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Beneficial Use of Dredged Clay from Newark Bay and Environs

A Field Feasibly Study

FINAL REPORT
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Submitted by

Dr. Ali Maher
Professor and Department Chair

Center for Advanced Infrastructure & Transportation (CAIT)
Civil & Environmental Engineering
Rutgers, The State University
Piscataway, NJ 08854-8014

NJDOT Research Project Manager
Mr. Scott Douglas

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16. Abstract

The objective of the work was to provide NJDOT with useful information in order to pursue beneficial use of dredged sediments. This study focused on the geotechnical properties of materials; other studies conducted concurrently considered ceramic uses and environmental characteristics of the materials. This study used common field and laboratory investigation methods to evaluate the dredged material for potential future roadway, embankment, and waste containment applications. The results are compared to those of more common materials, and published standards, where existing, used in these applications.

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Executive Summary

This report presents the findings from a pilot study sponsored by New Jersey Department of Transportation, Office of Maritime Resources (NJDOT/OMR) on the potential for beneficially use of dredged red clay for various environmental or geotechnical engineering applications. Specifically, the study focused on using dredged red clay for low-hydraulic-conductivity caps in sanitary landfills at upland sites. The study was implemented by the Center for Advanced Infrastructure and Transportation (CAIT) at Rutgers University in cooperation with Bean Stuyvesant Dredging Company, Bayshore Recycling Corporation, Soilteknik Inc. and Sadat Associates, Inc.

At present, dredging operations are underway in the New York / New Jersey navigational channels. In order to accommodate the new generation of container ships, the channels must be dredged to a depth of 50 feet. By the end of 2012, dredging activities are expected to generate approximately 7 million cubic yards (cy) of red clay, as well as 40 million cubic yards of silt, sand, till and rock. Currently, red clay is placed at the Historic Area Remediation Site (HARS) where it is used to cap the contaminated silty sediments historically placed at the HARS. However, alternative beneficial uses of dredged red clay may be more appropriate and serve to conserve capacity at the HARS for less valuable materials.

One alternative to HARS placement could be to beneficially use the red clay for capping former industrial upland sites. Sanitary landfills or "brownfields" that typically require a low hydraulic conductivity cap as part of their closure could benefit from using the red clay, especially if the costs are lower than the costs of mined clay. Moreover, the engineering properties of the red clay are similar to those of mined clay, and replacing this mined clay with the clay dredged for channel deepening would mitigate any environmental impacts associated with mining clay.

However, red clay has not been historically used at upland sites. While there are demonstrable benefits to using the dredged red clay, testing would be required before it could be employed for engineering applications. Moreover, because experience with the dredged clay shows that it typically remains in large chunks (up to several feet in diameter, depending on the equipment used), it was unclear whether it will be practical to spread the material in 6-to-12-inch layers (as is typically done in landfills). In response to these concerns, the New Jersey Department of Transportation, Office of Maritime Resources (NJDOT/OMR) sponsored a pilot study to investigate the feasibility of beneficially using the red clay at upland sites for low-hydraulic-conductivity caps and other engineering applications. As part of the study, approximately 4,000 cubic yards of red clay from ongoing channel construction were transferred from Newark Bay to Bayshore Recycling Corporation facility located at Keasbey, New Jersey. To evaluate the

behavior and workability of the material, red clay was placed in layers of varying thicknesses. The practicality of spreading and compacting the red clay was monitored extensively during the pilot study. In addition, in-situ and laboratory geotechnical testing was conducted to determine the engineering properties of the material at different moisture contents and compaction conditions.

In general, the red clay's natural moisture content is significantly higher than the optimum moisture content. Therefore, moisture conditioning is necessary prior to compacting the red clay. This could be achieved by spreading red clay in 12-inch thick layers and allowing it to dry. Periodic displacement by using farming disks accelerates the drying process. Preferably, such moisture conditioning should take place in warm seasons to make the operation more economical.

As part of the study, 2,000 cubic yards of red clay were transported to the ILR landfill in Edison, New Jersey to be used as a low-hydraulic-conductivity cap where a portion of the existing landfill cap had been removed for the installation of a gas extraction system. Field and laboratory geotechnical testing indicated that the hydraulic conductivity of $1x10^{-7}$ cm/sec was achieved once the red clay was compacted at moisture content 13% less than its natural moisture content of 35%. A hydraulic conductivity of $1x10^{-7}$ cm/sec is typically required by the NJDEP and other regulatory agencies for liners and cap applications.

During the course of the pilot study, it was demonstrated that conventional construction equipment such as wide-track bulldozers, front loaders and smooth-wheel or sheep-foot rollers could be used for placement and compaction of red clay. Moreover, conventional road trucks could be used for on-land transportation of the red clay within construction sites or on public roads with no modification to the trucks.

With respect to the associated cost for using the red clay, it was estimated that a cost savings of approximately $3.5/cy could be expected if red clay is used in lieu of clay mined from upland sites. A dedicated site for moisture conditioning and storage of the red clay (in case no immediate use is identified) could facilitate the overall usage of red clay at upland sites. Finally, using red clay instead of mined clay would eliminate any environmental impacts associated with mining clay from green acres, while ensuring that capacity at the HARS is reserved for those material s that have little or no value for use in construction.

The investigations conducted as part of this study indicate that there is sufficient and viable market for the upland use of red clay. The estimated potential market for the upland use of red clay for the next 10 years is approximately 22 MCY. Out of this, the potential market for use as containment barriers for landfill capping is 9.66 MCY and for use in site remediation projects is 10.23MCY. The potential market for Civil Engineering applications like pond liners, wetland restoration etc. is estimated as 1.2MCY. Additional market exists for use of red clay as structural backfill material in civil engineering applications. The market for use of clay in ceramic manufacturing industry is estimated as 1.0 MCY. However, the red clay material will require amendment before it can be used for ceramic manufacture.

The cost comparisons demonstrate that the costs associated with the use of red clay material for all upland applications are comparable to those of the competing products. The red clay costs associated with containment barrier applications show substantial advantage over costs of competing products. The financial viability of using red cay as an alternative to conventional upland clay, synthetic liners or common fill depends heavily on the applicable transportation costs. If red clay can be transported via scows directly to the site of application, there will be substantial cost savings.

Table of Contents

List of Figures

Appendices

1.0 Introduction

Major dredging for the purpose of deepening the New York/New Jersey navigational channels is currently ongoing to allow for berthing of the new generation of container ships, which typically require 50 feet of draft. The dredging is part of a 10-year dredging project by the Army Corps of Engineers and the Port Authority of NY& NJ that requires dredging more than 50 million cubic yards of materials to achieve the desired 50-foot-deep channels.

While the deepening dredging is in progress, maintenance dredging is also required to maintain the existing navigational channels. While the material generated from maintenance dredging consists mostly of silt with low percentages of clay and fine sand (typically less than 25% of sand and clay combined), material generated from channel deepening varies widely in composition and includes blasted rock, glacial drift, , gravel, sand, silt or clay.

Typically, materials dredged from maintenance projects are unsuitable for ocean disposal and must be placed at upland sites or landfills with environmental controls in place. Unlike the material dredged from maintenance projects, much of the material dredged during channel deepening has never been exposed to industrial pollution, and biological testing shows that it is suitable for ocean placement. Much of the material that meets accepted criteria is currently being placed at the Historic Area Remediation Site (HARS) in the Atlantic Ocean off of Sandy Hook as a cap for historically placed contaminated sediments. Rock material is placed at artificial reef sites.

One of the materials presently being dredged from Newark Bay, Arthur Kill and Kill van Kull is red clay. It is estimated that approximately 7 million cubic yards of red clay will have been generated from the dredging activities by the year 2012, according to the US Army Corps of Engineers projections. This red clay is currently being placed at the HARS. One potential alternative to HARS placement is to use the red clay for capping former industrial upland sites. Sanitary landfills or Brownfields, which typically require a low-hydraulic-conductivity cap as part of their closure, could benefit from taking the red clay at potentially lower costs than mined clay. Moreover, the red clay demonstrates engineering properties similar to those of mined clay, and using red clay could mitigate the environmental impacts associated with mining clay.

While there are obvious advantages to beneficially using the dredged red clay, it has not been used historically at upland sites, and testing would be required before it could be employed for engineering applications. Moreover, because experience with the clay indicates that it remains in large cohesive chunks when dredged with conventional equipment, it is unclear whether it will be practical to spread the material in 6-to-12-inch layers (as is typically done in landfills). In response to these concerns, the New Jersey Department of Transportation, Office of Maritime Resources (NJDOT/OMR) sponsored a pilot study to investigate the feasibility of beneficially using the red clay at upland sites for low-hydraulic-conductivity caps and other engineering applications.

As part of the pilot study, the feasibility of placing red clay in layers using conventional construction equipment was investigated. In addition, the engineering properties of the red clay were determined in order to evaluate whether the red clay would be suitable for use in low-hydraulic-conductivity caps in landfills or in Brownfields. The economic feasibility of handling and placing the clay was also assessed. Finally, a preliminary market study was conducted to identify applications for the red clay in addition to landfill cover.

2.0 Scope of Work

In general, the activities included in the scope of this study consisted of handling, placing and testing dredged red clay at an upland site. These activities were performed to study the beneficial use of dredged red clay as an impermeable cap given the material's engineering and environmental properties defined during handling and placement. Specifically, the scope included the following:

1. Receipt of 4,000 cy of red clay at an upland site;
2. Unloading and transportation of the red clay to a test area at the Bayshore Recycling Facility;
3. Field and laboratory geotechnical testing;
4. Transferring of 2,000 cy of red clay to the ILR landfill in Edison, New Jersey to further study the feasibility of using red clay in an actual landfill with marginal foundation soil, and using conventional construction equipment;
5. Engineering evaluation and cost analysis for handling and placement of the clay as a low-hydraulic-conductivity cap, and;
6. Market study for identifying beneficial uses other than cap material.

In October of 2003, the red clay was dredged from the lower Newark Bay by the Bean Stuyvesant Dredging Company, and transported to the Bayshore Recycling Corporation (Bayshore) Facility in Keasbey, NJ. The unloading, on-site transportation and placement of the material were performed by Bayshore. In-situ density and moisture content were periodically determined for clay being placed in layers. Samples from compacted red clay were collected and transferred to the Rutgers University geotechnical laboratory for identification, and to determine certain engineering characteristics such as strength and hydraulic conductivity. Finally, an engineering evaluation was performed to determine the potential applicability of red clay for use as a low-hydraulic-conductivity cap.

3.0 Background

3.1 Dredging Site Location

The red clay was dredged from Newark Bay as part of a channel deepening contract. The location of the dredging site is shown in Figure 1. Approximately 4,000 cubic yards of red clay, dredged as part of the Army Corps of Engineers (ACOE) Navigational Improvement Project Phase II, Contract 7 Area 6, was re-routed to the Bayshore Facility (see Figure 2), while the rest of the dredged red clay was placed at the HARS. Bean Stuyvesant delivered the clay in hopper scows to the Bayshore Facility. The clay was dredged and received at the Bayshore Facility on October 24 and 25, 2003.

3.2 Regional Geology

The Project Site is located within the Piedmont Physiographic Province of New Jersey. The Piedmont is an area of approximately 1,600 square miles, which makes up approximately one-fifth of the state. It occupies all of Essex, Hudson, and Union Counties, most of Bergen, Hunterdon, and Somerset, and parts of Mercer, Middlesex, Morris, and Passaic. It is underlain mainly by slightly folded and faulted sedimentary rocks of Triassic and Jurassic age (240 to 140 million years old) and igneous rocks of Jurassic age. Highly folded and faulted lower Paleozoic sedimentary rocks along the northwestern margin in the Clinton and the Peapack areas, as well as at several smaller areas, are included as part of the Piedmont. In the Trenton and Jersey City areas, along the southern margin of the province, there are small bands of highly metamorphosed rocks ranging in age from Middle Proterozoic to Cambrian.

The boundary with the Coastal Plain Province lies at the contact between the rock units of the Piedmont and the unconsolidated Cretaceous sediments. It is essentially a line from Carteret through Princeton Junction to Trenton. This boundary line is known as the Fall Line because it is marked by a series of waterfalls and rapids all along the East Coast. The Sand Hills are erosional remnants of Coastal Plain sediments that lie within the Piedmont.

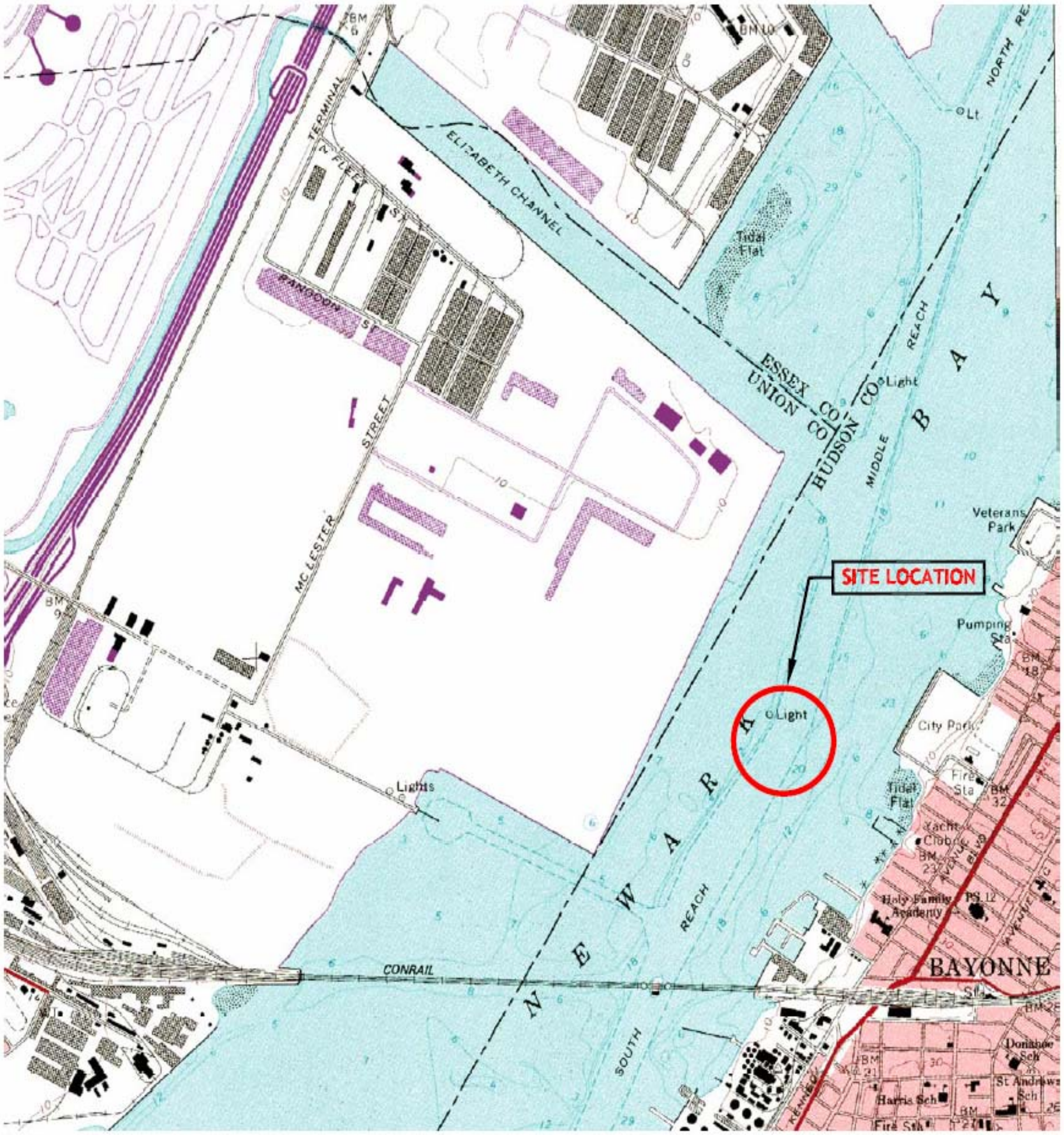


Figure 1

DREDGING SITE LOCATION MAP

NEWARK BAY, NEW JERSEY

Graphic Scale

2000 1000 0 2000

1 inch = 2000 feet

Project:

Scale: 1 IN. = 2000 FT.

Date:

File: FIGURE 1

SOURCE: U.S.G.S. - ELIZABETH QUADRANGLE
7.5 MINUTE SERIES

Surficial Geology

The Project Site is directly underlain by recent alluvial deposits of the Passaic and Hackensack Rivers and glacial lake deposits of late Wisconsinan age.

Late Wisconsinan ice reached its southernmost position at Perth Amboy about 21,000 yrs ago. A continuous terminal moraine was deposited at the position of maximum advance. As the ice front retreated, a series of glacial lakes formed, dammed to the south by a moraine. One of these, Lake Bayonne, occupied the Arthur Kill, Newark Bay, and the upper New York Bay lowlands.

There are two primary sedimentary layers located beneath the waters of Newark Bay at the Project Site. The overlying layer is comprised of a black to dark brown organic layer consisting of silt, clay and peat. Some sand and fine gravel are common components of this layer. The layer is mapped as having a maximum thickness of approximately 25 feet.

The underlying layer is composed of a reddish-brown to gray layer of silt, clay and fine sand. This layer is well-sorted and thinly layered or varved and can have a maximum thickness of approximately 200 feet. Based on regional surficial geology maps (Surficial Geology of the Elizabeth Quadrangle - Stanford, 2002) it is estimated that the thickness of this layer at or near the Project Site is approximately 75 to 100 feet thick.

Bedrock

The bedrock at the location of the Project Site is composed of the Lockatong Formation. The Lockatong is composed of Late Triassic cyclical deposits, consisting of light to dark gray, greenish-gray and black, dolomitic argillite, laminated mudstone, silty to calcareous, argillaceous, very fine grained pyretic sandstone and siltstone, and minor silty limestone. Two types of cycles are recognized: detrital and chemical. Detrital cycles average 17 feet thick and consist of basal, argillaceous, very fine-grained sandstone to coarse siltstone; medial, dark-gray to black, laminated siltstone, silty mudstone or silty limestone. Chemical cycles are similar to detrital cycles, but thinner, averaging 10.5 feet. The maximum thickness of the Lockatong Formation is about 3,510 feet thick.

4.0 Field Operation

4.1 Transportation and Placement within Bayshore Facility

Bayshore Corporation, the owner and the operator of the Bayshore Recycling Facility in Keasbey, NJ (Figure 2), was responsible for unloading the red clay, as well as for on-site transportation and placement of the clay. On October 25, 26 of 2003, the red clay was unloaded from two hopper scows and placed directly into tandem trucks at the Bayshore facility's waterfront area. A long reach CAT 325 and a CAT 345 excavator were used for unloading the red clay. The long reach excavator was used to pull the clay from the far side of the scow to the land side to facilitate excavation of the material by the CAT 345 excavator. In a 12-hour period, the CAT 345 unloaded all of the clay from one scow directly into road trucks. Each scow contained approximately 2,000 cy of material. No special provisions, such as lining of the trucks or modifications to their tailgates, were necessary. No spillage of clay over the haul roads was observed during transportation. Photos taken during unloading and transportation are presented in Appendix C.

