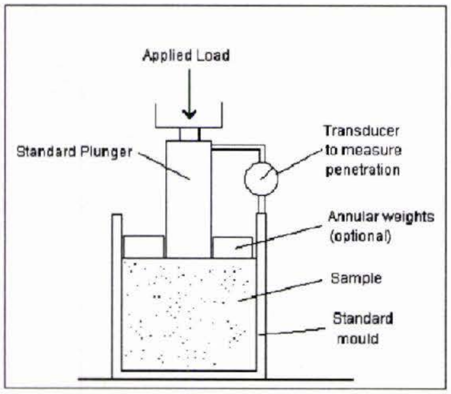
CRB Procedure

1. Obtain air-dry soil on which the compaction test is to be conducted. Break all the soil lumps.
2. Sieve the soil on a No. 4 U.S. sieve. Collect all of the minus-4 material in a large pan.
3. Add enough water to the minus-4 material and mix it in thoroughly to bring the moisture content up to about 5%.
4. Determine the weight of the proctor mold + base plate + surcharge weight (not the extension), (lb).
5. Now attach the extension to the top of the mold.
6. Place the surcharge weights at the bottom of the mold.
7. Place hydration paper on weights.
8. Rub Vaseline on mold insides to prevent sticking.
9. Pour the moist soil into the mold in five equal layers. Each layer should be compacted uniformly by the standard proctor hammer 25, 40, or 56 times before the next layer of loose soil is poured into the mold. *Note*: The layers of loose soil that are being poured into the mold should be such that, at the end of the three-layer compaction, the soil should extend slightly above the top of the rim of the compaction mold.
10. Remove the top attachment from the mold. Be careful not to break off any of the compacted soil will be even with the top of the mold.
11. Using a straight edge, trim the excess soil above the mold. Now the top of the compacted soil will be even with the top of the mold.
12. Determine the weight of the mold + base plate +compacted moist soil + surcharge weight in the mold, (lb).
13. Take a moisture can sample, dry in oven and determine its dry unit weight (lb)
14. Cover the mold in plastic with some wet towels
15. Place a pressure reading gauge on top of the mold to detect any swelling.
16. After seven days, remove the molds and place them into a hydration chamber for 96 hours.
17. Perform CBR test on mold.
18. 1.95 diameter piston is pushed into the sample at a rate of 0.05 inches per minute.

19. The force of resistance is measured every 0.025 inches of penetration, up to 0.3 inches, and every 0.05 inches up to a total penetration of 0.5 inches.
20. These loads are compared that of standard crushed stone to determine the suitability for road design.



CBR Equipment



Side View of CBR Mold

APPENDIX D

MIDWEST TESTING PILOT STUDY
LABORATORY RESULTS

MIDWEST TESTING LABORATORY

4102 - 7th Ave. N. / P.O. Box 3042 / Fargo, North Dakota 58108
Phone (701) 282-9633 / Fax. (701) 282-9635

REPORT OF: TESTS OF SOILS

PROJECT: Plant Tests 2005
Amy Decker Senior Design

DATE: April 7, 2005

REPORTED TO: Lafarge Dakota, Inc.
P.O. Box 757
Valley City, ND 58072-0757

COPIES: Amy Decker

PROJECT NO: 12597

SAMPLE NUMBER	1	2
LOCATION	Soil	Soil w/fly ash and cement
COLOR	grayish brown	grayish brown
ATTERBERG LIMITS		
Liquid Limit	45	53
Plastic Limit	27	33
LABORATORY MOISTURE-DENSITY RELATION (See attached curve)		
Method	ASTM D698-00 "A"	
Optimum Moisture (%)	23.6	21.7
Maximum Density (pcf)	99.0	100.2

REMARKS

Sample was submitted for test on March 11, 2005.

SIGNED Keith O[illegible]