4.2 Spreading and Compaction

Once the red clay had been unloaded and transported to the test area and stockpiled, fieldwork at the Bayshore Facility began. Specifically, placement of the red clay at Bayshore began on November 3, 2003 and continued until December 4, 2003. Following the stockpiling, a 980G CAT front loader and a wide track D3 LGP CAT bulldozer were used to spread the material. The front loader moved the clay from the stockpile to the designated placement areas where it was spread by a bulldozer. Spreading the red clay was performed using conventional construction equipment.

Initially, two areas, approximately 100 by 100 feet (marked as Areas 1 and 2 on Figure 3) were each covered by a layer of red clay, with a thickness of 24 inches and 12 inches respectively. Subsequently, Area 2 received additional layers of red clay and a 50-x-50-foot area (marked as Area 3) received a 6-inch-thick layer of clay on December 3.

A smooth wheel BOMAG 172 AD roller and a BOMAG 120 DD sheepsfoot roller were used to compact the layers. Since the initial moisture content was approximately 35%, or

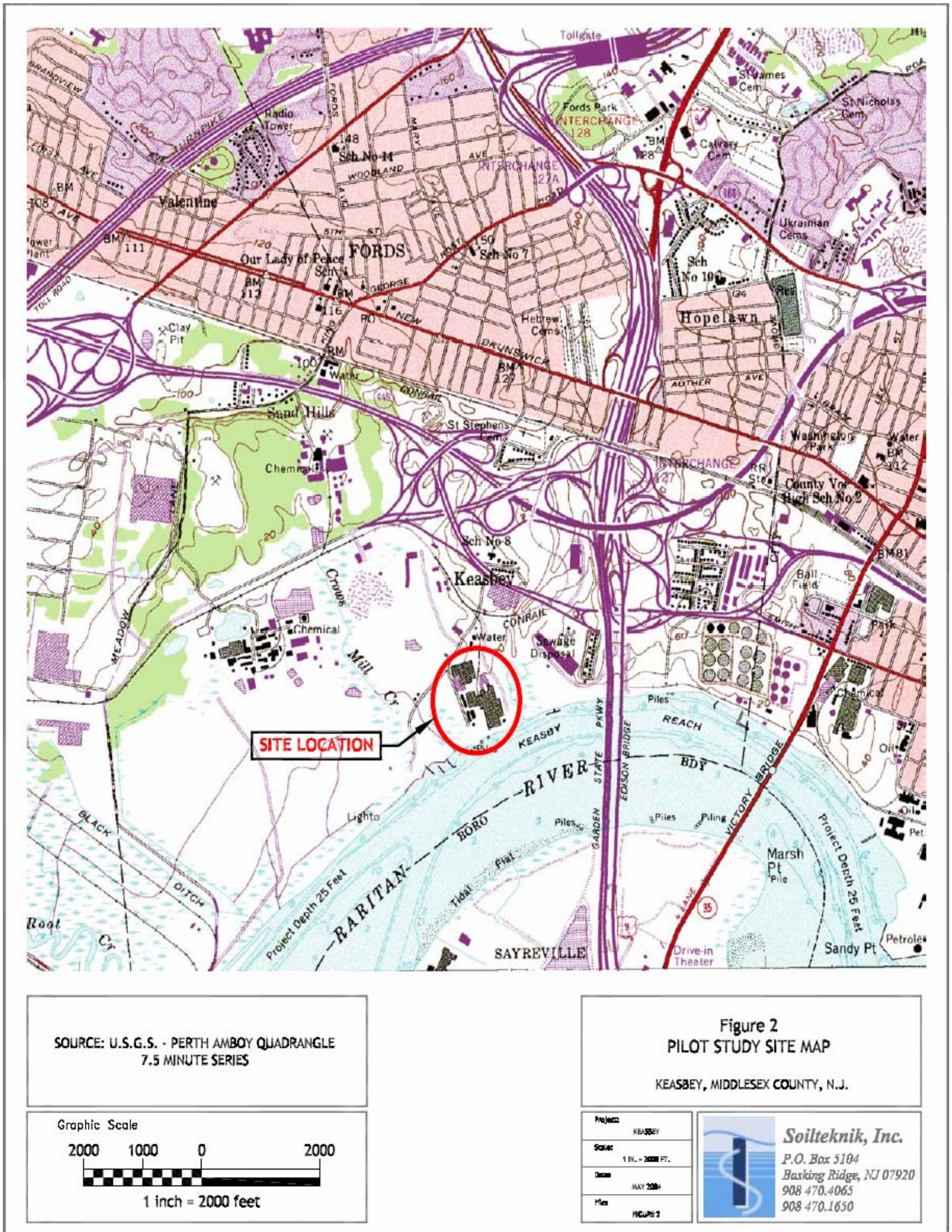


Figure 2. **Pilot Study Site Map**

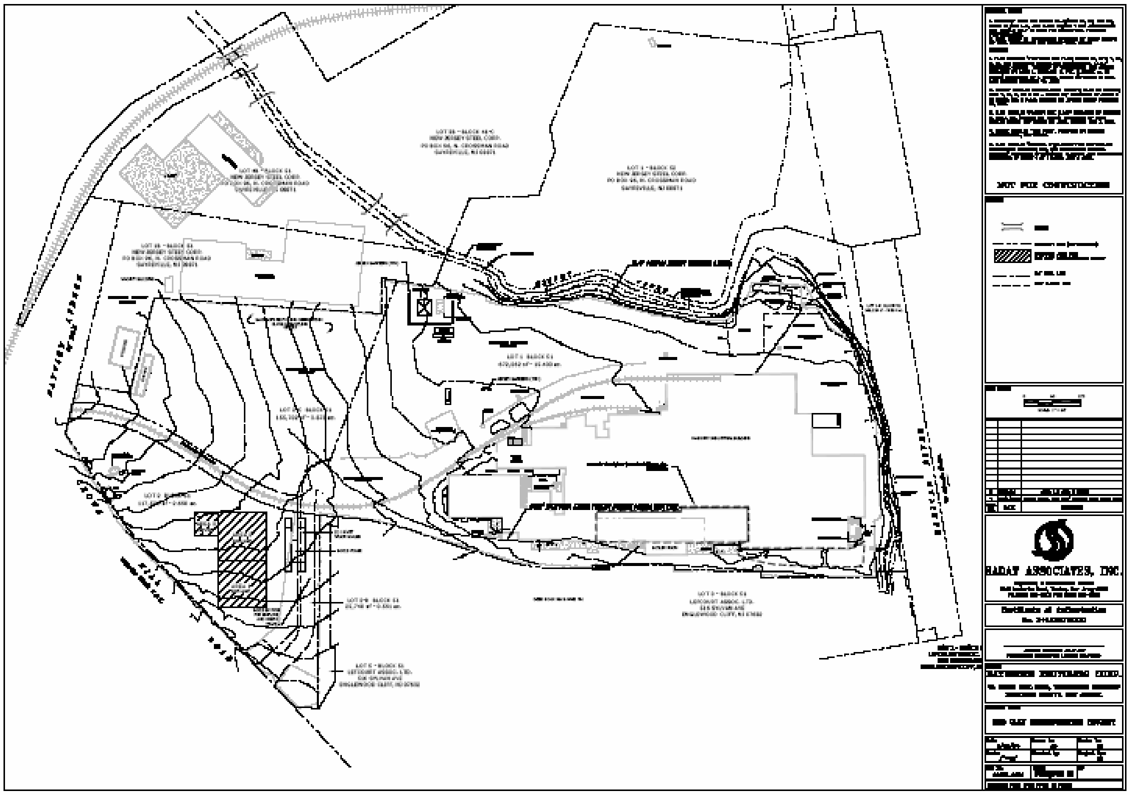


Figure 3. **Testing Locations**

18% above optimum moisture content, placement of the 24-inch layer did not allow for evaporation, thus resulting in little or no change to the moisture content. With the 12-inch layer, however, the results were more promising. The 12-inch layer was worked and rolled several times using both types of rollers, and densities as high as 90% of the maximum modified proctor density were recorded. The moisture content of the red clay in this layer was approximately 23% or 12% lower than the initial moisture content.

A decision was made to prepare test Area 3, where a 6-inch layer of red clay was placed. Unfortunately, adverse weather conditions in December 2003 made compaction and testing of Area 3 impossible. During the period from November 3 to December 4, 2003, the maximum daily temperature ranged from 70 degrees to 29 degrees, with an average temperature of 48 degrees. In addition, precipitation over 10 days in November and December 2003 resulted in saturation of the red clay that adversely affected material placement and compaction operations. Field operations stopped and were to be resumed in May of 2004, once weather condition allowed for re-compaction of the placed layers of red clay.

The second phase of field operation started in June of 2004, when favorable weather condition allowed for further moisture reduction and compaction. The same smooth wheel BOMAG 172 AD roller (with an operating weight of 7 tons) was used for compaction. Area 2, where 12 inches of clay had been placed, was rolled by four overlapping passes of the roller. Moisture contents were significantly lower than those measured in December 2003, although no provisions had been made for aeration and drying of the material since December 2003. In-situ density tests were conducted and densities exceeding 100% of modified proctor density, and moisture contents ranging from 11% to 14%, were recorded. Grab soil samples were collected for further laboratory testing since thin wall Shelby tubes could not be pushed through the highly compacted clay. Those samples were compacted in the laboratory and tested for shear strength and hydraulic conductivity.

Field testing of the red clay at Bayshore Facility was completed in July of 2004. Upon completion of the testing and monitoring activities, the red clay was stockpiled for use in future studies. In November of 2004, approximately 2,000 cubic yards of the material was transferred by tandem trucks to the ILR landfill in Edison, New Jersey. At the landfill approximately one acre of the capping material had been removed during the installation of a gas extraction system. Approximately 12 inches of the red clay were placed over this one-acre area as a low-hydraulic-conductivity cap. A D32P Komatsu bulldozer was utilized for spreading the red clay. Following spreading, the placed material was compacted using a SD 122DX roller (operating weight of 12 tons). Using a heavier roller at ILR than that which was used at Bayshore resulted in achieving higher densities and lower hydraulic conductivities while similar moisture conditions were recorded for the red clay at both sites.

Once the red clay was placed at the ILR landfill, it was further subjected to testing and engineering evaluations. It is important to note that the clay was placed over marginal foundation soil, a condition encountered in most landfills, and using conventional construction equipment. Testing at the landfill indicated that the compacted red clay met the NJDEP's compaction criterion of $1x10^{-7}$ cm/sec. Prior to the placement of the red clay, there were concerns regarding the practicality of spreading the material in thin layers (e.g. less than a foot in thickness). However, subsequent field observations demonstrated that spreading the red clay presented no special difficulties in comparison to mined clay. Additional placement and testing procedures are discussed in the following sections.

5.0 Material Testing

5.1 Scope of Field Testing

Following compaction of each layer, density and moisture content tests were conducted. A nuclear density gauge was used for measuring density and moisture contents in accordance with ASTM D 2922 test procedure. For each location tested, wet/dry density and moisture content were recorded with respect to depth. Measurements were taken at the surface and at 2", 4", 6", 8", 10" and 12" below grade (maximum penetration depth of the gauge probe) to determine variations in dry density and moisture content with depth. The test results are presented in Appendix B of this report. In addition, grab and Shelby tube samples were taken periodically and sent to the laboratory for moisture content tests. Field and laboratory density test results are discussed in the following sections.

5.2 Scope of Laboratory Testing

The laboratory testing plan was designed primarily to characterize the clay for potential applications, such as use in low-conductivity caps in sanitary landfills. For such potential use, strength for slope stability and hydraulic conductivity were of most concern. Sampling of compacted red clay was done by advancing a 12-inch-long, 3-inch-diameter thin-wall Shelby tube into the compacted clay. Collected samples were transferred to the Rutgers University geotechnical laboratory for identification, hydraulic conductivity and strength tests. Specifically, laboratory tests included Triaxial shear UU test (ASTM D2850) and unconfined compression (ASTM D2166), Flexible wall hydraulic conductivity (ASTM D5084), moisture-density relation (Standard Proctor ASTM D698 and Modified Proctor ASTM D1557), Atterberg Limits (ASTM D4318) and Gradation Analysis (ASTM D422).

Laboratory tests were conducted on samples collected from the Bayshore Facility in November/December 2003, and in June 2004 following re-compaction of Area 2, and from compacted clay at the ILR Landfill in November of 2004. Again, 12-inch-long, 3-inch-diameter Shelby tubes were advanced into the compacted clay using a driving head. The assembly consists of a 10 lb weight which rides along a stem which connects a handle and drive head. Applying excessive force to drive the Shelby tubes into drier and highly compacted clay in June 2004 resulted in bending of some of the tubes. Therefore, additional tests were conducted on laboratory reconstituted clay samples. These were prepared at moisture contents ranging from field moisture content (approximately 20%) to slightly below optimum (10%). Laboratory reconstituted samples provided more reliable results, as the disturbances due to sampling and extruding of the dry clay were eliminated.

6.0 Engineering Evaluation

6.1 Material Handling

During this pilot study, it was determined that it would be feasible and practical to handle the red clay using conventional construction equipment. Specifically, unloading the material was performed by two hydraulic excavators (long reach CAT 325 and CAT 345). The use of a long reach excavator eliminated the associated cost for a stand-by tugboat typically needed for maneuvering the scow during unloading operations. The long reach excavator was used for pulling the clay to the landside of the scow, where it could be unloaded by the CAT 345 excavator (refer to the photos in Appendix C). Approximately 4,000 cubic yards of material were unloaded in two 12-hour shifts.

The clay was directly loaded into road trucks and transported approximately 2,500 feet to the test area. The test area was chosen so that placement of material within 500 feet from the mean high water line could be avoided; otherwise a NJDEP Waterfront Development Permit would have been required.

For spreading and compaction of the red clay, conventional construction equipment consisting of D3 LGP CAT wide track bulldozer, 980G CAT front loader, BOMAG 120 DD sheepsfoot and BOMAG 172 AD smooth wheel roller were utilized. The clay was stockpiled initially prior to spreading. Subsequently, a front loader and a wide track bulldozer moved and spread the red clay. The first layer was placed over the existing native material, which consisted of recycled masonry and gravel. Area 2 received two additional layers, 12 inches in thickness and 6 inches in thickness, respectively. As mentioned earlier, due to adverse weather conditions in December of 2003 and January of 2004, the final compaction and testing was postponed until June of 2004.

The red clay placed over Area 2 was re-compacted in June 2004, followed by field and laboratory testing. The moisture content of the red clay over Area 2 decreased from approximately 23% in December 2003, to 13% on average in June of 2004. As the modified optimum moisture content is 12%, rolling of the clay resulted in densities near or above 100% of modified maximum dry density. Field density test results are presented in Appendix B.

Finally, in November of 2004, 2,000 cubic yards of the red clay (mostly that portion of the red clay which was not spread in layers and aerated) was transferred to the ILR

Landfill in Edison, NJ. There, a 12-inch-thick layer of red clay was placed as a low-hydraulic-conductivity cap over one acre of the Landfill. Once the material was spread, its initial moisture content averaged 25%. Following one day of aeration using a D32P Komatsu bulldozer, the moisture content was reduced to 20%. The red clay was then compacted using a SD 122DX Ingersoll smooth drum roller with an operating weight of 12 tons. Samples collected from the field and tested for hydraulic conductivity confirmed that a hydraulic conductivity of less than $1x10^{-7}$ cm/sec was achieved.

6.2 Field Testing

Field testing consisted primarily of moisture content and density measurement testing using a nuclear density gauge in accordance with ASTM D2922. As mentioned earlier, density and moisture contents were measured at 2 inches intervals starting at the surface and advancing to 12 inches below grade. This allowed measuring the moisture content variation with respect to depth. According to the test results (presented in Appendix B), no significant change in density or moisture content was measured with respect to depth.

The average density and moisture content measured on November 2003, June 2004 and November 2004 are summarized in the table below:

Date	Moisture Content (%)	Dry Density (pcf)	Percent Compaction (modified proctor)
November 17, 2003	22	101	86.3
November 24, 2003	22.5	104	89
June 2004	12.5	113.3	98.6

Table 1. Average Field Density Test Results

Since the same roller was used for compacting the clay in November of 2003 and June of 2004, the increase in dry density and percent compaction must be attributed to a moisture content reduction from December 2003 to June 2004.Attempts to collect Shelby tube samples were unsuccessful, therefore, hydraulic conductivity tests were performed on laboratory reconstituted samples compacted to the same densities as those measured in the field in June 2004. The test results are presented in Appendix A.

The clay was used as cap material to cover approximately one acre where the cap had been removed for the installation of a gas extraction system at the ILR landfill. Two 6-inch layers of clay were placed and then compacted 24 hours after placement. The initial moisture content of the clay was approximately 25%. Following one day of active aeration the moisture content was reduced to 20%. Following compaction of a placed layer using a SD 122DX Ingersoll roller, density tests were conducted and Shelby tube samples collected for laboratory hydraulic conductivity tests.

Hydraulic conductivity tests conducted on the collected samples indicated that all samples met the 1x 10^{-7} cm/sec criteria for landfill caps. A summary of the test results is presented in the following section. A review of the hydraulic conductivity test results that were conducted on some of the Shelby tube samples collected from the Bayshore Site and the three samples collected from the ILR Landfill revealed that, although moisture contents were similar, higher dry densities and lower hydraulic conductivity were measured for samples collected at the ILR Landfill. This is due to utilization of a heavier compactor at ILR. A seven (7) ton BOMAG 172 AD roller was used at the Bayshore Site, while a twelve (12) ton SD 122DX Ingersoll roller was used for compacting the clay at ILR. Therefore, it was concluded that heavier compactors could provide more favorable compaction, and consequently lower hydraulic conductivity.

6.3 Laboratory Testing

Laboratory tests included identification, shear strength, moisture-density relationship and hydraulic conductivity. ASTM designations for each test procedure were provided in the previous sections. Laboratory tests were formulated to provide information regarding:

- Index Properties or typical range for plasticity and gradation,
- Classification according to Unified Soil Classification System (USCS),
- Moisture-density relationship for field quality control purposes,
- Shear Strength for slope stability analysis and load bearing capacity determination and;
- Hydraulic Conductivity if red clay is to be used as material for low-hydraulic-conductivity caps in landfills.