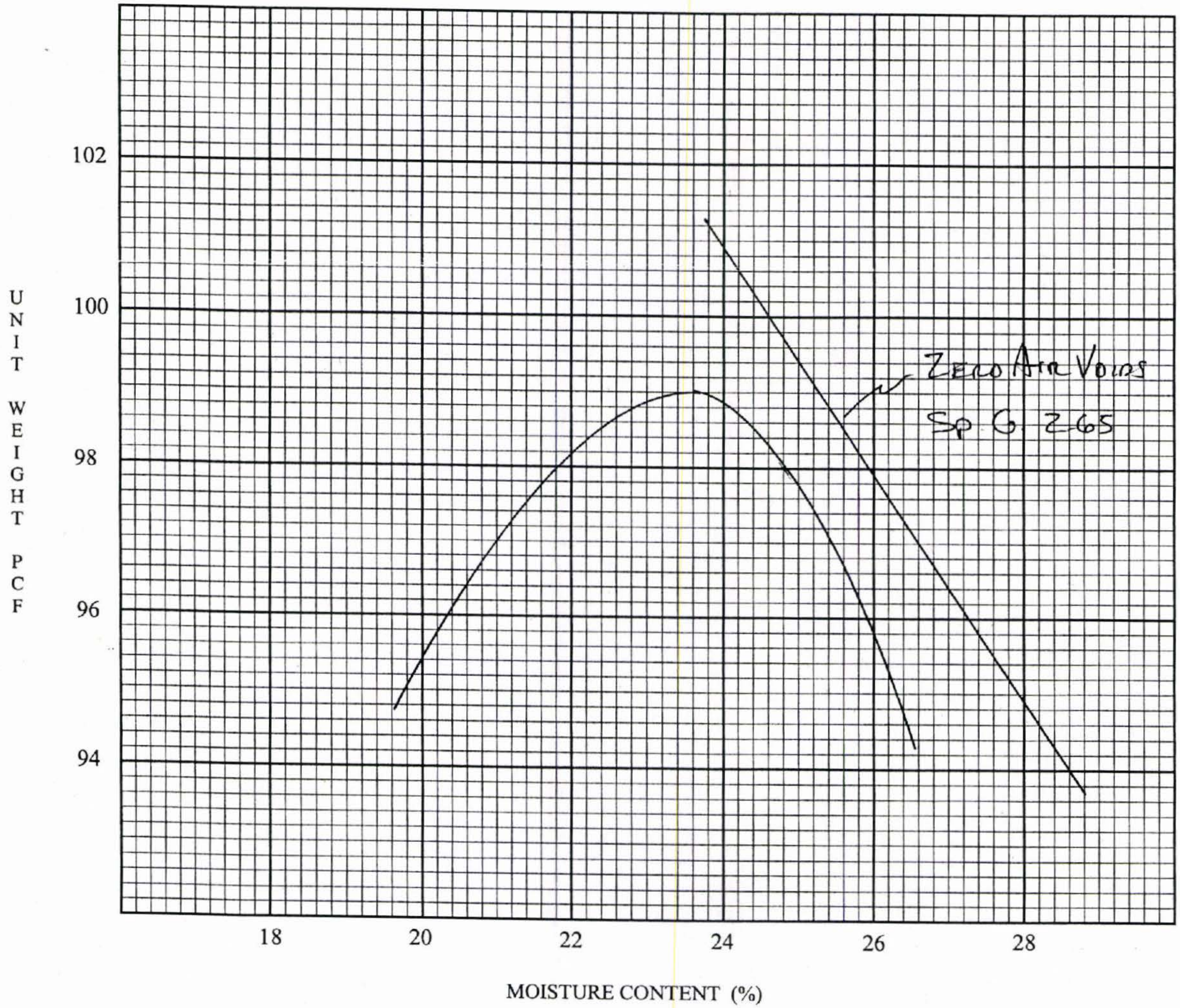
MIDWEST TESTING LABORATORY

4102 - 7th Ave. N. / P.O. Box 3042 / Fargo, North Dakota 58108
Phone (701) 282-9633 / Fax (701) 282-9635

REPORT OF: MOISTURE DENSITY RELATIONS OF SOIL

PROJECT:	Plant Tests 2005 Amy Decker Senior Design	DATE:	April 7, 2005
REPORTED TO:	Lafarge Dakota, Inc. P.O. Box 757 Valley City, ND 58072-0757	COPIES:	Amy Decker
PROJECT NO.:	12597		

SAMPLE NUMBER:	1		
METHOD:	Standard Proctor ASTM D698-00a Method "A"	MAXIMUM DENSITY:	99.0 pcf
SOIL TYPE:	SOIL-grayish brown	OPTIMUM MOISTURE:	23.6%



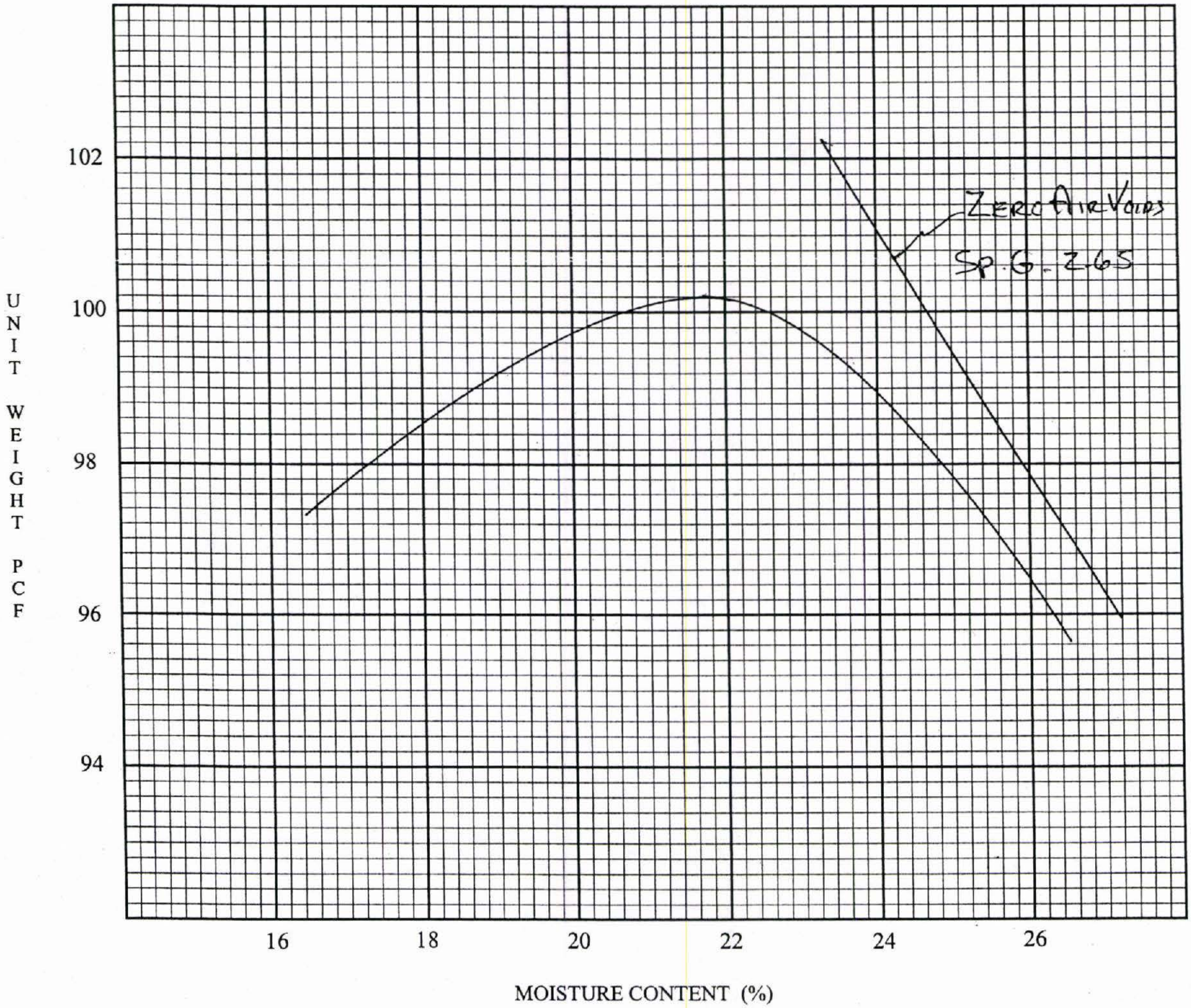
MIDWEST TESTING LABORATORY

4102 - 7th Ave. N. / P.O. Box 3042 / Fargo, North Dakota 58108
Phone (701) 282-9633 / Fax (701) 282-9635

REPORT OF: MOISTURE DENSITY RELATIONS OF SOIL

PROJECT:	Plant Tests 2005 Amy Decker Senior Design	DATE:	April 7, 2005
REPORTED TO:	Lafarge Dakota, Inc. P.O. Box 757 Valley City, ND 58072-0757	COPIES:	Amy Decker
PROJECT NO.:	12597		

SAMPLE NUMBER:	2		
METHOD:	Standard Proctor ASTM D698-00a Method "A"	MAXIMUM DENSITY:	100.2 pcf
SOIL TYPE:	SOIL WITH FLY ASH AND CEMENT	OPTIMUM MOISTURE:	21.7%