6.3.1 Identification tests

Identification tests included Atterberg Limits and gradation analysis. The red clay could be generally classified as lean clay (CL) based on Unified Soil Classification System (USCS). The Plastic Limit (PL) and Liquid Limit (LL) ranged from 25 to 26.1% and 34.3 to 38.9% respectively. The Plasticity Index (PI) ranged from 9 to 12% and the natural moisture contents were in the range of 31 to 36%.

Gradation analysis tests were conducted on selected red clay samples to determine the particle size distribution. The gradation analysis included sieve and hydrometer tests. The test results are presented in the table below:

Gradation Analysis	**Clay (%)**	**Silt (%)**	**Sand (%)**	**Gravel (%)**
Sample taken on 11/05/03	59.5	32	5.7	2.8
Sample taken on 11/11/03	58.8	36.2	4.7	0.3
Sample taken on 11/13/03	61.4	29	6.4	3.2
Sample taken on 11/24/03	60.8	31.8	6.3	1.1
Sample taken on 12/04/03	61.6	35.6	2.4	0.2
Average	**60.5**	**33**	**5**	**1.5**

Table 2. Gradation Analysis of Red Clay Samples

On average, 60.5% of the material is clay, 33% silt and 6.5% sand and gravel.

6.3.2 Moisture Density Relationship

Grab samples were tested for moisture density relationship (compaction test) in accordance with Standard Proctor (ASTM D698) and Modified Proctor (ASTM D1557) test procedures. Such a determination is necessary to define a range of moisture contents at which the target strength and hydraulic conductivity is achieved. Laboratory test results are summarized in the table below:

Moisture-Density Relation	Maximum Dry Density (pcf)	Optimum Moisture Content (%)
Standard Proctor (ASTM D698)		
Sample taken on 11/05/03	105	17
Sample taken on 11/11/03	105.5	17.5
Sample taken on 11/13/03	104	16.5
Sample taken on 11/24/03	106	15.5
Sample taken on 12/04/03	103.5	16.5
Average	**104.9**	**16.6**
Modified Proctor (ASTM D1557)		
Sample taken on 11/05/03	117	12.5
Sample taken on 11/11/03	115	12
Sample taken on 11/13/03	114.5	12
Sample taken on 11/24/03	114.5	12
Sample taken on 12/04/03	112	12
Average	**114.6**	**12.1**

Table 3. Moisture Density Relation of Red Clay

The average maximum dry density and optimum moisture content using Standard Proctor energy were 104.9 pcf and 16.6%, while those values for samples compacted with Modified Proctor energy were 114.6 pcf and 12.1%. The narrow range in the measured maximum dry densities and optimum moistures for each method indicates the uniformity of the red clay.

6.3.3 Hydraulic Conductivity

A total of twenty two (22) hydraulic conductivity tests were conducted on field-collected samples in conformance with ASTM D5084, Flexible Wall Method test procedure. In addition, eight (8) laboratory reconstituted samples were tested. Those samples were prepared at a wide range of moisture contents, but lower than those initially measured in the field. This was done to determine the red clay's hydraulic conductivity at different moisture and density conditions.

Field samples were collected using 12-inch-long, 2.875 ID thin-wall Shelby tubes. The tubes were driven into the clay layer using a surface soil sampler built to USACE specification. The apparatus includes a hammer assembly, which consists of a 10 lb weight that rides along a stem that connects a handle and the drive head. However, high quality samples were not obtained when the tubes were advanced into highly compacted clay. Excessive hammering resulted in bending the tubes and destroying the sample. Therefore, it was decided that laboratory reconstituted samples would be used to estimate hydraulic conductivity of the clay at moisture contents near optimum. Laboratory reconstituted samples were compacted in a 4-inch compaction mold at predetermined moisture contents, trimmed to 2.8 diameter and tested in a triaxial chamber in accordance with ASTM D5084. The hydraulic conductivity test results are presented in the table below:

Flexible Wall Hydraulic Conductivity Test	**Moisture Content**	**Compaction Ratio (%) Standard & Modified**	**Hydraulic conductivity (cm/sec)**
Samples Collected from Bayshore Site on:			
11/05/03			
Sample #1	32.4	83 & 76	2.12 $X10^{-6}$
Sample #2	35	81 & 74	5.27 $X10^{-6}$
11/11/03			
Sample #1	32.9	85 & 78	5.6 $X10^{-6}$
Sample #2	26.4	95 & 88	1.52 $X10^{-6}$
Sample #3	30.3	87 & 79	3.62 $X10^{-8}$
Sample #4	26.8	91 & 84	1.8 $X10^{-7}$
11/13/03			
Sample #1	32.3	72 & 66	2.65 $X10^{-7}$
Sample #2	28.6	92 & 84	1.35 $X10^{-7}$
Sample #3	35.9	89 & 81	3.38 $X10^{-6}$
11/17/03			
Sample #1	31.9	91 & 83	1.66 $X10^{-7}$
Sample #2	30.5	95 & 87	2.62 $X10^{-7}$
Sample #3	26.9	92 & 85	1.28 $X10^{-6}$
Sample # 4	28.9	90 & 82	1.39 $X10^{-6}$
11/24/03			
Sample #1	29.6	90 & 83	8.4 $X10^{-7}$
Sample #2	27.5	93 & 86	1.11 $X10^{-6}$
Sample #3	25.2	95 & 87	1.19 $X10^{-6}$
Sample #4	31.3	87 & 81	3.38 $X10^{-7}$

Flexible Wall Hydraulic Conductivity Test	Moisture Content	Compaction Ratio (%) Standard & Modified	Hydraulic conductivity (cm/sec)
12/04/03			
Sample #1	26.9	95 & 87	5.1 $X10^{-7}$
Sample #2	24.9	98 & 90	6.9 $X10^{-7}$
Sample #3	25.2	98 & 90	5.47 $X10^{-7}$
Sample taken at ILR Landfill			
11/17/04			
Sample #1	21.9	101 & 92	8.8 $X10^{-8}$
Sample #2	20.9	99 & 91	4.86 $X10^{-8}$
Sample #3	19.7	102 & 94	4.29 $X10^{-8}$
Laboratory Reconstituted Samples			
Compacted at Standard Proctor Energy			
Sample #1C	13.3	97 & 88	1.45 $X10^{-7}$
Sample #2	16.4	98 & 90	1.29 $X10^{-7}$
Sample #3	18.9	100 & 92	9.64 $X10^{-8}$
Sample #4	20.1	96 & 88	1.25 $X10^{-7}$
Sample #5*	26.4	89 & 81	7.89 $X10^{-8}$
Compacted at Modified Proctor Energy			
Sample #1	8	108 & 99	8.01 $X10^{-8}$
Sample #2	12	110 & 102	4.70 $X10^{-8}$
Sample #3	15.8	109 &100	4.38 $X10^{-8}$
Sample #4	18	105 & 96	5.09 $X10^{-8}$

* Possible Test Error

Table 4. Hydraulic Conductivity Test Results on Field Collected Samples

Figure 4 presents the hydraulic conductivity test results for the field collected samples with respect to their in-situ moisture contents. In general, hydraulic conductivity decreases at lower moisture contents on the wet side of the optimum. However, a hydraulic conductivity of $1x10^{-7}$ cm/sec could not be achieved for uncompacted samples with moisture contents of 25% or above (as shown in Figure 4). Such hydraulic conductivity was achieved once the clay was compacted at moisture contents closer to the optimum.

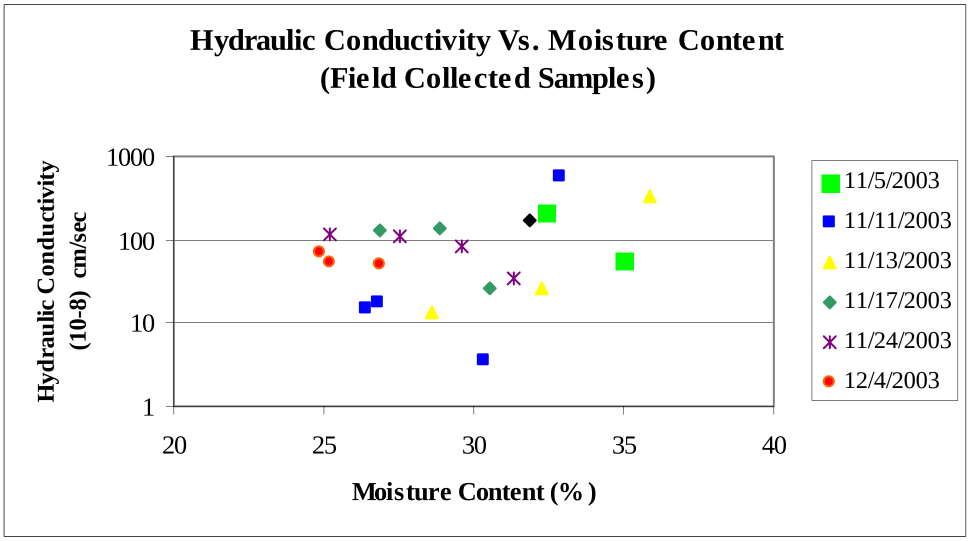


Figure 4. Hydraulic Conductivity of Field Collected Samples

The relation between the hydraulic conductivity and moisture content of laboratory reconstituted samples is presented in Figure 5. The results are consistent with similar studies conducted by others (Daniel, D. et. al) on mined clays typically used for landfill liners and caps. The minimum hydraulic conductivity is typically associated with moisture contents slightly on the wet side of the optimum. In the case of dredged red clay, as shown in Figure 5, for samples compacted at standard proctor energy, the minimum hydraulic conductivity was associated with the sample compacted at 18.9% moisture content or 2.3% above the optimum. As for samples compacted at modified proctor energy, the minimum hydraulic conductivity was recorded for the sample compacted at 15.8%, or 3.7% above the optimum.

Figure 5 also presents the hydraulic conductivity test results for samples collected from the red clay placed at the ILR Landfill as liner. As shown in Figure 5, the three samples tested all met the NJDEP criterion of $1x10^{-7}$ cm/sec.

The test results indicate that once the clay is compacted at energies equal to or greater than modified proctor, and at moisture contents below 22% but above optimum, the hydraulic conductivity criterion suggested by regulatory agencies is achievable. Samples compacted at standard proctor energy failed to meet the suggested maximum hydraulic conductivity value, therefore in practice, heavy compactors capable of delivering energies equal to or greater than modified proctor must be utilized. A 12-ton compactor could deliver the required compaction energy at the ILR landfill.

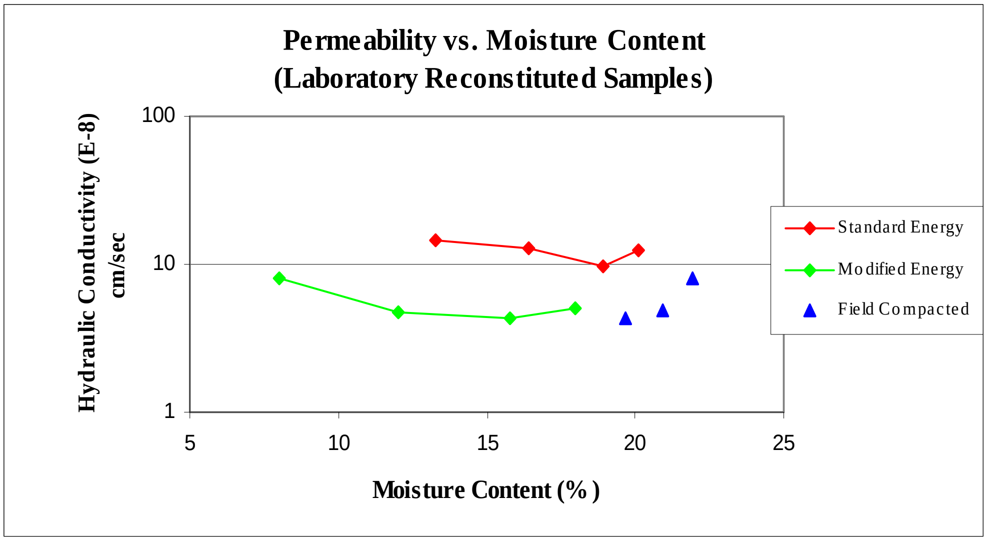


Figure 5. Hydraulic Conductivity of Laboratory Reconstituted/Field Samples

6.3.4 Shear Strength

Field collected samples were tested for their unconsolidated undrained shear strength (UU) in conformance with ASTM D2850 test procedure. 12-inch-long and 3-inch-diameter (OD) thin-wall Shelby tubes were advanced into compacted layers of red clay and extracted. The tubes were later extruded in the laboratory and samples were tested for shear strength, density and moisture content. Samples typically had a diameter of approximately 2.8 inches and a height to diameter ratio of two. The field collected samples exhibited high moisture contents (well above the optimum), therefore laboratory reconstituted samples were prepared at lower moisture contents and tested for their unconfined shear strength (ASTM D2166). Those samples had a diameter of approximately 2.3 inches. The unconfined shear test results are presented in Table 5.

Shear Strength Test Field Collected Samples	Moisture Content (%)	Dry Density (pcf)	Undrained Shear Strength (psf)
Samples taken on 11/05/03 Sample #1	31.5	91-92	279
Samples taken on 11/11/03 Sample #1	31.1-31.3	91-92	323

Shear Strength Test Field Collected Samples	**Moisture Content (%)**	**Dry Density (pcf)**	**Undrained Shear Strength (psf)**
Sample #2	31.8-33	90-91	391
Samples taken on 11/13/03			
Sample #1	28.2	98	755
Samples taken on 11/17/03			
Sample #1	29.5	95	619
Sample #2	24.1	101	2,248
Samples taken on 11/24/03			
Sample #1	25.3	99	1,282
Laboratory Reconstituted Samples			**Unconfined Compression Shear**
Compacted at Standard Proctor Energy			
Sample #1	11.5	101	2,543
Sample #2	16.4	103	3,863
Sample #3	20.3	101	2,809
Sample #4	25.6	92	374
Compacted at Modified Proctor			
Energy	8.3	110	5,959
Sample #5	11.6	112	9,922
Sample #6	18	108	4,947
Sample #7	21	102	1,472
Sample #8			

Table 5. Shear Strength of Field Collected and Laboratory Reconstituted Clay Samples

Shear strength of field collected and laboratory reconstituted samples are plotted against their moisture contents in Figure 6.

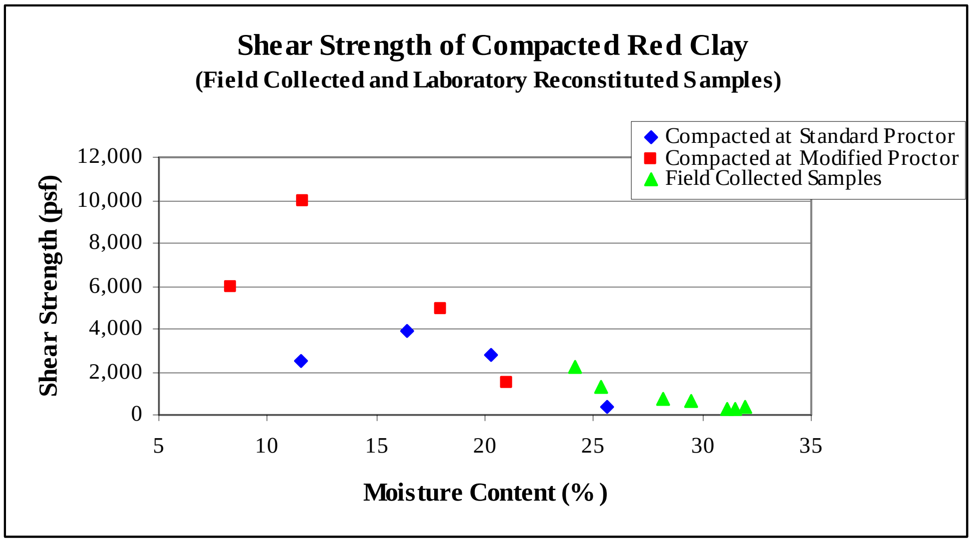


Figure 6. Shear Strength of Red Clay at Various Moisture Contents

As shown in Figure 6, samples compacted at lower moisture contents exhibit higher shear strength, which is typically the case for clays. The exception is for samples compacted at moisture contents well below the optimum. The decrease could be attributed to the presence of silt (33%) and sand/gravel (6%). Nevertheless, based on the test results, once the clay is compacted at moisture contents below 20% using standard or modified energy, a shear strength of 2000 pounds per square foot (psf) or higher is achieved. If utilized as cap over the side slopes of sanitary landfills, such strength is sufficient to provide an adequate safety factor against slope failure.

7.0 Handling, Placement and Cost Analysis

To use red clay in large volumes at landfills or industrial sites where capping is required, the following steps should be taken:

1. Offshore transportation of red clay from a dredging site to an upland facility (with barge access and usable bulkhead),
2. Unloading into road trucks,
3. Transportation to a designated site,
4. Spreading, moisture conditioning (most probably moisture reduction), compaction; and
5. In-situ QA/QC testing.

7.1 Offshore Transportation

As stated, the red clay dredged from ACOE channel deepening projects is currently placed at the HARS. Split hull scows with a typical capacity of 5,000 cubic yards transfer the clay from dredging sites to designated areas within the HARS. For transportation of the red clay to upland sites, hopper scows are more economically feasible. Hopper scows used in dredging operations in the NY/NJ harbor have a typical capacity ranging from 1,500 to 4,000 tons of dredged material. Depending on density of the dredged material, the volume could vary. During the pilot study, two 3,000-ton-capacity scows were used and each transferred approximately 2,000 cubic yards of clay to the Bayshore Recycling Facility.

With respect to the cost difference incurred by the dredgers for the transportation of red clay to the HARS or an upland site, the following should be considered:

- Ideally, red clay can be dredged at a daily rate of 8,000 cubic yards, and on average 6,000 cubic yards could be dredged in an 18-hour shift according to the dredging companies,

- For ocean placement of red clay, typically two split hull scows are dedicated to each dredge. If hopper scows are used for transportation of red clay to upland sites, three hopper scows are needed. The unit cost for addition of three hopper scows is $0.17 per cy of red clay assuming monthly rental of $10,000 per scow (3X $10,000 per month/ (6,000 cy X 30 days)),

- Tug boats are typically used for moving scows. Since a split hull scow transports approximately twice as much material as hopper scows, the number of tug boats used for upland transportation (conservatively) doubles. However, the sizes and the cost of ocean-going tugs are larger than tugs used for upland operation. The current daily rate for ocean going tugs is $6,500 while smaller tugs suitable for moving hopper scows cost approximately $4,500 daily. The added cost per cubic yards of dredged material therefore would be $0.42 ((2 x $4,500 - $6,500)/6000) per cubic yard,

- Adding scows to the dredging operation will reduce the efficiency of dredging operations by approximately 8% (It is assumed that two hours is lost daily as a result of maneuvering hopper scows). On the other hand, transportation of clay to upland sites will not be affected by adverse weather conditions. In fact, the average weather dependent inefficiency is typically 5%, according to the dredgers. Therefore, the overall estimated added cost, assuming a daily operational cost of $60,000, would be $0.30 per cubic yards (3% (or 8-5) X 60,000/6000day),

- The overall added cost for offshore transportation of the red clay to an upland site is $0.89 per cubic yard or $1 including 10% contingency.