Total Stress Triaxial Compression

Unconsolidated Undrained

Sample details

Sketch showing specimen location in original Sample

Depth

Description: Soil with Fly Ash and Cement - grayish brown, LL=45, PL=27

	Specimen 1	Specimen 2	Specimen 3
Type	Remolded	Remolded	Remolded
Height H_0 (in)	5.536	5.546	5.573
Diameter D_0 (in)	2.807	2.807	2.807
Weight W_0 (gr)	1083.18	1083.97	1088.37
Bulk Density ρ (PCF)	120.45	120.32	120.22
Particle Density ρ_s	2.65 (assumed)	2.65 (assumed)	2.65 (assumed)

Initial Conditions

	Specimen 1	Specimen 2	Specimen 3
Cell Pressure $\sigma 3$ (lbf/in2)	1.0	10.0	20.0
Machine Speed d_r(in/min)	0.020	0.020	0.020
No. of Membranes	1	1	1
Total Thickness (in)	0.012	0.012	0.012
Strain Channel	Dial #1	Dial #1	Dial #1
Load Channel	Load	Load	Load
Moisture Content w_0%	24.6	24.6	24.6
Dry Density ρ_{d0} (PCF)	96.67	96.57	96.49
Voids Ratio e_0	0.71	0.71	0.71
Deg of Saturation S_0%	91.73	91.50	91.32

Final Condition

	Specimen 1	Specimen 2	Specimen 3
Max Deviator Stress (lbf/in2)	88.8	111.7	126.7
Membrane Correction σ_{mb} (lbf/in2)	0.4	0.5	0.7
Corr Stress $(\sigma_1 - \sigma_3)_c$ (lbf/in2)	88.5	111.2	126.0
Strain at Failure ε_f%	2.5286	3.9664	7.1767
Shear Strength c_u (lbf/in2)	44.2	55.6	63.0
Moisture Content w_f%	24.1	23.5	23.9
Dry Density ρ_{df} (PCF)	97.02	97.43	97.03
Voids Ratio e_f	0.70	0.70	0.70
Deg of Saturation S_f%	90.85	89.30	89.94

Notes:

Failure Sketch

Sp 1 Sp 2

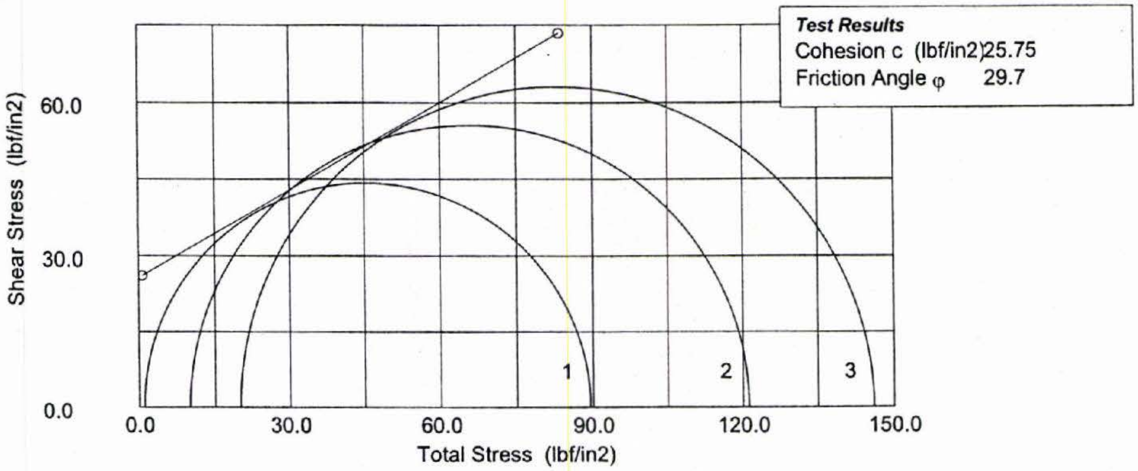
Sp 3

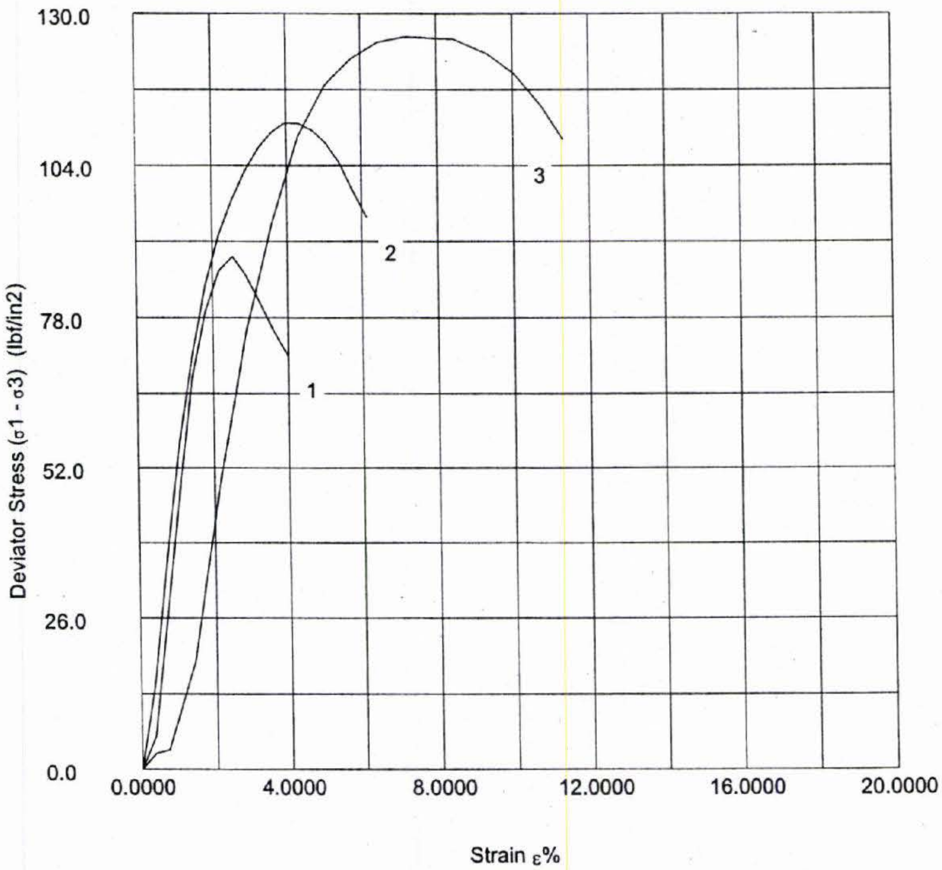
Surface Inclination

Test Method : ASTM D2850-95		Test name Date of Test:	Soil w/ Fly Ash (SS, MS) 4/4/2005
Site Reference: Jobfile:	Plant Tests 2005 C:\WINCLISP\SOILUU.JOB	Sample: Borehole:	Amy Decker Senior Design Soil UU Casselton Soil Sample
Operator:	*Checked:*		*Approved:*

Total Stress Triaxial Compression

Unconsolidated Undrained





Test Method : ASTM D2850-95		Test name Date of Test:	Soil w/ Fly Ash (SS, MS) 4/4/2005
Site Reference: Jobfile:	Plant Tests 2005 C:\WINCLISP\SOILUU.JOB	Sample: Borehole:	Amy Decker Senior Design Soil UU Casselton Soil Sample
Operator:	*Checked:*		*Approved:*

Total Stress Triaxial Compression

Unconsolidated Undrained

Sample details

Sketch showing specimen location in original Sample

Depth
Description: Soil- grayish brown, LL=45, PL=27

	Specimen 1	Specimen 2	Specimen 3
Type	Remolded	Remolded	Remolded
Height H_0 (in)	5.505	5.589	5.592
Diameter D_0 (in)	2.807	2.805	2.808
Weight W_0 (gr)	1089.37	1106.65	1104.75
Bulk Density ρ (PCF)	121.82	122.07	121.53
Particle Density ρ_s	2.65 (assumed)	2.65 (assumed)	2.65 (assumed)

Initial Conditions

	Specimen 1	Specimen 2	Specimen 3
Cell Pressure $\sigma 3$ (lbf/in2)	1.0	10.0	20.0
Machine Speed d_r(in/min)	0.020	0.020	0.020
No. of Membranes	1	1	1
Total Thickness (in)	0.012	0.012	0.012
Strain Channel	Dial #1	Dial #1	Dial #1
Load Channel	Load	Load	Load
Moisture Content w_0%	24.5	20.3	20.3
Dry Density ρ_{d0} (PCF)	97.81	101.47	101.02
Voids Ratio e_0	0.69	0.63	0.64
Deg of Saturation S_0%	94.18	85.43	84.47

Final Condition

	Specimen 1	Specimen 2	Specimen 3
Max Deviator Stress (lbf/in2)	36.4	44.7	47.2
Membrane Correction σ_{mb} (lbf/in2)	1.3	1.3	1.3
Corr Stress $(\sigma_1 - \sigma_3)_c$ (lbf/in2)	35.1	43.3	45.9
Strain at Failure ε_f%	15.2573	15.0280	15.0200
Shear Strength c_u (lbf/in2)	17.5	21.7	22.9
Moisture Content w_f%	24.1	23.6	23.6
Dry Density ρ_{df} (PCF)	98.17	98.77	98.31
Voids Ratio e_f	0.68	0.67	0.68
Deg of Saturation S_f%	93.27	92.71	91.79

Notes:

Failure Sketch

Sp 1 Sp 2

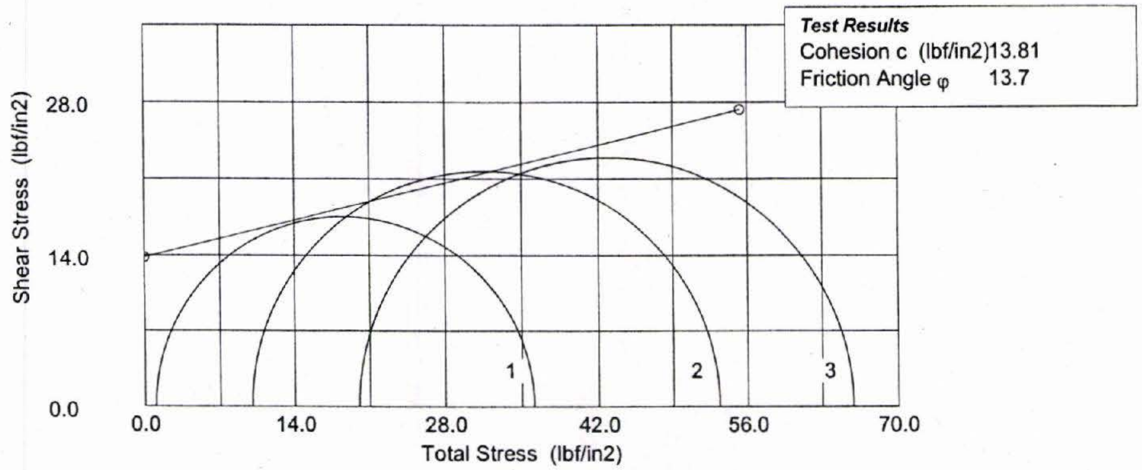
Sp 3

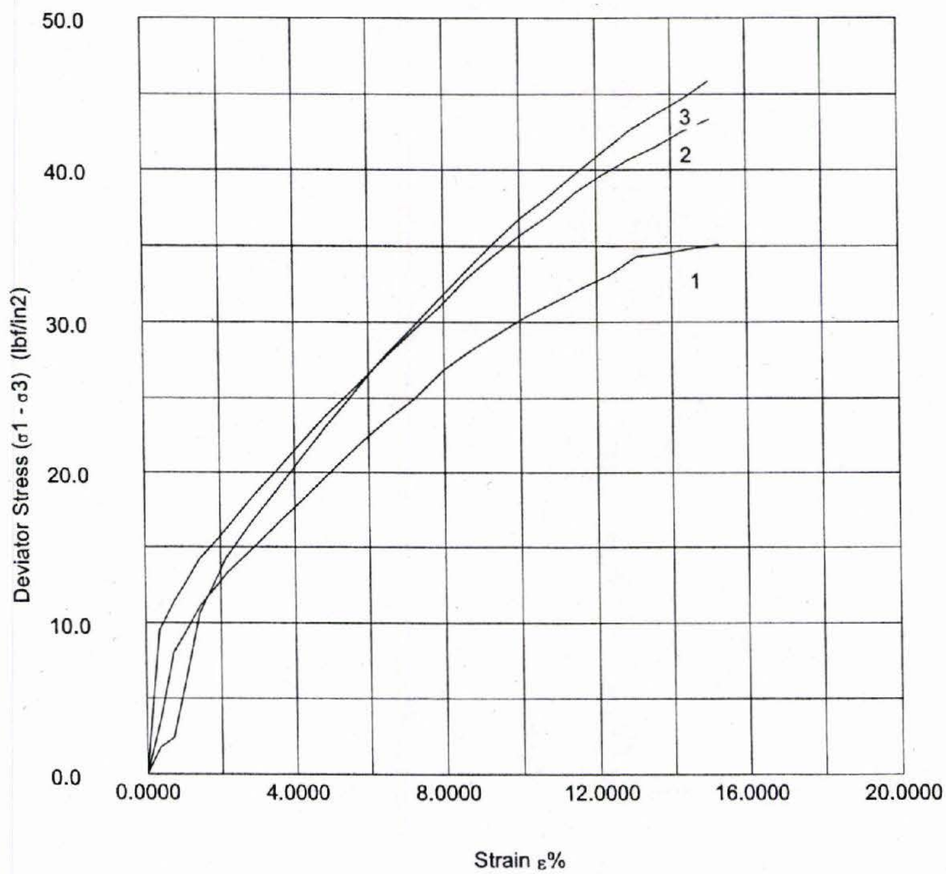
Surface Inclination

Test Method : ASTM D2850-95		Test name Date of Test:	Soil UU (SS, MS) 4/4/2005
Site Reference: Jobfile:	Plant Tests 2005 C:\WINCLISP\SOILUU.JOB	Sample: Borehole:	Amy Decker Senior Design Soil UU Casselton Soil Sample
Operator:	*Checked:*		*Approved:*