7.2 Unloading

Hydraulic long reach excavators could be efficiently used for unloading the scows. Their advantage over cranes is that their cycle time is almost three times faster than that of cranes. During the pilot study, the contractor chose to use two excavators including a long reach excavator that pulled the clay towards the bulkhead side of the scow where it was unloaded by a Caterpillar 350 excavator. Alternatively, a stand-by tug boat and one excavator could be used to maneuver the scow, since conventional excavators may not reach the far side of the scows. The rate of unloading could be fine tuned with the volume of material delivered to ensure that scows are returned to the dredging site in a timely manner without adversely affecting the dredging operation.

The associated cost for two excavator’s, laborers, foremen and operators working 24 hours per day, 7 days a week including overtime fees for Saturday and Sundays is approximately $200,000 per week. Given that 6,000 cubic yards daily or 42,000 cubic yards weekly could be unloaded, the cost of unloading on average is $5/cy including a 5% contingency.

7.3 Land Transportation

During the demonstration project, the clay was transported to the designated area within the Bayshore Site by conventional over-the-road dump trucks. Modification of the hauling trucks was not necessary since no spillage occurred during transportation. Transportation of the red clay over public roads is not expected to require any additional provisions. The associated cost would be comparable to other clay material excavated from clay mines and is dependent on distance from the source to the application site. If the application site is close to the Port however, costs for transportation of dredged clay could be substantially lower than for mined clay.

7.4 Material Placement

If the red clay is used for low-hydraulic-conductivity caps, moisture reduction would be necessary to achieve $1x10^{-7}$ cm/sec required by regulatory agencies. It was demonstrated that in order to meet the target hydraulic conductivity, the moisture content should not exceed 22% but be above optimum. The natural moisture content of the red clay used in this study was 35%. Therefore, moisture reduction of 13% or more was required prior to compaction. Moisture reduction is typically achieved by displacement and aeration of clay using farming (harrowing) disks pulled by bulldozers. The time required for such moisture reduction depends on environmental factors such as ambient temperature, sun, wind and precipitation.

During the pilot study in November 2003, adverse weather conditions delayed the drying process to the extent that the field operations were put on hold until June of 2004.. Moisture reduction of approximately 11% was measured in June 2004 without any attempt at moisture reduction (average moisture content of 23% in December 2003 was reduced to 12% in June 2004). Later in November of 2004, 2,000 cubic yards of red clay (not used for the pilot study) were transferred to the ILR landfill. The red clay had an initial average moisture content of 25%. Following 24 hours of active drying, the moisture content decreased to 20%. At an ambient temperature of 40 degrees, a bulldozer displaced and aerated the red clay for one 24 hours to reduce the moisture content prior to compaction. Hydraulic conductivity tests performed on three samples collected from the field were below $1x10^{-7}$ cm/sec for all three samples (Fig 5).

Ideally, if the red clay is spread in thin layers (12 inches or less) starting in May until October, minimal effort is needed to prepare the material for final compaction. To quantify the additional cost of placement of dredged red clay compared to mined clay (assuming mined clay has ideal initial moisture content) the following assumptions were made:

- A wide track D6 bulldozer at unit cost of $1,800/day is needed to spread 1,500 cubic yards of red clay,

- On average, three days of disking/aeration is necessary to reduce the natural moisture content to the desired moisture content, and

- One heavy roller at a daily cost of $1,000/day is required to compact 1,500 cubic yards of clay.

Therefore, the unit cost of material placement would be approximately $5 ((3x$1,800+ $1,000)/1500 cy) including 15% contingency. The overall cost comparison for utilizing the red clay and mined clay is summarized in Table 6:

Material Type / Construction Item	Mined Clay/cy	Dredged Red Clay/cy
Material Purchase[(1)]	$15	None
Offshore Transportation	None	$1
Unloading [(2)]	None	$5
Bulkhead Usage	None	$0.50
Upland Transportation	Same for Both Materials	Same for Both Materials
Moisture Adjustment [(3)]	None	$5
Spreading and Compaction	$2.30	$2.30
Total	$17.30	$13.80

(1) Current market price (2)Unloading of dredged red clay to trucks (3) Moisture conditioning using farming disks or other means

The associated cost for lease or purchase of such property is not included in the overall cost estimates.

7.5 Evaluation Summary

Based on the above cost estimates, utilization of dredged red clay for low-hydraulic-conductivity caps could be cost effective in comparison to mined clay. However, some limitations are associated with utilization of red clay as described below:

- *Availability*

Dredging of red clay is performed per the dredging contract schedules. Therefore, the dredging schedule may not coincide with the schedule for clay placement at a brown-field or a landfill site. Alternatively, clay may be available when it cannot be immediately used at an upland site. Therefore, a dedicated site for storage/moisture conditioning of red clay would facilitate its use.

- *Consistency*

Depending on the dredging area, the engineering properties of red clay may vary. Additional characterization may be necessary to accurately determine engineering properties of red clay taken from different dredging sites. In addition, the dredgers should take extra care not to mix clay with soil layers immediately underneath or above the clay (e.g. glacial drift). If glacial drift is mixed with clay, it affects the engineering properties of the clay to the extent that it may no longer be suitable for capping applications.

- *Moisture Adjustment*

Since the natural moisture content of clay is expected to be higher than the moisture content at which it could be compacted, moisture reduction will be necessary. Specifically in cold seasons, moisture reduction becomes a slow process because of low ambient temperature, frequent periods of rain or snow, and frost. A dedicated site as described for moisture conditioning and storage of red clay could facilitate use of red clay at upland sites. Clay should be stockpiled at the site if received during cold seasons. If received in warm seasons, it could be directly transported to the sites in need of clay capping. In warm weather, moisture reduction could be achieved in one to two days. If an immediate need is not identified, the clay could be spread; moisture conditioned and stockpiled. The associated cost for lease or purchase of such property is not included in the overall cost estimates.

8.0 Market Analysis

This task was performed by Sadat Associates Inc. (SAI) and included a study on the nature of potential uses in remedial projects, focusing on liners, cut off walls and caps. A forecast of annual volume needs in North and Central New Jersey was prepared. The advantages and disadvantages of using dredged clay over other natural clays, synthetic materials, or other impermeable materials. Sadat Associate's Report is presented in Appendix D. This section is directly screened from Sadat's Report.

Potential market for dredged red clay (DRC) applications has been estimated based on the best available information and prudent engineering assumptions. The estimated potential DRC market along with the adopted methodologies and the assumptions used for the estimation are discussed in the following sections.

8.1 Containment Barrier Applications

Several approaches were employed to estimate the available market for DRC as containment barrier layer in landfill and site remediation applications. Although the applications are similar, the markets for landfills and remediation sites were studied separately.

8.1.1 Landfills

In order to estimate the DRC market in the landfill industry, landfills were classified into the following categories; (1) operating regional landfills, (2) closed landfills that require capping and, (3) landfills under the NJDEP landfill remediation program. A fourth category includes landfills that can be considered as exceptions from the above general categories because they would require large quantities of capping material as part of their closure plan.

Questionnaires were sent to the landfill mangers of all the thirteen (13) regional landfills in New Jersey, requesting information regarding the potential market for low permeability material. The landfill managers were telephoned to follow-up on the questionnaire and interviewed on the proposed activities at the landfill that may require low permeability material. The responses did not lead to a conclusive estimate of the future demand scenarios. Therefore, a different approach was devised. The required future landfill capacity for each regional landfill was projected based on the population of the county from which the landfill receives solid wastes. The actual future volumes may be higher than the projections due to the fact that many of the landfills accept solid waste from municipalities in neighboring counties. The required number of landfill cells was then estimated using a typical landfill cell configuration. The required quantity of clay was then estimated based on the fact that a low permeability bottom liner and a top cap would be required for each cell that will be opened. The thickness of the clay layers was assumed as one (1) foot, based on the New Jersey Solid Waste Regulations.

The estimated potential market for clay and the assumptions used in the calculation of the potential market are shown in Table 8.1. As shown in the Table, the estimated potential market for DRC for use as containment layers at the thirteen (13) regional landfills, for the next ten years is approximately 5.25 Million CY. The contact details, the proposed year of final closing and the acreage of all the regional landfills in New Jersey are provided in Table 8.2. Additional information on all New Jersey landfills is available from the New Jersey Landfills Database, maintained by NJDEP.

Table 8.1 - Estimation of Potential DRC Market for Regional Landfills

	Year 2003 Population*	Pop. Growth Rate from 2000-'03	Annual % Growth Rate**	Jan 1, 2010 Projected Population	Required LF Volume (CY/Year)	Addl. Cells Required in a 10 YR Period	Required Vol. of Clay (CY) ***
Atlantic	263,410	4.30	1.304	286,550	561,863	10.74	346,423
Burlington	444,381	5.00	1.513	489,930	960,647	18.36	592,297
Camden	513,909	1.00	0.307	524,239	1,027,919	19.64	633,774
Cape May	101,845	-0.50	-0.154	100,829	197,704	3.78	121,897
Cumberland	149,306	2.00	0.611	155,338	304,584	5.82	187,795
Gloucester	266,962	4.80	1.453	293,205	574,913	10.99	354,468
Middlesex	780,995	4.10	1.244	846,349	1,659,509	31.71	1,023,188
Monmouth	632,274	2.80	0.853	668,177	1,310,151	25.03	807,787
Ocean	546,081	6.90	2.074	624,040	1,223,608	23.38	754,428
Salem	64,854	0.90	0.276	66,027	129,464	2.47	79,822
Sussex	151,146	4.80	1.453	166,004	325,499	6.22	200,690
Warren	109,219	6.60	1.986	124,112	243,356	4.65	150,044
			TOTAL	**4,344,801**	**8,519,217**	**163**	**5,252,613**

* US Census Bureau, 2003 Projected Population

** Based on US Census Bureau 2000-2003 Growth Rate

*** Assuming one foot thick cap and liner

Percapita SW Generated	2000	lb/yr
LF Compacted SW Density	1,200	lb/CY
Landfill Compaction Ratio	0.85	

Area of Typical LF Cell	10	Acres
Height of Typical LF Cell	50	Feet
Side Slope of Typical Cell	3	H = 1V
LF Volume of One Cell	523333	CY

Table 8.2 - New Jersey Regional Landfills Data

Facility Name	Facility Location	City	County	Mailing Name	Mail Contact	Mail Street	Mail City	Year of Closing	Acrage
Atlantic County Sanitary Landfill	Delilah Road	Egg Harbor Township	Atlantic	Atlantic County Utilities Authority	Richard S. Dovey, President	P.O. Box 996	Pleasantville, N.J. 08232	2022	308
Burlington County Resource Recovery Complex	Burlington-Columbus Road, Rte. 543	Florence and Mansfield Township	Burlington	Burlington County Board of Chosen Freeholders	Frederick F. Galdo, Clerk/Administrator	P.O. Box 6000	Mount Holly, NJ 08060	2015	496
Cape May County MUA Sanitary Landfill	Kearney Ave. & Route 610	Upper Twp. & Woodbine Borough	Cape May	Cape May County Municipal Utilities Authority	Charles M. Norkis,P.E., Chief Engineer	P.O. Box 610	Cape May Court House, NJ 08210	2039	372
Cumberland County Solid Waste Complex	Jesse's Bridge Road, Rt.636	Deerfield Township	Cumberland	Cumberland County Improvement Authority	Steven Wymbs, Executive Director	2 North High Street	Millville, NJ 08332	2021	300
Gloucester County Solid Waste Complex	Swedesboro-Monroeville Road	South Harrison Township	Gloucester	Gloucester County Improvement Authority	David Shields, Executive Director	109 Budd Blvd.	Woodbury, NJ 08096	2012	216
NJMC Erie landfill	Valley Brook Avenue	North Arlington	Bergen	New Jersey Meadowlands Commission	Thomas Marturano	Two DeKorte Park Plaza, P.O. Box 6	Lyndhurst, NJ 07071	2006	172
Middlesex County Sanitary landfill	Edgeboro Road	East Brunswick	Middlesex	Middlesex County Utilities Authority	Richard Fitamant, Executive Director	P.O. Box B-1	Sayreville, NJ 08872-0086	2015	932
Monmouth County Reclamation Center	Asbury Ave. & Shafto Rd.	Tinton Falls	Monmouth	Monmouth County Board of Chosen Freeholders	Robert J. Collins, County Administrator	Hall of Records, P.O. Box 1255	Freehold, NJ 07728-1255	2015	400
Ocean County Landfill Corp.	Route 70 & Route 571	Manchester	Ocean	Ocean County Landfill Corp.	Charles J Hesse	P.O. Box 207	Belford, NJ 08733	2016	992
Pennsauken Sanitary Landfill	9600 River Road	Pennsauken	Camden	Pollution Control Financing Authority of Camden Co	Rtd. John Jacobs, Deputy Director	729 Hylton Road	Pennsauken, NJ 08110	2013	432
Salem County Sanitary Landfill	Rt 540 & McKillip Rd.	Alloway Township	Salem	Salem County Utilities Authority	Michael Chapman, Executive Director	P.O. Box 674	Alloway, NJ 08801-0674	2018	156
Sussex County Sanitary Landfill	Rte 94 & 15	Lafayette Township	Sussex	Sussex County Municipal Utilities Authority	Frederick Vanderbeck, Chairman	RD#1, Box 900A	Lafayette, NJ 07848	2012	204
Warren County District Landfill	Edison Road	White Township	Warren	Pollution Control Financing Authority of Warren Co	John Carlton, Executive Director	P.O. Box 587	Oxford, NJ 07863-0587	2014	180

A different approach was used in estimating the potential market for DRC in closed industrial and sanitary landfills that require capping. There are about 500 landfills in New Jersey that are closed but are not properly capped. The major hurdle in capping these landfills is financing. Recent trends indicate that redevelopment opportunities are the most common incentive for the capping and closure of these types of landfills. Senior staff from the NJDEP Bureau of Landfills and Recycling Management (BLRM) and other sources were consulted to evaluate the frequency at which the abandoned landfills come up for capping and closure. It is estimated that the closure plans for about 5-10 old landfills are submitted each year for approval to the NJDEP. Average area of these landfills is assumed based on expert opinion as 10 acres. Some of the capped landfills are not redeveloped and some are redeveloped into residential/commercial facilities, golf courses etc. Thickness of the clay cap layer is assumed to be one (1) foot for estimation purposes, based on the NJ Solid Waste Regulations. In redevelopment projects involving buildings and infrastructure, the clay cap may be replaced by building slabs, pavements etc. However, this will be offset by the increased potential to use DRC as structural fill in such projects. Thus the potential market for use of DRC in capping closed New Jersey landfills, estimated at a rate of 5 landfills per year, for the next ten (10) years is approximately 0.8 Million CY.

New Jersey landfills that are being capped under the NJDEP site remediation program are not included in the above estimation. Based on information from the NJDEP site remediation program, a total landfill area of 335 acres is currently under the site remediation program. The list of landfills under the NJDEP site remediation program is provided in Table 5.3. It can be reasonably assumed that all these landfills will be capped within the next ten (10) years. Assuming a one (1) foot thick cap layer, the potential market for use of DRC in capping the landfills under NJDEP site remediation program is approximately 0.54 Million CY.

Table 8.3 - Potential DRC Market for Capping of Landfills Under NJDEP Site Remediation Program

Landfill Project	Landfill Area (Acres)	Required Volume of Cap Material (MCY)*
Fazzio Landfill	100	0.16
Winslow Landfill	95	0.15
James Landfill	21	0.03
Woodstown Landfill	44	0.07
Somerville Landfill	47	0.08
Harris Landfill	28	0.05
Total	**335**	**0.54**
* Estimated based on approximate area of the landfill and a one (1) foot thick cap		

SAI is familiar with several landfill projects that require large quantities of fill material, as part of their closure plan. Previous experiences with similar projects indicate that DRC material will be a potential alternative for those applications. Since the quantities of DRC material required for these landfill projects are substantially higher than the typical scenarios discussed above, the potential DRC market for these projects are estimated as a separate category. The landfill projects and the estimated quantity of required fill material are as shown in Table 8.4.

Table 8.4 - Potential DRC Market for Capping of Specific Landfills

Landfill Project	Landfill Area (Acres)	Required Volume of Cap Material (MCY)*
EnCAP Golf, Inc.,	785	1.27
Overpeck Landfill	400	0.65
Wildwood Landfill	29	0.05
Stafford Landfill	60	0.10
Mall Landfill	30	0.05
Edgeboro Landfill	100	0.16
Keyport Landfill	34	0.05
Fresh Kills Landfill	460	0.74
Total		**3.07**

A summary of the estimated DRC market for landfill capping is provided in Table 8.5

Table 8.5 - Summary of Potential DRC Market Estimation for Landfill Capping

Description of Landfill Market	Estimated Market (Million CY)
Regional Landfills	5.25
Capping of Abandoned Landfills	0.80
Landfills Under NJDEP Site Remediation	0.54
Specific Landfills Listed in Table 5.5	3.07
TOTAL	**9.66**

8.1.2 Site Remediation

The first step in the estimation of DRC market for site remediation applications was an in-house evaluation of the site remediation projects performed by SAI, managed several site remediation projects ranging from Preliminary Assessments to Remedial Action Work plans. These projects were evaluated retrospectively for the potential to have used DRC at any stage of the project as part of site remediation.

The review revealed that there were 14 projects completed, which required soil remediation and backfill at the site. Out of this, 12 projects were small-scale projects, with the potential of using a quantity of DRC less than 10,000 CY. All the 12 small-scale projects together had only a potential of using approximately 900 CY. This is equivalent to a quantity of 75 CY of potential DRC market per one small-scale site remediation project.

Projects that had the potential to use more than 10,000 CY of DRC were classified as large-scale projects. Two projects were identified in this category, with a total potential for DRC usage of approximately 80,000 CY. This is equivalent to a quantity of 40,000 CY of potential DRC market per one large-scale site remediation project. However, considering that the estimate is based on a small sample size of only two projects in this category, the quantity was divided by a factor of 2, to make the estimate more conservative. Thus the potential DRC market per one large-scale site remediation project is estimated to be 20,000 CY.