Total Stress Triaxial Compression

Unconsolidated Undrained

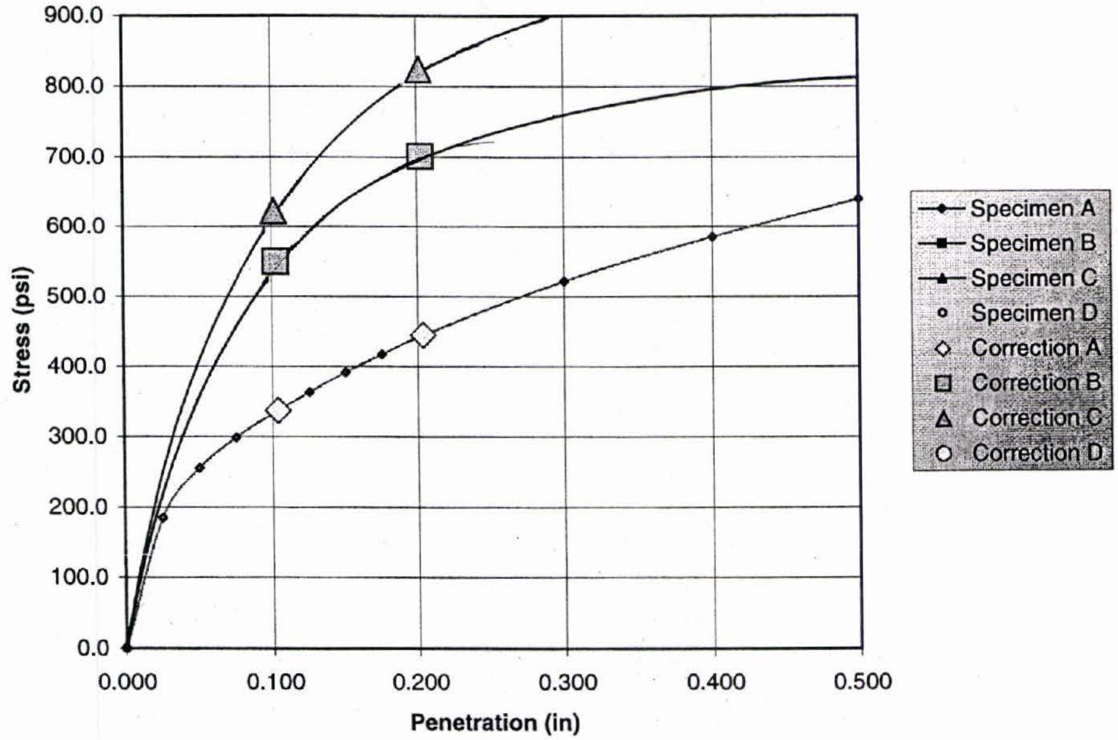




Test Method : ASTM D2850-95		Test name Date of Test:	Soil UU (SS, MS) 4/4/2005
Site Reference: Jobfile:	Plant Tests 2005 C:\WINCLISP\SOILUU.JOB	Sample: Borehole:	Amy Decker Senior Design Soil UU Casselton Soil Sample
Operator:	*Checked:*		*Approved:*

Midwest Testing Laboratory, Inc
California Bearing Ratio Test Report (ASTM D1883)

Load Penetration Curve



CBR Results					
Results	**A**	**B**	**C**	**D**	**Average**
0.1" Pen.	33.7	55.0	62.2		50.3
0.2" Pen.	29.6	46.7	54.9		43.8
Moisture (%)	20.7	20.9	20.3		20.6
Density (PCF)	96.4	100.7	101.8		99.6

Project Information			
Project Num	12597	**Sample Location**	
Project	Plant Tests 2005	Specimen A	Casselton
Date	3/25/2005	Specimen B	Casselton
Client	LaFarge Dakota, Inc	Specimen C	Casselton
		Specimen D	
		Test Variables	
Job Ref.	Amy Decker Senior Design	Liquid Limit:	53.0
Sample Num.	Casselton	Plastic Limit:	33.0
Remarks	See individual specimen test data sheets.		

Specimen A Information
CBR Test

Midwest Testing Laboratory, Inc

File Name
Soil and Ash CBR.HSD

Project Information

Project No. 12597 Date: 3/25/2005
Project Name: Plant Tests 2005
Client: LaFarge Dakota, Inc
Sample Location: Casselton
Sample Description: Soil with fly ash and cement
Remarks: 3 lifts remolded with 25 blows per lift.

Specimen A Data

Soaked Sample Height: 4.50 Liquid Limit: 53 Max Dry Dens. (pcf): 100.2
Swell: 0.067 Plastic Limit: 33 Opt. Moisture (%): 21.7

Mold Info	
Height (in)	4.50
Weight (g)	6846.3
Soil Weight + Mold (g)	10732.60
Soil Weight (g)	3886.30
Dry Density (pcf)	96.4

Moisture Percentage	Initial	Avg Final
Moist Soil + tare (g)	98.30	478.90
Dry Soil + tare (g)	83.75	382.60
Tare (g)	13.60	0.00
Moisture %	20.7	25.2

Specimen A Test Data

Read Number	Load (lbs)	Disp.	Stress (psi)	Penetration (in)	CBR
0	0.0	0.000	0.0	0.000	
1	555.3	0.025	185.1	0.025	
2	766.9	0.050	255.6	0.050	
3	896.0	0.075	298.7	0.075	
4	997.3	0.100	332.4	0.100	33.24
5	1089.4	0.125	363.1	0.125	
6	1173.8	0.150	391.3	0.150	
7	1251.7	0.175	417.2	0.175	
8	1325.0	0.200	441.7	0.200	29.45
9	1566.1	0.300	522.0	0.300	27.47
10	1754.8	0.400	584.9	0.400	25.43
11	1918.0	0.500	639.3	0.500	24.59

Specimen B Information
CBR Test

Midwest Testing Laboratory, Inc

File Name
Soil and Ash CBR.HSD

Project Information

Project No. 12597 Date: 3/25/2005
Project Name: Plant Tests 2005
Client: LaFarge Dakota, Inc
Sample Location: Casselton
Sample Description: Soil with fly ash and cement
Remarks: 3 lifts remolded with 40 blows per lift.