The data available from the NJDEP known contaminated site database was analyzed to quantify the market for potential use of DRC. There are approximately 12,000 known contaminated sites listed in the NJDEP database for known contaminated sites. Out of this, approximately 3,500 sites have been identified by NJDEP as requiring multi-phased remedial action. The land area involved in the remedial action or other similar data valuable for estimation of potential DRC market associated with each site remediation project were not available from the NJDEP database or from other NJDEP sources. Therefore, using the same ratio derived from the SAI projects, to categorize the NJDEP projects into small/large scale projects, there will be 3000 small-scale and 500 large-scale projects that have the potential to use DRC as part of site remediation. Assuming that all the sites currently listed in the NJDEP known contaminated site database will be remediated during the next 10 years, the total estimated market for this application is 10.23 MCY. This estimate includes the potential market for use of DRC as containment barriers and as structural backfill for site remediation projects. The estimation of potential DRC market for site remediation is presented in Table 8.6.

Table 8.6 - Estimated Potential DRC Market for Site Remediation Projects

Category	SAI Projects			NJDEP Projects	
	No. of Projects	Ratio to Total	Potential for DRC Use (CY/project)	Number of Projects	Total DRC Market (Million CY)
Small-scale projects (< 10,000 CY)	12	0.86	75	3,000	0.225
Large-scale Projects (>10,000)	2	0.14	20,000	500	10.00
Total	**14**	**1.0**		**3,500**	**10.23**

8.2 Civil Engineering Applications

The DRC market in Civil Engineering applications depend primarily on the feasibility of using DRC in structural fill applications. The potential market for use of DRC as pond liners and in wetland restoration work is estimated based on the construction activity in New Jersey. Based on the most recent data available from the New Jersey Department of Community Affairs, construction of about 35,000 residential units, 10 Million Sq. ft. of office space and 6 Million square feet of retail space was authorized in the year 2003. Data for the year 2004 is not available at this time. Assuming an average floor area of 1,500 Sq. ft. per housing unit, the total building area is approximately 86 Million Sq. ft. Assuming a Floor Area Ratio (FAR) of 1.5, this is equivalent to construction in a total land area of approximately 3,000 acres. It can be reasonably assumed that approximately 2.5% of the total land area will be used for stormwater retention facilities or wetland restoration, requiring low permeability liners. Thus the total area requiring low permeability liners will be approximately 75 acres. Assuming a 1 foot thick low permeability liner, the potential market for DRC for this application is approximately

0.12 Million CY per year and amounts to 1.2 Million CY during a 10 year period. Additional Civil Engineering applications like the construction of berms, embankments and backfills are not included in this estimate.

Potential market for use of DRC as backfill and for construction of berms and embankments was not quantified under this study. This market offer immense potential for use of DRC, especially large scale applications, which are economically more viable. Sadat Associates Inc. is specifically aware of several such projects where quantities over 0.5M Million CY each will be required for backfill applications as part of site remediation activities.

8.3 Manufacturing Applications

The brick manufacturing facility in Hillsborough, New Jersey manufactures about 35 Million bricks per year. This amounts to a total volume of 0.1 Million CY of clay per year and 1.0 Million CY for a 10-year period. However, the applicability studies indicate that the DRC will require some amendment prior to use in manufacturing applications.

9.0 Summary of Results

This pilot study evaluated the feasibility of using dredged red clay from the New York, New Jersey harbor at upland sites for low-hydraulic-conductivity caps at landfills or brown-fields applications. Approximately 7 million cubic yards of red clay will be dredged from the NY/NJ navigational channels by 2012.

In November of 2003, approximately 4,000 cubic yards of dredged red clay from Newark Bay was transferred to an upland site where it was unloaded, spread and compacted. Later in November of 2004, 2,000 cubic yards of red clay was placed at the ILR landfill, where it was used to cap an approximately one acre area of the site.

During the study, conventional construction equipment including bulldozers, front loaders, sheep-foot/smooth wheel roller, and road trucks were used for transporting ad placing the red clay. The clay was placed in layers with varying thicknesses ranging from 6 to 24 inches. The maximum recommended thickness for each layer however is 12 inches.

Moisture conditioning was necessary to compact the red clay in order to ensure that the desired engineering properties were achieved. A hydraulic conductivity of $1X10^{-7}$ cm/sec, as required by most regulatory agencies, was measured on samples of red clay compacted at 22% moisture content or less. As the natural moisture content of red clay is 35%, a 13% moisture content reduction was necessary prior to compaction and testing.

Red clay consisted of 60.5% clay size particles, 33% silt and 6.5% sand and gravel. As for its moisture density relation, the optimum moisture content determined by standard (ASTM D698) and modified proctor (ASTM D1557) energy were 16.6 and 12.1 respectively. The corresponding maximum dry density was 104.9 and 114.6 pcf, respectively. Plasticity Index of red clay ranged from 9% to 12%.

The associated cost for transportation, unloading, moisture conditioning and placement was estimated to be $13.60 per cubic yards. The current market price of mined clay from upland sites is $15 per cubic yard, and $2.30 should be added for placement costs making the overall cost of mined clay $17.30. Therefore, it appears cost effective to use dredged red clay in lieu of mined clay.

On site moisture conditioning of the red clay in cold seasons, however, may not be cost effective. This may be true for mined clay too. A site dedicated to unloading and moisture conditioning could facilitate the material's use. Moreover, the site could be used for interim storage if no immediate need for clay is identified.

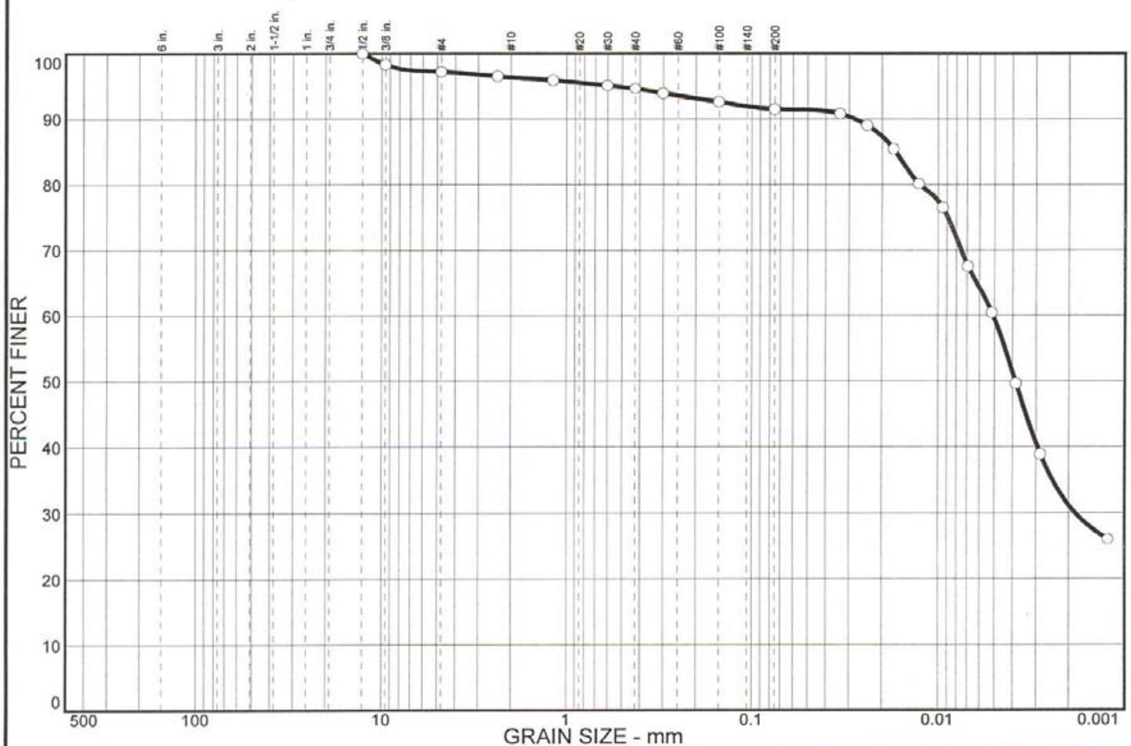
The investigations conducted as part of this study indicate that there is sufficient and viable market for the upland use of red clay. The estimated potential market for the upland use of red clay for the next 10 years is approximately 22 MCY. Out of this, the potential market for use as containment barriers for landfill capping is 9.66 MCY and for use in site remediation projects is 10.23MCY. The potential market for Civil Engineering applications like pond liners, wetland restoration etc. is estimated as 1.2MCY. Additional market exists for use of ed clay as structural backfill material in civil engineering applications. The market for use of clay in ceramic manufacturing industry is estimated as 1.0 MCY. However, the red clay material will require amendment before it can be used for ceramic manufacture.

The cost comparisons demonstrate that the costs associated with the use of red clay material for all upland applications are comparable to those of the competing products. The red clay costs associated with containment barrier applications show substantial advantage over costs of competing products. The financial viability of using red clay as an alternative to conventional upland clay, synthetic liners or common fill depends heavily on the applicable transportation costs. If red clay can be transported via scows directly to the site of application, there will be substantial cost savings.

Appendix A

Laboratory Test Results

Particle Size Distribution Report



% COBBLES	% GRAVEL		% SAND			% FINES	
	CRS.	FINE	CRS.	MEDIUM	FINE	SILT	CLAY
0.0	0.0	2.8	0.9	1.7	3.1	32.0	59.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1/2 in.	100.0		
3/8 in.	98.3		
#4	97.2		
#8	96.5		
#16	95.9		
#30	95.1		
#40	94.6		
#50	93.9		
#100	92.6		
#200	91.5		

* (no specification provided)

Soil Description

Atterberg Limits

PL= 25.0 LL= 36.8 PI= 11.8

Coefficients

D_{85}= 0.0169 D_{60}= 0.0051 D_{50}= 0.0039
D_{30}= 0.0018 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= CL AASHTO=

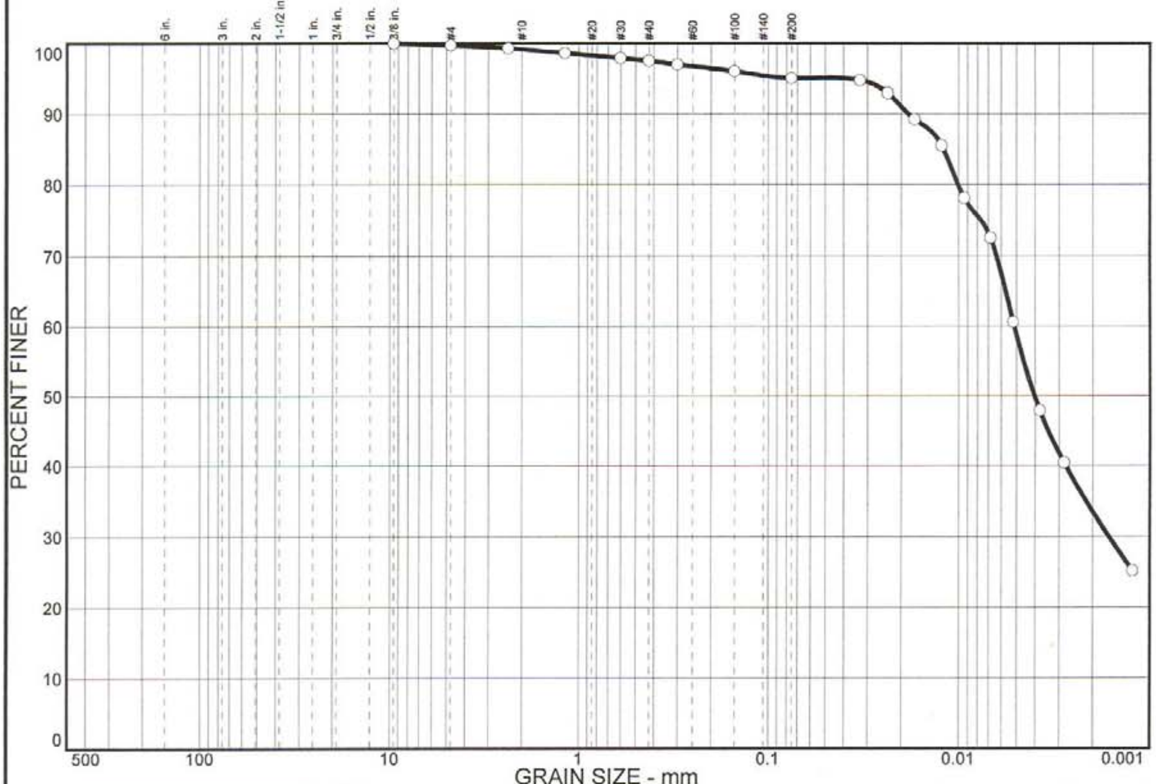
Remarks

Sample No.: 11/05/03 Sampling **Source of Sample:** **Date:** 11/24/03
Location: **Elev./Depth:**

RUTGERS THE STATE UNIVERSITY OF NEW JERSEY

Client:
Project: Red Clay
Project No: **Plate**

Particle Size Distribution Report



% COBBLES	% GRAVEL		% SAND			% FINES	
	CRS.	FINE	CRS.	MEDIUM	FINE	SILT	CLAY
0.0	0.0	0.3	0.6	1.7	2.4	36.2	58.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/8 in.	100.0		
#4	99.7		
#8	99.3		
#16	98.6		
#30	97.9		
#40	97.5		
#50	97.0		
#100	96.0		
#200	95.0		

* (no specification provided)

Soil Description

Atterberg Limits

PL= 26.1 LL= 38.9 PI= 12.8

Coefficients

D_{85}= 0.0120 D_{60}= 0.0051 D_{50}= 0.0040
D_{30}= 0.0016 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= CL AASHTO=

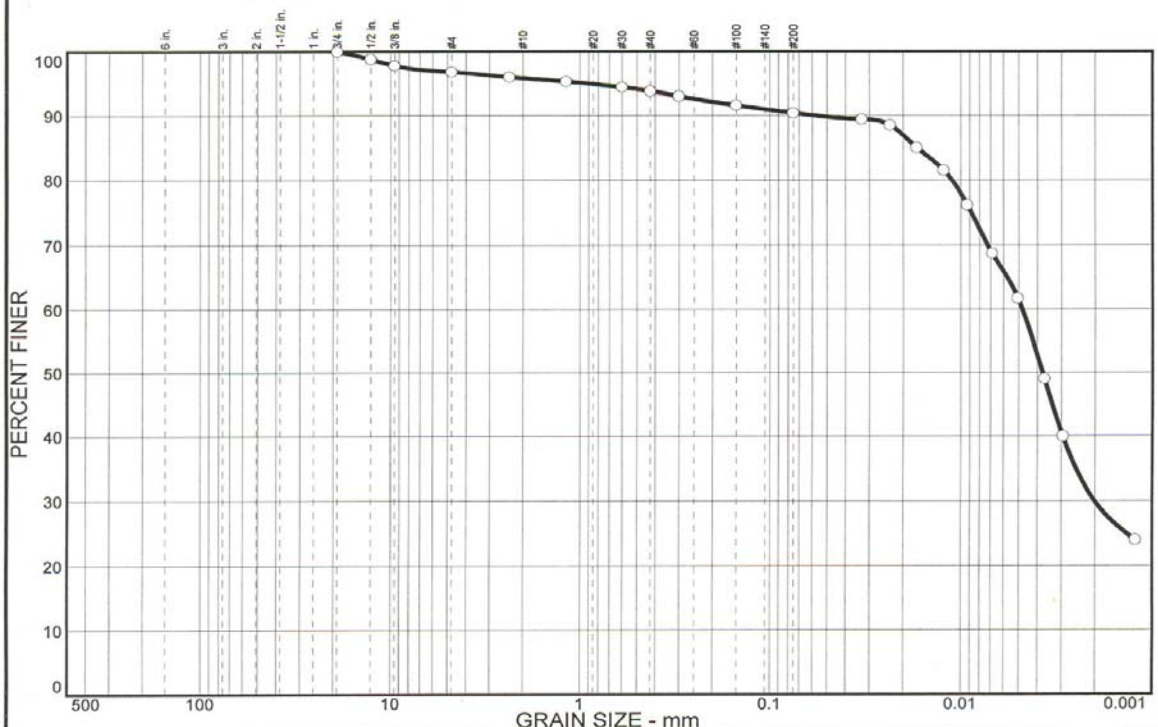
Remarks

Sample No.: 11/11/03 Sampling **Source of Sample:** **Date:** 11/24/03
Location: **Elev./Depth:**

RUTGERS THE STATE UNIVERSITY OF NEW JERSEY

Client:
Project: Red Clay
Project No: **Plate**

Particle Size Distribution Report



% COBBLES	% GRAVEL		% SAND			% FINES	
	CRS.	FINE	CRS.	MEDIUM	FINE	SILT	CLAY
0.0	0.0	3.2	1.0	2.0	3.4	29.0	61.4

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/4 in.	100.0		
1/2 in.	98.8		
3/8 in.	97.8		
#4	96.8		
#8	96.0		
#16	95.3		
#30	94.4		
#40	93.8		
#50	93.0		
#100	91.6		
#200	90.4		

* (no specification provided)

Soil Description

Atterberg Limits

PL= 25.3 LL= 34.3 PI= 9.0

Coefficients

D_{85}= 0.0170 D_{60}= 0.0048 D_{50}= 0.0037
D_{30}= 0.0020 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= CL AASHTO=