Specimen B Data

Soaked Sample Height: 4.50 Liquid Limit: 53 Max Dry Dens. (pcf): 100.2
Swell: 0.044 Plastic Limit: 33 Opt. Moisture (%): 21.7

Mold Info	
Height (in)	4.50
Weight (g)	7100.6
Soil Weight + Mold (g)	11172.90
Soil Weight (g)	4072.30
Dry Density (pcf)	100.7

Moisture Percentage	Initial	Avg Final
Moist Soil + tare (g)	89.30	578.97
Dry Soil + tare (g)	76.40	469.37
Tare (g)	14.70	0.00
Moisture %	20.9	23.4

Specimen B Test Data

Read Number	Load (lbs)	Disp.	Stress (psi)	Penetration (in)	CBR
0	0.0	0.000	0.0	0.000	
1	786.0	0.025	262.0	0.025	
2	1180.0	0.050	393.3	0.050	
3	1438.9	0.075	479.6	0.075	
4	1632.3	0.100	544.1	0.100	54.41
5	1789.3	0.125	596.4	0.125	
6	1918.9	0.150	639.6	0.150	
7	2017.6	0.175	672.5	0.175	
8	2092.0	0.200	697.3	0.200	46.49
9	2452.0	0.300	817.3	0.300	43.02
10	2782.0	0.400	927.3	0.400	40.32
11	3082.0	0.500	1027.3	0.500	39.51

Specimen C Information
CBR Test

Midwest Testing Laboratory, Inc

File Name
Soil and Ash CBR.HSD

Project Information

Project No. 12597 Date: 3/25/2005
Project Name: Plant Tests 2005
Client: LaFarge Dakota, Inc
Sample Location: Casselton
Sample Description: Soil with fly ash and cement
Remarks: 3 lifts remolded with 56 blows per lift.

Specimen C Data

Soaked Sample Height: 4.51
Swell: 0.133
Liquid Limit: 53
Plastic Limit: 33
Max Dry Dens. (pcf): 100.2
Opt. Moisture (%): 21.7

Mold Info	
Height (in)	4.50
Weight (g)	7082.4
Soil Weight + Mold (g)	11172.90
Soil Weight (g)	4090.50
Dry Density (pcf)	96.4

Moisture Percentage	Initial	Avg Final
Moist Soil + tare (g)	88.70	517.37
Dry Soil + tare (g)	76.08	421.63
Tare (g)	13.90	0.00
Moisture %	20.3	22.8

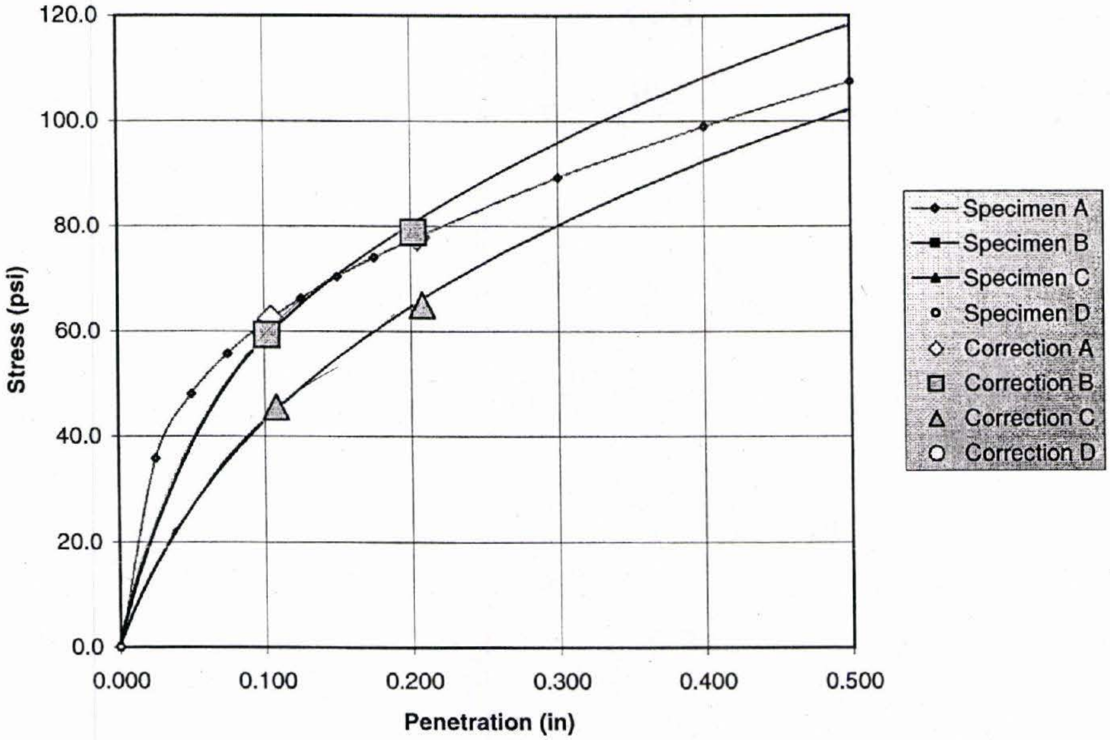
Specimen C Test Data

Read Number	Load (lbs)	Disp.	Stress (psi)	Penetration (in)	CBR
0	0.0	0.000	0.0	0.000	
1	851.7	0.025	283.9	0.025	
2	1392.7	0.050	464.2	0.050	
3	1659.7	0.075	553.2	0.075	
4	1857.0	0.100	619.0	0.100	61.90
5	2016.7	0.125	672.2	0.125	
6	2160.0	0.150	720.0	0.150	
7	2310.0	0.175	770.0	0.175	
8	2463.0	0.200	821.0	0.200	54.73
9	3013.0	0.300	1004.3	0.300	52.86
10	3488.0	0.400	1162.7	0.400	50.55
11	3888.0	0.500	1296.0	0.500	49.85

Midwest Testing Laboratory, Inc

California Bearing Ratio Test Report (ASTM D1883)

Load Penetration Curve



CBR Results					
Results	**A**	**B**	**C**	**D**	**Average**
0.1" Pen.	6.2	5.9	4.6		5.6
0.2" Pen.	5.2	5.3	4.3		4.9
Moisture (%)	25.1	25.2	25.1		25.1
Density (PCF)	96.3	98.0	98.6		97.6

Project Information

Project Num	12597	**Sample Location**	
Project	Plant Tests 2005	Specimen A	Casselton
Date	3/25/2005	Specimen B	Casselton
Client	LaFarge Dakota, Inc	Specimen C	Casselton
		Specimen D	
		Test Variables	
Job Ref.	Amy Decker Senior Design	Liquid Limit:	45.0
Sample Num.	Casselton	Plastic Limit:	27.0
Remarks	See individual specimen test data sheets.		