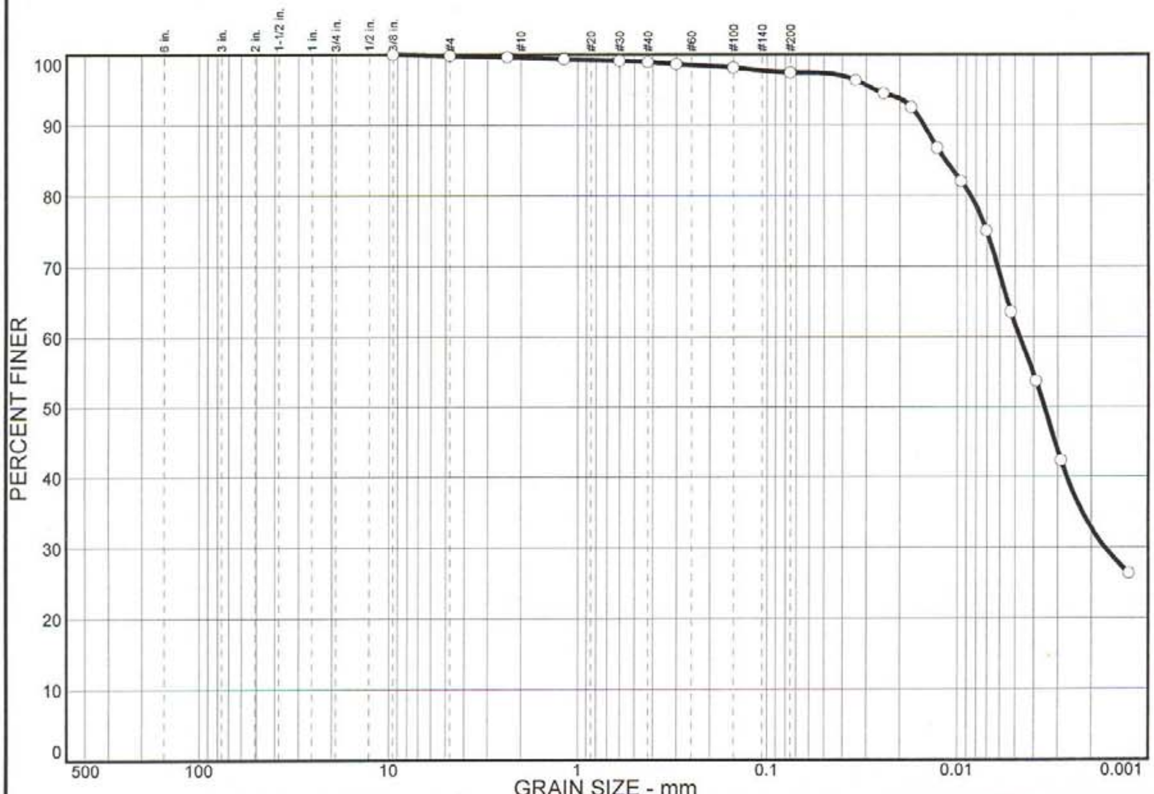
Remarks

Sample No.: 11/13/03 Sampling **Source of Sample:** **Date:** 11/29/03
Location: **Elev./Depth:**

RUTGERS
THE STATE UNIVERSITY
OF NEW JERSEY

Client:
Project: Red Clay
Project No: **Plate**

Particle Size Distribution Report



% COBBLES	% GRAVEL		% SAND			% FINES	
	CRS.	FINE	CRS.	MEDIUM	FINE	SILT	CLAY
0.0	0.0	0.2	0.3	0.6	1.5	35.6	61.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3/8 in.	100.0		
#4	99.8		
#8	99.6		
#16	99.3		
#30	99.1		
#40	98.9		
#50	98.6		
#100	98.1		
#200	97.4		

* (no specification provided)

Soil Description

Atterberg Limits

PL= 21.3 LL= 36.7 PI= 15.4

Coefficients

D_{85}= 0.0115 D_{60}= 0.0047 D_{50}= 0.0035
D_{30}= 0.0017 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= CL AASHTO=

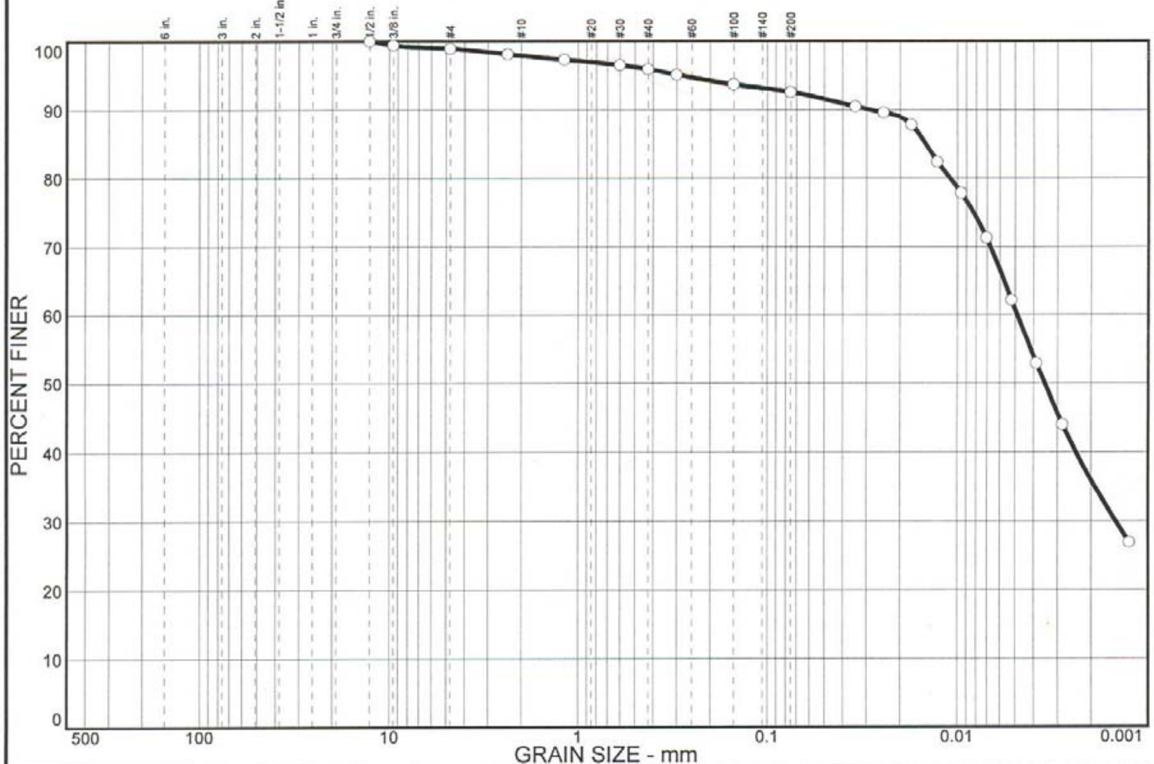
Remarks

Sample No.: 12/04/03 Sampling **Source of Sample:** **Date:** 12/13/03
Location: **Elev./Depth:**

RUTGERS THE STATE UNIVERSITY OF NEW JERSEY

Client:
Project: Red Clay
Project No: **Plate**

Particle Size Distribution Report



% COBBLES	% GRAVEL		% SAND			% FINES	
	CRS.	FINE	CRS.	MEDIUM	FINE	SILT	CLAY
0.0	0.0	1.1	1.0	2.0	3.3	31.8	60.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
1/2 in.	100.0		
3/8 in.	99.4		
#4	98.9		
#8	98.1		
#16	97.3		
#30	96.5		
#40	95.9		
#50	95.1		
#100	93.7		
#200	92.6		

* (no specification provided)

Soil Description

Atterberg Limits

PL= 20.6 LL= 38.3 PI= 17.7

Coefficients

D_{85}= 0.0147 D_{60}= 0.0049 D_{50}= 0.0035
D_{30}= 0.0015 D_{15}= D_{10}=
C_u= C_c=

Classification

USCS= CL AASHTO=

Remarks

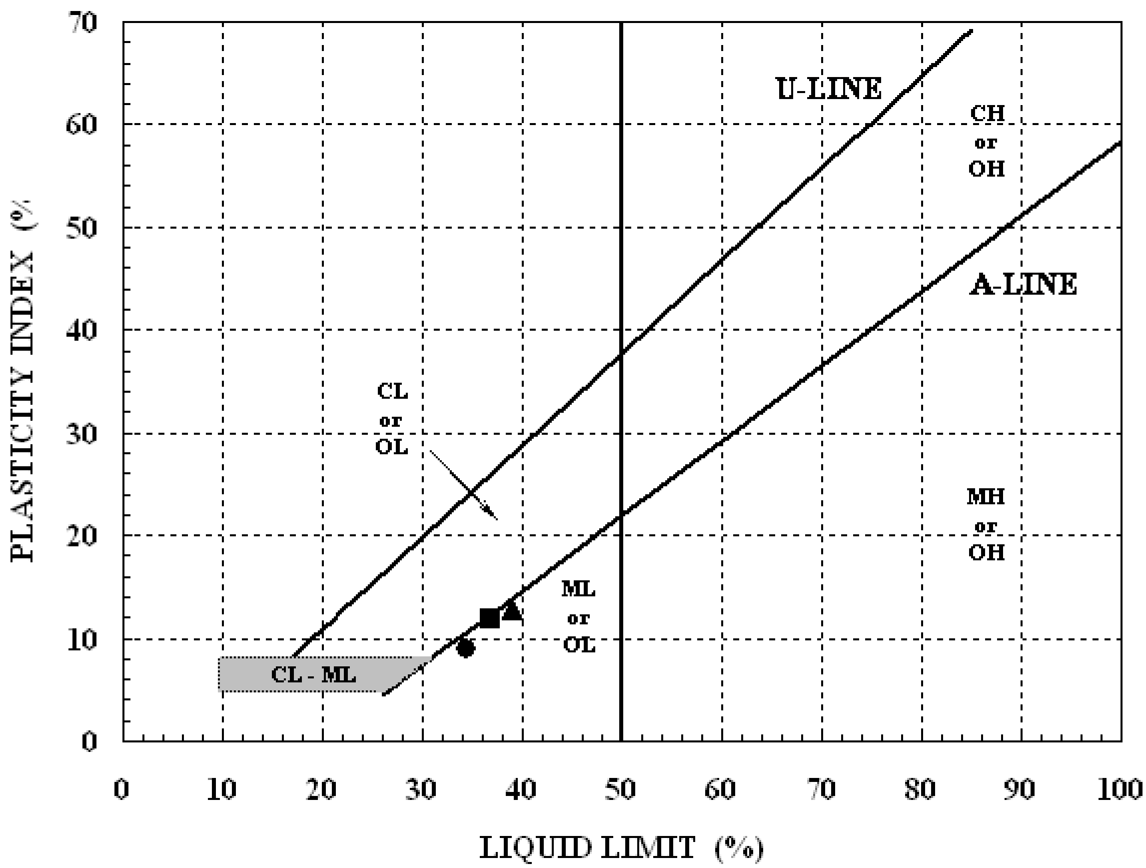
Sample No.: 11/24/03 Sampling **Source of Sample:** **Date:** 14/14/03
Location: **Elev./Depth:**

RUTGERS
THE STATE UNIVERSITY
OF NEW JERSEY

Client:
Project: Red Clay
Project No: **Plate**

Atterberg Limits Results

(ASTM D-4318)



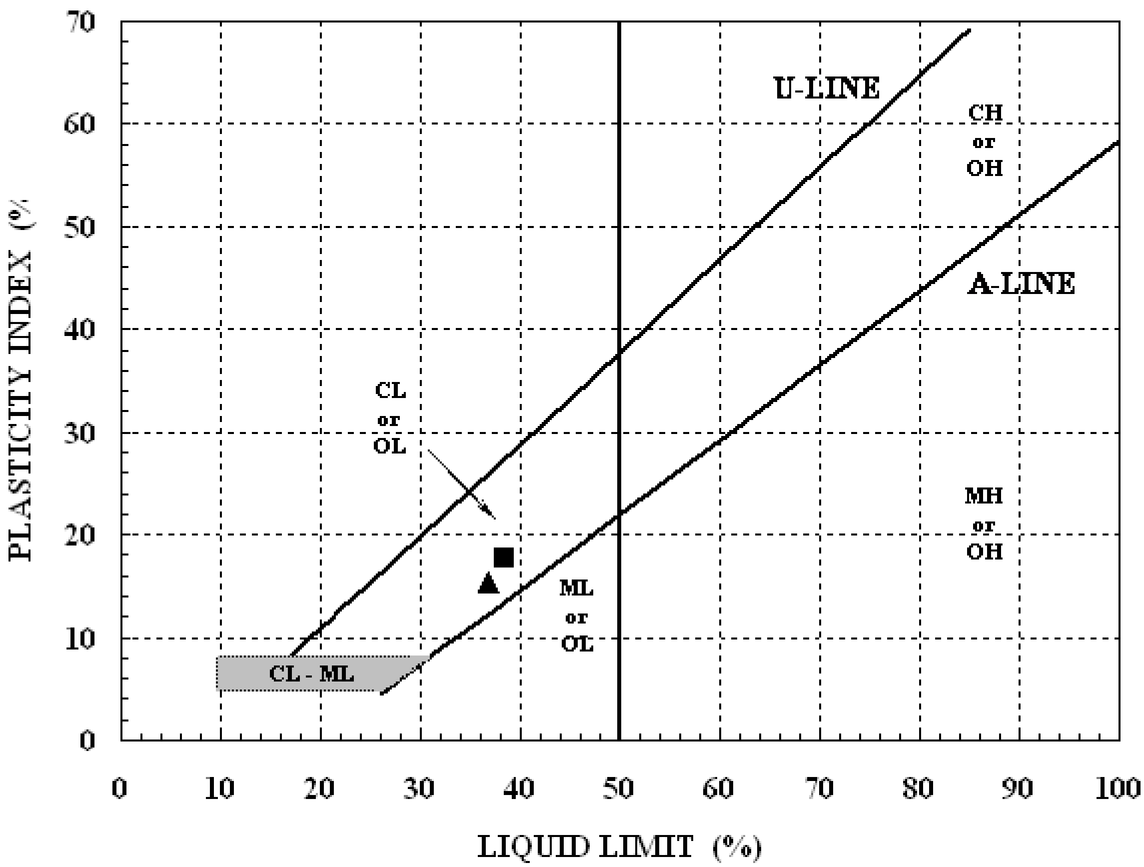
	Sample	LL	PL	PI	% < #200	USCS
■	11/05/03 Sampling	36.8	25.0	11.8	91.5	CL
▲	11/11/03 Sampling	38.9	26.1	12.8	95.0	CL
●	11/13/03 Sampling	34.3	25.3	9.0	90.4	CL

Project: **Red Clay**

Date: **12/01/2003**

Atterberg Limits Results

(ASTM D-4318)



	Sample	LL	PL	PI	% < #200	USCS
■	11/24/03 Sampling	38.3	20.6	17.7	91.5	CL
▲	12/04/03 Sampling	36.7	21.3	15.4	95.0	CL

Project: **Red Clay**
Date: **12/23/2003**

Moisture Content Test
(ASTM D-2216)

Sample	Pan (gr)	Pan + wet soil (gr)	Pan + dry soil (gr)	Moisture Content (%)
S-1	350.39	1491.18	1217.54	31.6

Sample	Pan (gr)	Pan + wet soil (gr)	Pan + dry soil (gr)	Moisture Content (%)
S-2	10.87	85.53	67.23	32.5

Sample	Pan (gr)	Pan + wet soil (gr)	Pan + dry soil (gr)	Moisture Content (%)
S-3	43.03	1169.71	899.56	31.5

Project: Red Clay
Description: 11/05/2003 Sampling
Date: 11/09/2003

Moisture Content Test

(ASTM D-2216)

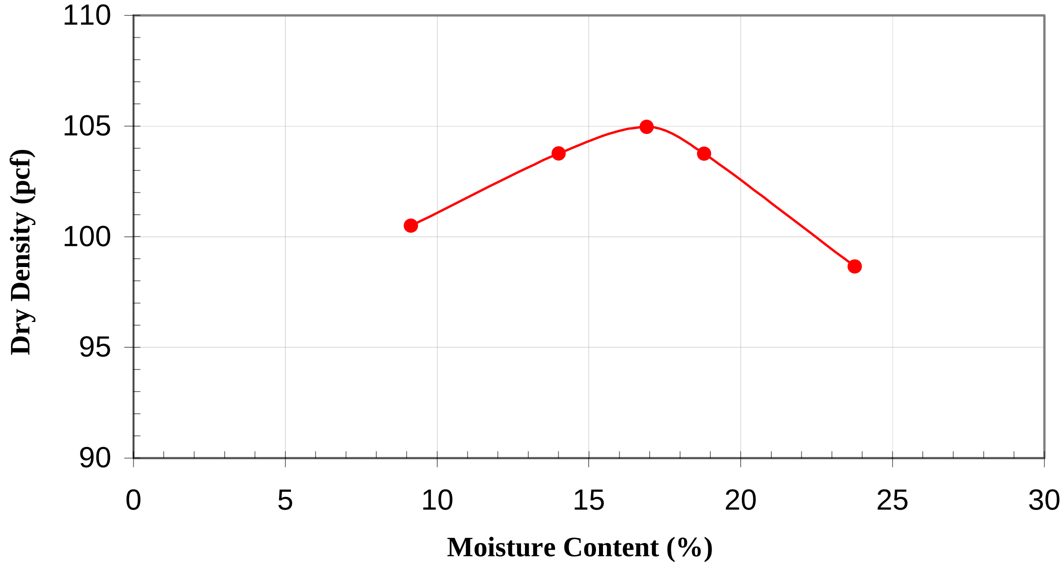
Sample	Pan (gr)	Pan + wet soil (gr)	Pan + dry soil (gr)	Moisture Content (%)
S-1	43.30	340.2	268.41	31.9

Sample	Pan (gr)	Pan + wet soil (gr)	Pan + dry soil (gr)	Moisture Content (%)
S-2	64.88	158.49	136.6	30.5

Project: **Red Clay**
Description: **11/17/2003 Sampling**
Date: **11/25/2003**

Standard Proctor Test

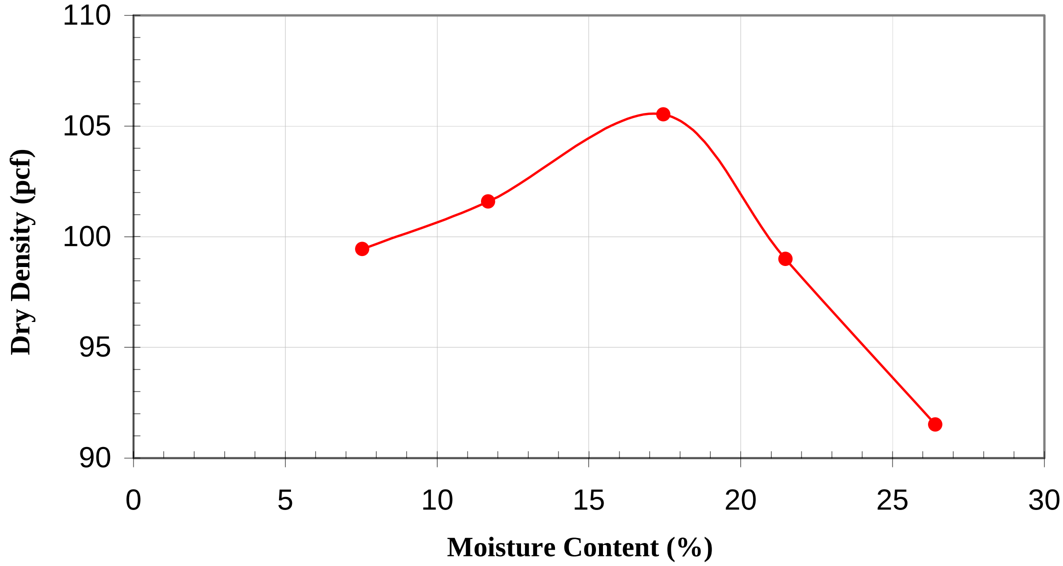
(ASTM D-698)



Optimum Moisture Content (%)	Maximum Dry Density (pcf)
17	**105**

Project: Red Clay
Description: 11/05/2003 Sampling
Date: 11/15/2003

Standard Proctor Test
(ASTM D-698)

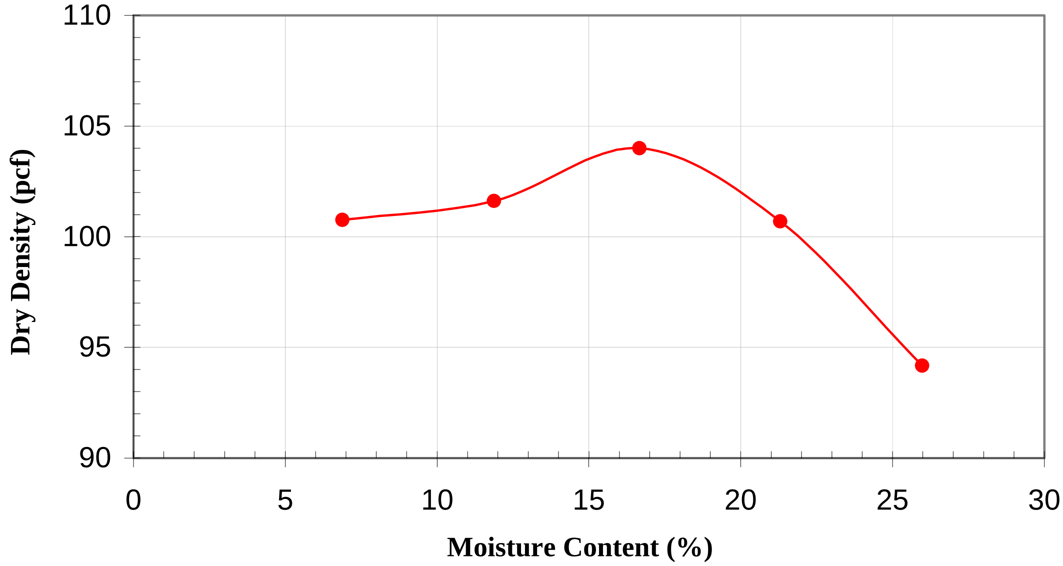


Optimum Moisture Content (%)	Maximum Dry Density (pcf)
17.5	**105.5**

Project: Red Clay
Description: 11/11/2003 Sampling
Date: 11/15/2003

Standard Proctor Test

(ASTM D-698)

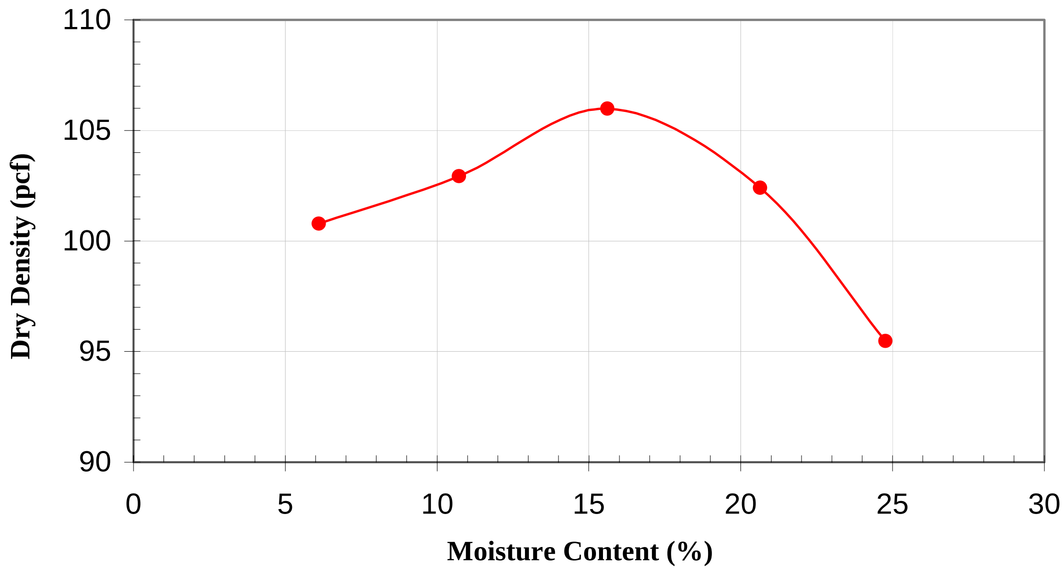


Optimum Moisture Content (%)	Maximum Dry Density (pcf)
16.5	104

Project: Red Clay
Description: 11/13/2003 Sampling
Date: 01/17/2004

Standard Proctor Test

(ASTM D-698)

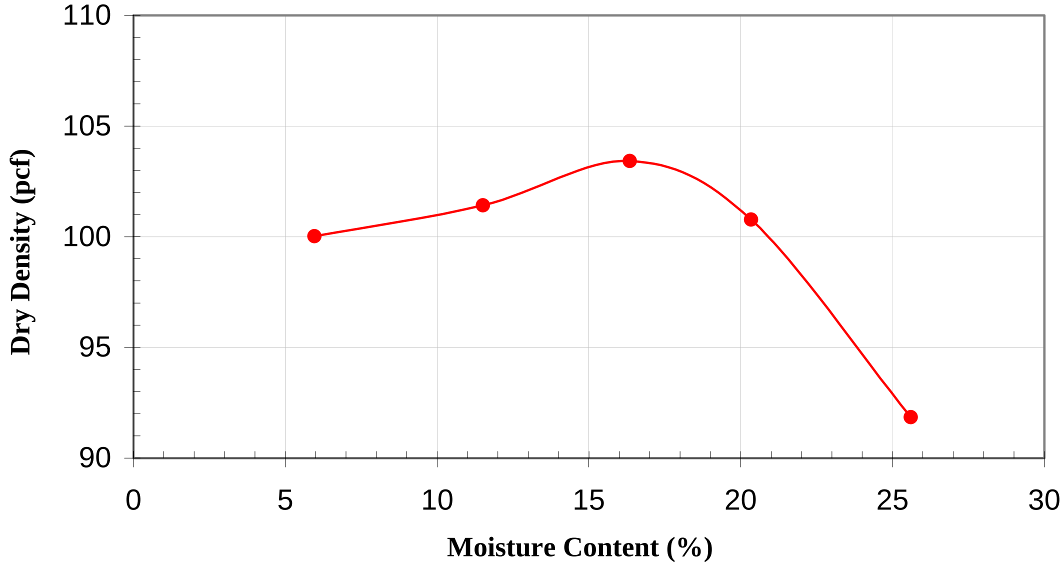


Optimum Moisture Content (%)	Maximum Dry Density (pcf)
15.5	106

Project: Red Clay
Description: 11/24/2003 Sampling
Date: 01/17/2004

Standard Proctor Test

(ASTM D-698)

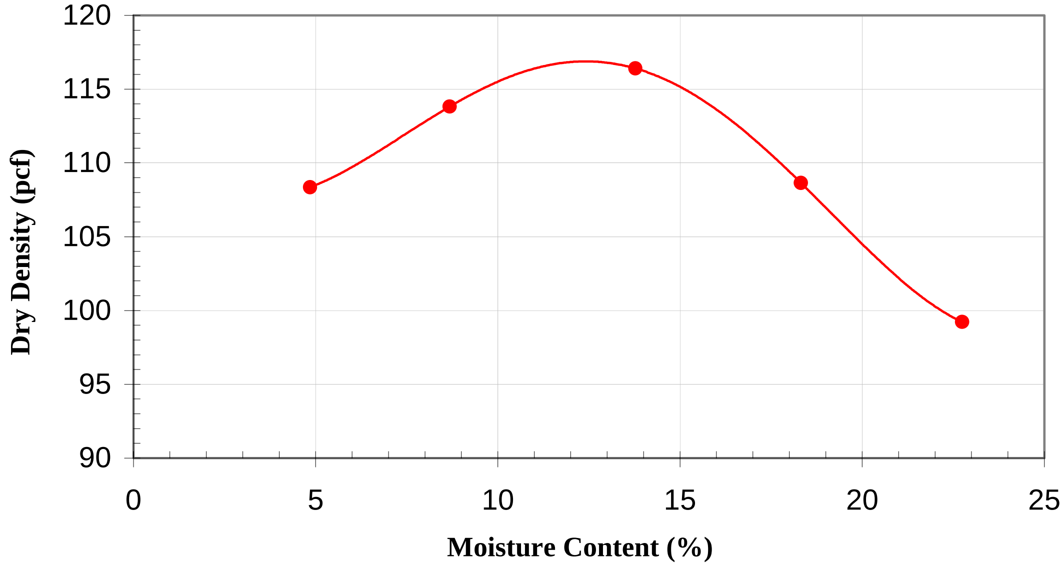


Optimum Moisture Content (%)	Maximum Dry Density (pcf)
16.5	**103.5**

Project: Red Clay
Description: 12/04/2003 Sampling
Date: 02/28/2004

Modified Proctor Test

(ASTM D-1557)

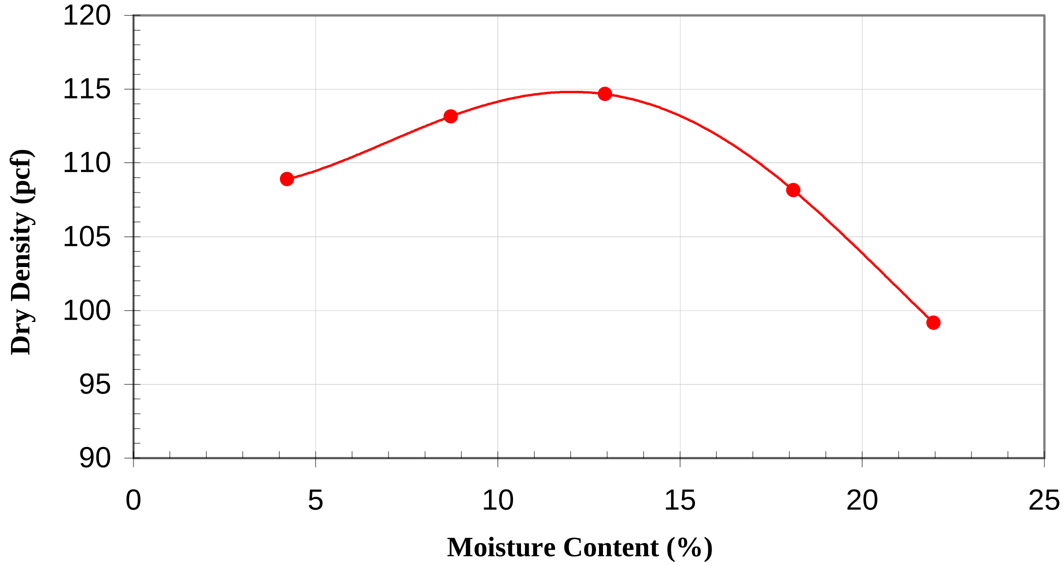


Optimum Moisture Content (%)	Maximum Dry Density (pcf)
12.5	**117**

Project: Red Clay
Description: 11/05/2003 Sampling
Date: 11/15/2003

Modified Proctor Test

(ASTM D-1557)

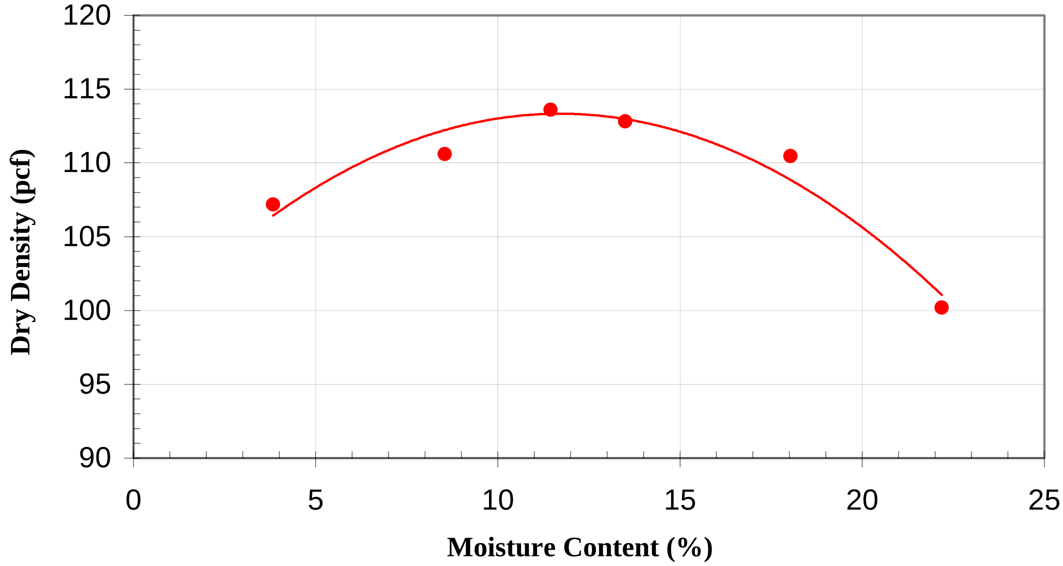


Optimum Moisture Content (%)	Maximum Dry Density (pcf)
12	115

Project: Red Clay
Description: 11/11/2003 Sampling
Date: 11/15/2003

Modified Proctor Test

(ASTM D-1557)

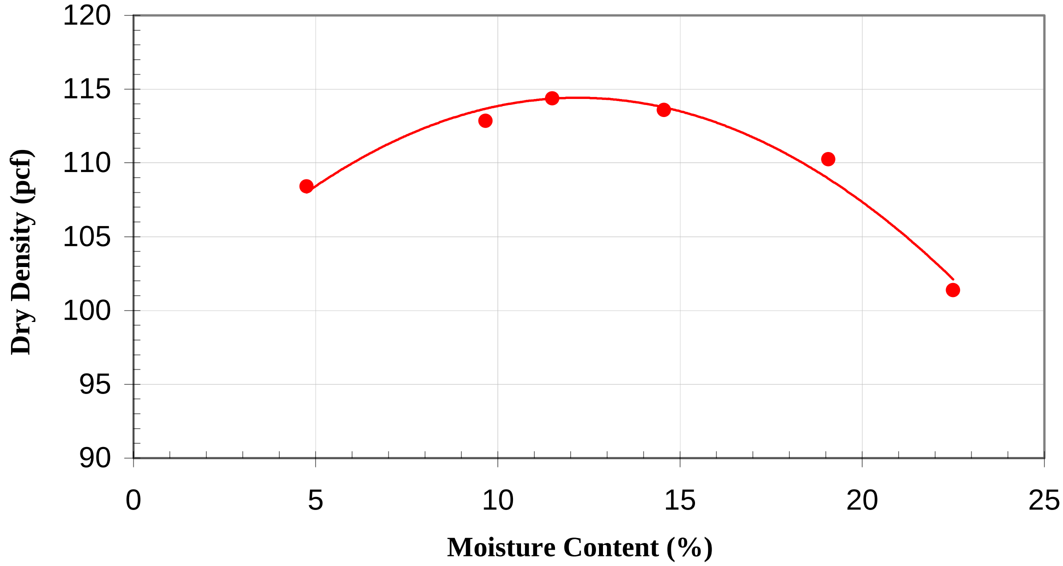


Optimum Moisture Content (%)	**Maximum Dry Density (pcf)**
12	**114.5**

Project: **Red Clay**
Description: **11/13/2003 Sampling**
Date: **1/10/2004**

Modified Proctor Test

(ASTM D-1557)

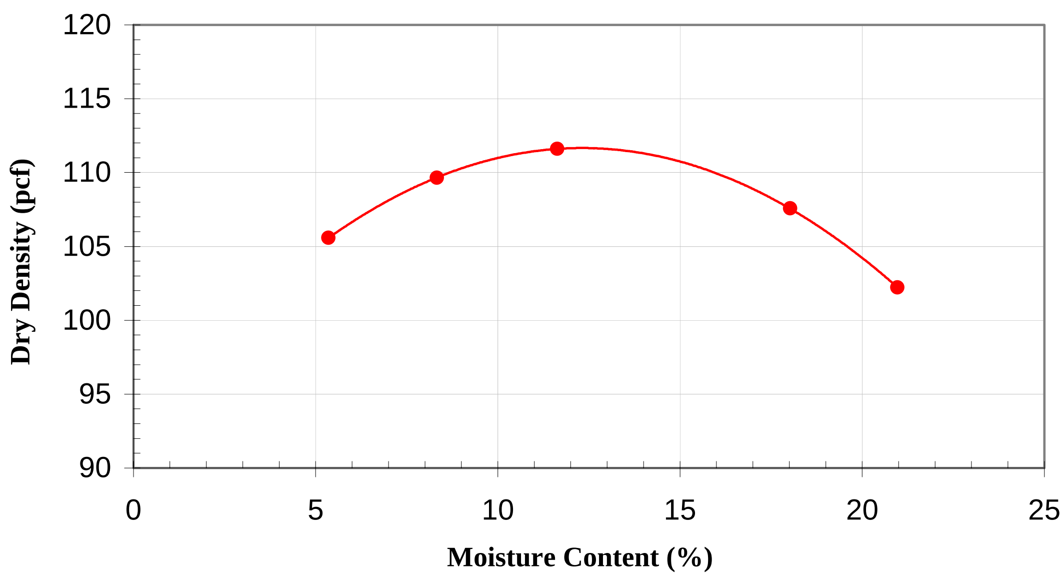


Optimum Moisture Content (%)	Maximum Dry Density (pcf)
12	114.5

Project: Red Clay
Description: 11/24/2003 Sampling
Date: 1/10/2004

Modified Proctor Test

(ASTM D-1557)



Optimum Moisture Content (%)	**Maximum Dry Density (pcf)**
12	**112**

Project: **Red Clay**
Description: **11/24/2003 Sampling**
Date: **2/28/2004**

Specific Gravity Test

(ASTM D-854)

Test No.	**# 1**	
Volume of flask at 20°C	500 ml.	
Method of air removal	VAC.	
Mass of flask	156.26	
Mass of dry soil (M_s)	143.58	
Mass of flask + water (M_{BW})	654.62	
Mass of flask + water + soil (M_{BWS})	746.14	
$M_W = M_S + M_{BW} - M_{BWS}$	52.06	
Temperature (° C)	23.0	
$a = r_t + r_{20}$	0.9993	
$G_S = (a) M_S / M_W$	2.756	
Average	**2.756**	

Project: Red Clay

Description: 11/05/2003 Sampling

Date: 11/29/2003

Specific Gravity Test
(ASTM D-854)