Specimen A Information
CBR Test

Midwest Testing Laboratory, Inc

File Name
Soil CBR.HSD

Project Information

Project No. 12597 Date: 3/25/2005
Project Name: Plant Tests 2005
Client: LaFarge Dakota, Inc
Sample Location: Casselton
Sample Description: Soil
Remarks: Remolded with 25 blows

Specimen A Data

Soaked Sample Height: 4.52
Swell: 0.356
Liquid Limit: 45
Plastic Limit: 27
Max Dry Dens. (pcf): 99
Opt. Moisture (%): 23.6

Mold Info	
Height (in)	4.50
Weight (g)	6991.6
Soil Weight + Mold (g)	11014.00
Soil Weight (g)	4022.40
Dry Density (pcf)	96.3

Moisture Percentage	Initial	Avg Final
Moist Soil + tare (g)	86.30	486.40
Dry Soil + tare (g)	71.96	386.27
Tare (g)	14.80	0.00
Moisture %	25.1	25.9

Specimen A Test Data

Read Number	Load (lbs)	Disp.	Stress (psi)	Penetration (in)	CBR
0	0.0	0.000	0.0	0.000	
1	107.4	0.025	35.8	0.025	
2	143.9	0.050	48.0	0.050	
3	167.2	0.075	55.7	0.075	
4	184.5	0.100	61.5	0.100	6.15
5	198.6	0.125	66.2	0.125	
6	211.0	0.150	70.3	0.150	
7	221.9	0.175	74.0	0.175	
8	232.0	0.200	77.3	0.200	5.15
9	268.0	0.300	89.3	0.300	4.70
10	297.1	0.400	99.0	0.400	4.30
11	322.4	0.500	107.5	0.500	4.13

Specimen B Information
CBR Test

Midwest Testing Laboratory, Inc

File Name
Soil CBR.HSD

Project Information

Project No. 12597 Date: 3/25/2005
Project Name: Plant Tests 2005
Client: LaFarge Dakota, Inc
Sample Location: Casselton
Sample Description: Soil
Remarks: 3 lifts remolded with 40 blows per lift.

Specimen B Data

Soaked Sample Height: 4.51 Liquid Limit: 45 Max Dry Dens. (pcf): 99
Swell: 0.289 Plastic Limit: 27 Opt. Moisture (%): 23.6

Mold Info	
Height (in)	4.50
Weight (g)	7046.1
Soil Weight + Mold (g)	11141.20
Soil Weight (g)	4095.10
Dry Density (pcf)	98.0

Moisture Percentage	Initial	Avg Final
Moist Soil + tare (g)	79.90	511.23
Dry Soil + tare (g)	66.59	407.70
Tare (g)	13.80	0.00
Moisture %	25.2	25.4

Specimen B Test Data

Read Number	Load (lbs)	Disp.	Stress (psi)	Penetration (in)	CBR
0	0.0	0.000	0.0	0.000	
1	96.5	0.025	32.2	0.025	
2	131.7	0.050	43.9	0.050	
3	157.2	0.075	52.4	0.075	
4	176.8	0.100	58.9	0.100	5.89
5	193.8	0.125	64.6	0.125	
6	208.5	0.150	69.5	0.150	
7	222.4	0.175	74.1	0.175	
8	235.6	0.200	78.5	0.200	5.23
9	284.2	0.300	94.7	0.300	4.98
10	323.1	0.400	107.7	0.400	4.68
11	357.5	0.500	119.2	0.500	4.58

Specimen C Information
CBR Test

Midwest Testing Laboratory, Inc

File Name
Soil CBR.HSD

Project Information

Project No. 12597 Date: 3/25/2005
Project Name: Plant Tests 2005
Client: LaFarge Dakota, Inc
Sample Location: Casselton
Sample Description: Soil
Remarks: 3 lifts remolded with 56 blows per lift.

Specimen C Data

Soaked Sample Height: 4.52
Swell: 0.333
Liquid Limit: 45
Plastic Limit: 27
Max Dry Dens. (pcf): 99
Opt. Moisture (%): 23.6

Mold Info	
Height (in)	4.50
Weight (g)	6764.6
Soil Weight + Mold (g)	10886.90
Soil Weight (g)	4122.30
Dry Density (pcf)	96.3

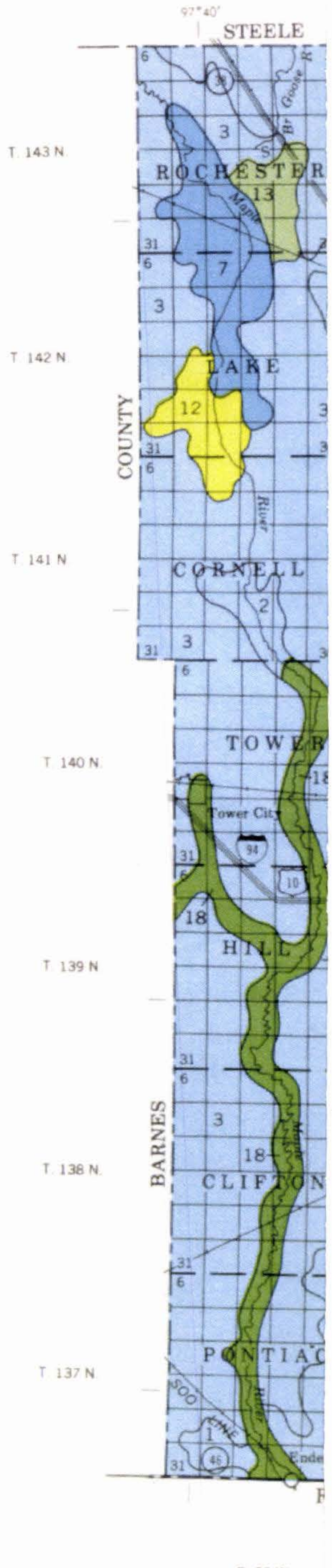
Moisture Percentage	Initial	Avg Final
Moist Soil + tare (g)	83.30	505.60
Dry Soil + tare (g)	69.66	403.93
Tare (g)	15.30	0.00
Moisture %	25.1	25.2

Specimen C Test Data

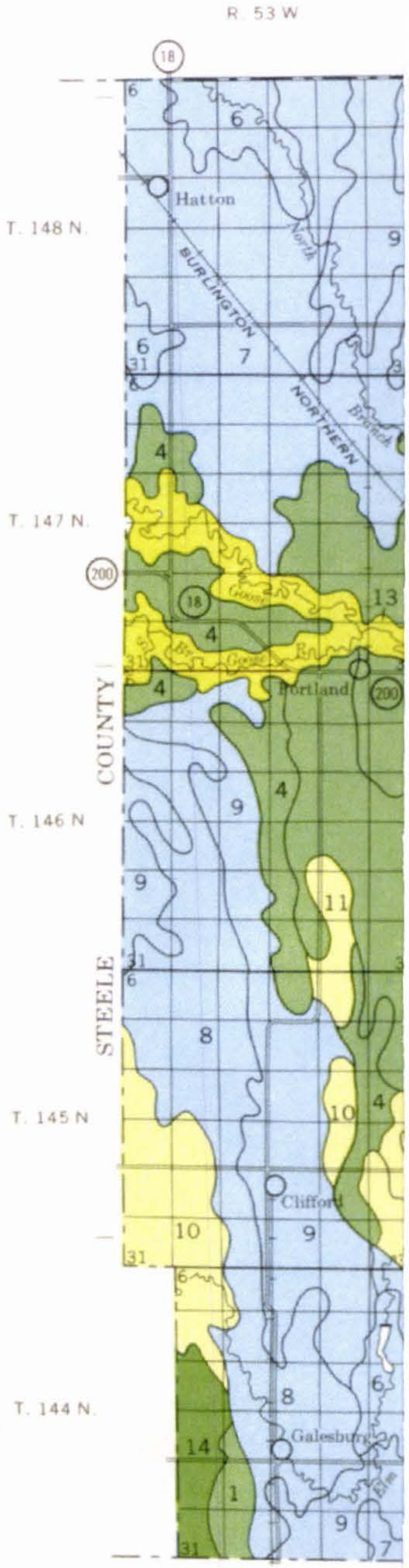
Read Number	Load (lbs)	Disp.	Stress (psi)	Penetration (in)	CBR
0	0.0	0.000	0.0	0.000	
1	51.3	0.025	17.1	0.025	
2	85.6	0.050	28.5	0.050	
3	111.8	0.075	37.3	0.075	
4	131.4	0.100	43.8	0.100	4.38
5	148.1	0.125	49.4	0.125	
6	163.3	0.150	54.4	0.150	
7	177.7	0.175	59.2	0.175	
8	191.2	0.200	63.7	0.200	4.25
9	240.4	0.300	80.1	0.300	4.22
10	279.9	0.400	93.3	0.400	4.06
11	314.4	0.500	104.8	0.500	4.03

APPENDIX E

NORTHERN RED RIVER VALLEY
SOIL CHARTS



Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.



Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a ba[sis] for decisions on the use of specific tracts.

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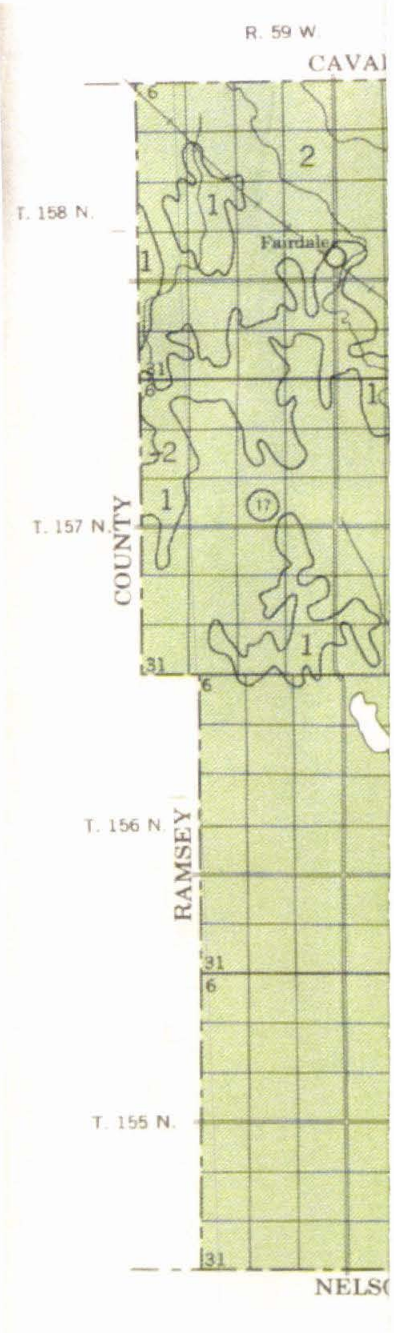
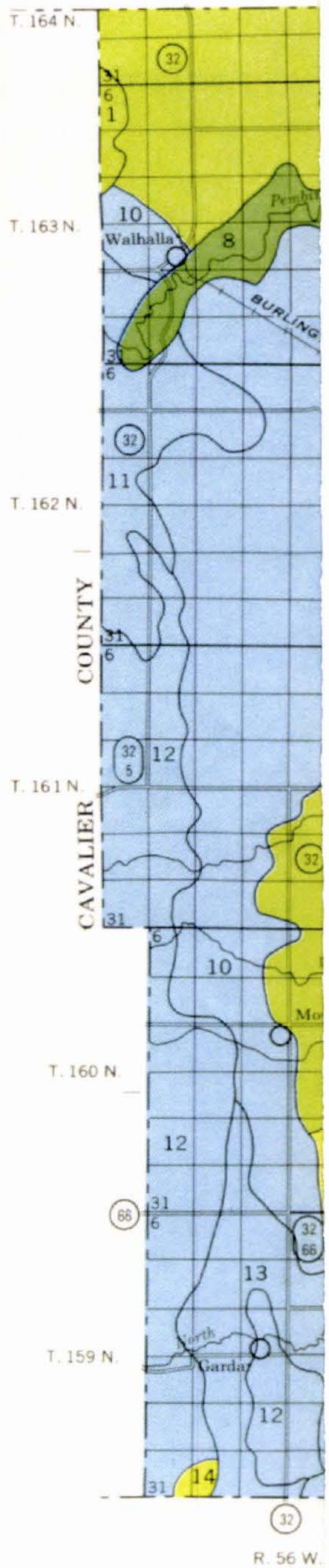


SOILS OF T

1	Cresbard-Hamerly-Sv moderately well drai loamy soils
2	Hamerly-Svea-Barnes to rolling, somewhat loamy soils
3	Barnes-Svea-Parnell to rolling, well drain loamy soils and near loamy and clayey so
4	Svea-Barnes associa sloping, moderately soils
5	Barnes-Buse associa steep, well-drained o on the Edinburg mora
6	Kloten-Edgeley asso level to undulating a over shale bedrock
7	Buse-Fairdale associ excessively drained soils



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more than one kind of soil. The map i
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for decisions on the use of specific tra

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