Test No.	# 1	
Volume of flask at 20°C	500 ml.	
Method of air removal	VAC.	
Mass of flask	156.26	
Mass of dry soil (M_s)	140.75	
Mass of flask + water (M_{BW})	654.62	
Mass of flask + water + soil (M_{BWS})	744.46	
$M_W = M_S + M_{BW} - M_{BWS}$	50.91	
Temperature (° C)	19.6	
$a = r_{t} + r_{20}$	1.0001	
$G_S = (a)\ M_S / M_W$	2.765	
Average	**2.765**	

Project: Red Clay
Description: 11/11/2003 Sampling
Date: 11/29/2003

Specific Gravity Test

(ASTM D-854)

Test No.	# 1	
Volume of flask at 20°C	500 ml.	
Method of air removal	VAC.	
Mass of flask	156.26	
Mass of dry soil (M_s)	142.46	
Mass of flask + water (M_{BW})	654.62	
Mass of flask + water + soil (M_{BWS})	745.53	
$M_W = M_S + M_{BW} - M_{BWS}$	51.55	
Temperature (° C)	19.4	
$a = r_{t} + r_{20}$	1.0001	
$G_S = (a)\, M_S / M_W$	2.764	
Average	**2.764**	

Project: Red Clay

Description: 11/13/2003 Sampling

Date: 11/29/2003

Specific Gravity Test

(ASTM D-854)

Test No.	# 1	
Volume of flask at 20°C	500 ml.	
Method of air removal	VAC.	
Mass of flask	165.9	
Mass of dry soil (M_s)	143.58	
Mass of flask + water (M_{BW})	664.61	
Mass of flask + water + soil (M_{BWS})	755.65	
$M_W = M_S + M_{BW} - M_{BWS}$	52.54	
Temperature (° C)	19.9	
$a = r_{t} + r_{20}$	1.0000	
G_S = (a) M_S / M_W	2.733	
Average	**2.733**	

Project: Red Clay

Description: 11/24/2003 Sampling

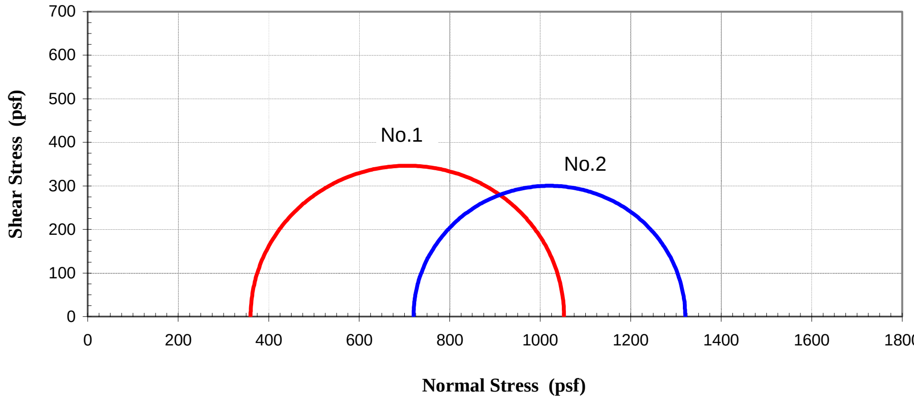
Date: 12/13/2003

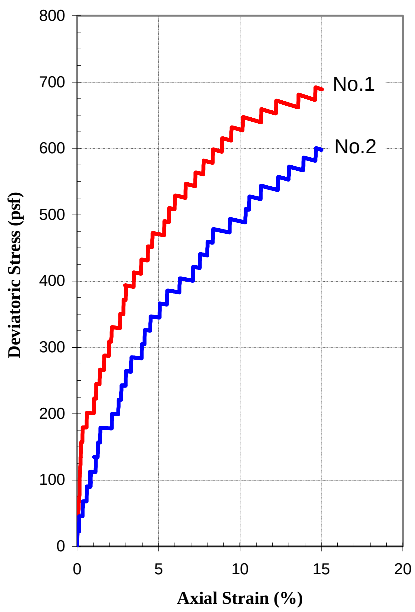
Specific Gravity Test
(ASTM D-854)

Test No.	# 1	
Volume of flask at 20°C	500 ml.	
Method of air removal	VAC.	
Mass of flask	165.9	
Mass of dry soil (M_s)	142.83	
Mass of flask + water (M_{BW})	664.61	
Mass of flask + water + soil (M_{BWS})	755.22	
$M_W = M_S + M_{BW} - M_{BWS}$	52.22	
Temperature (° C)	20.5	
$a = r_{t} + r_{20}$	0.9999	
G_S = (a) M_S / M_W	2.735	
Average	**2.735**	

Project: Red Clay
Description: 12/04/2003 Sampling
Date: 12/13/2003

Triaxial Test (UU)
(ASTM D-2850)

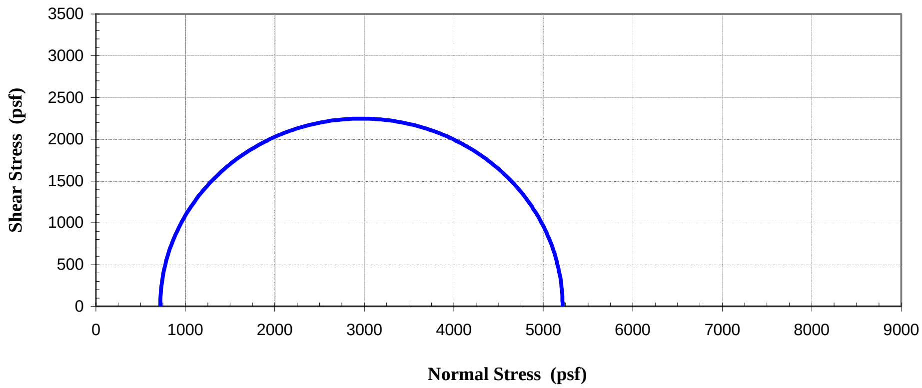


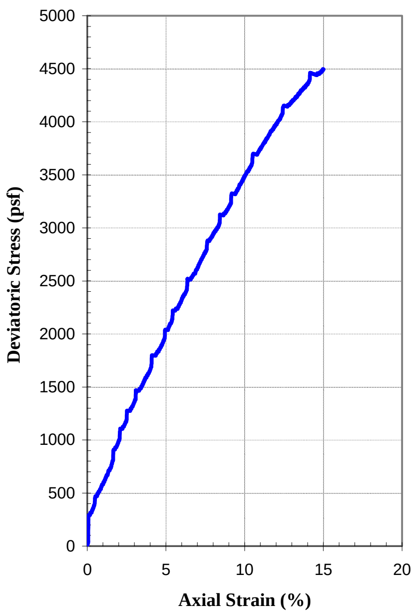


Sample	1	2
Diameter (in)	2.85	2.84
Length (in)	5.76	5.77
Weight (lb)	2.53	2.56
Moisture Content (%)	31.1	31.3
Wet Unit Weight (pcf)	119	121
Dry Unit Weight (pcf)	91	92
Strain rate (%/min)	1	1
Confining Pressure (psi)	2.5	5.0
Dev. Failure Stress (psf)	693	600
Shear Stress (psf)	346	300
Average Shear Stress	***323 psf***	

Project: **Red Clay**
Description: **11/11/2003 Sampling**
Date: **12/12/2003**

Triaxial Test (UU)
(ASTM D-2850)

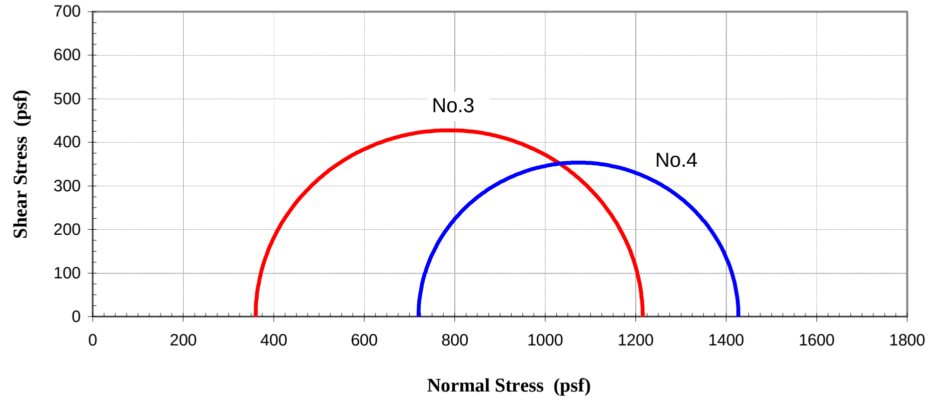


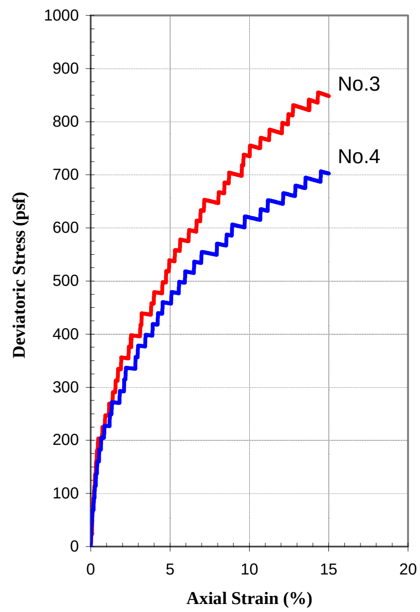


Sample	1	
Diameter (in)	2.85	
Length (in)	5.74	
Weight (lb)	2.64	
Moisture Content (%)	24.1	
Wet Unit Weight (pcf)	125	
Dry Unit Weight (pcf)	101	
Strain rate (%/min)	1	
Confining Pressure (psi)	5.0	
Dev. Failure Stress (psf)	4496	
Shear Stress (psf)	2248	
Average Shear Stress	***2248 psf***	

Project: **Red Clay**
Description: **11/17/2003 Sampling**
Date: **1/12/2004**

Triaxial Test (UU)
(ASTM D-2850)



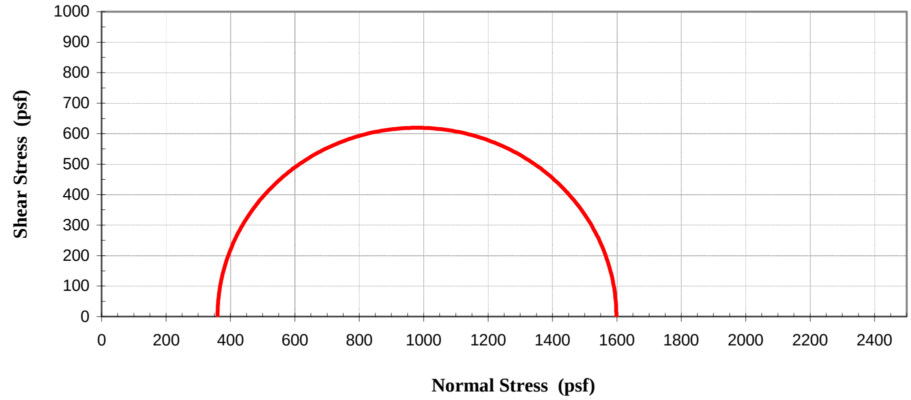


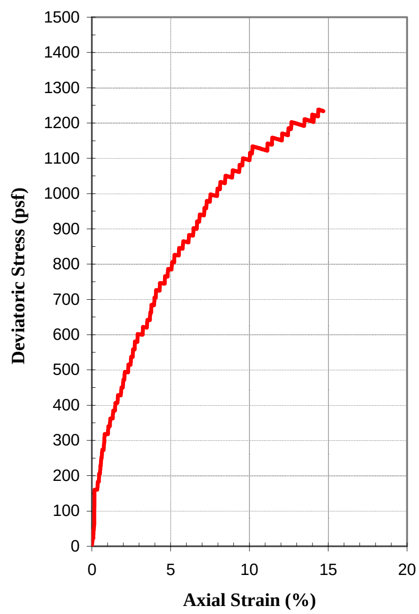
Sample	3	4
Diameter (in)	2.84	2.83
Length (in)	5.71	5.75
Weight (lb)	2.52	2.50
Moisture Content (%)	33.0	31.8
Wet Unit Weight (pcf)	120	120
Dry Unit Weight (pcf)	90	91
Strain rate (%/min)	1	1
Confining Pressure (psi)	2.5	5.0
Dev. Failure Stress (psf)	855	707
Shear Stress (psf)	428	354
Average Shear Stress	***391 psf***	

Project: **Red Clay**
Description: **11/11/2003 Sampling**
Date: **12/12/2003**

Triaxial Test (UU)

(ASTM D-2850)



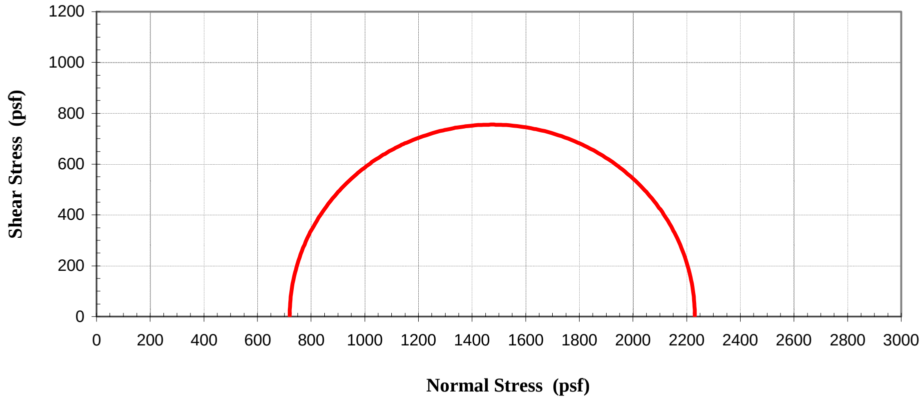


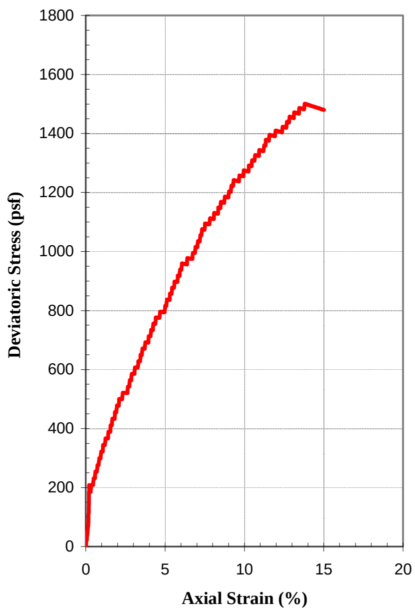
Sample	1	
Diameter (in)	2.83	
Length (in)	5.76	
Weight (lb)	2.56	
Moisture Content (%)	29.5	
Wet Unit Weight (pcf)	122	
Dry Unit Weight (pcf)	95	
Strain rate (%/min)	1	
Confining Pressure (psi)	2.5	
Dev. Failure Stress (psf)	1238	
Shear Stress (psf)	619	
Average Shear Stress	***619 psf***	

Project: **Red Clay**
Description: **11/17/2003 Sampling**
Date: **12/14/2003**

Triaxial Test (UU)

(ASTM D-2850)

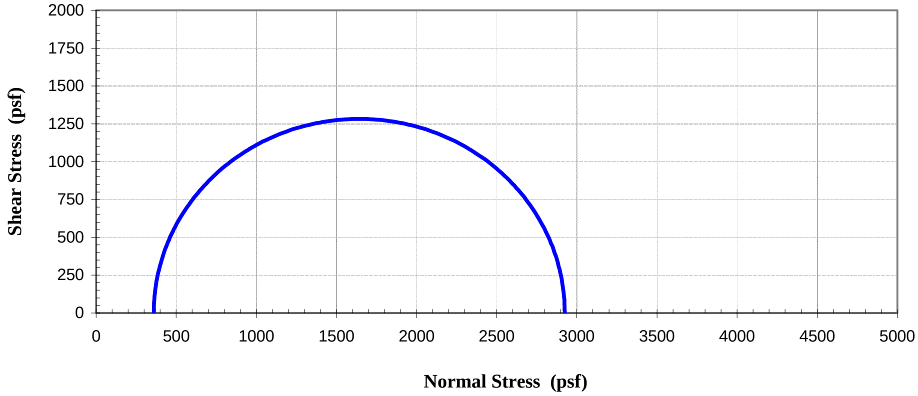


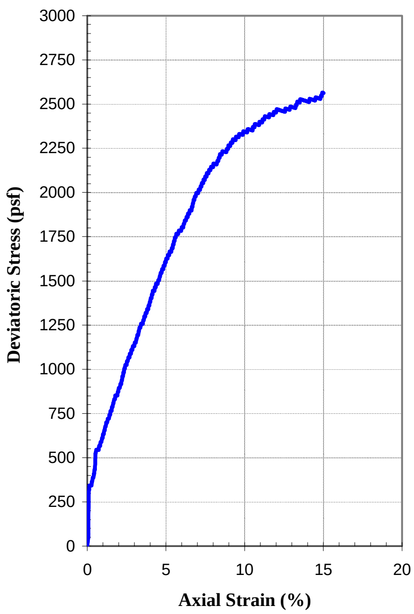


Sample	1	
Diameter (in)	2.81	
Length (in)	5.68	
Weight (lb)	2.56	
Moisture Content (%)	28.2	
Wet Unit Weight (pcf)	126	
Dry Unit Weight (pcf)	98	
Strain rate (%/min)	1	
Confining Pressure (psi)	5.0	
Dev. Failure Stress (psf)	1511	
Shear Stress (psf)	755	
Average Shear Stress	***755 psf***	

Project: **Red Clay**
Description: **11/13/2003 Sampling**
Date: **1/04/2004**

Triaxial Test (UU)
(ASTM D-2850)

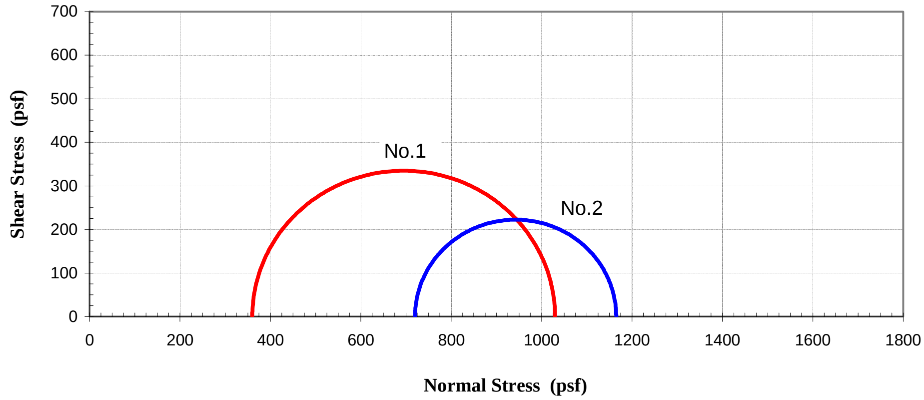


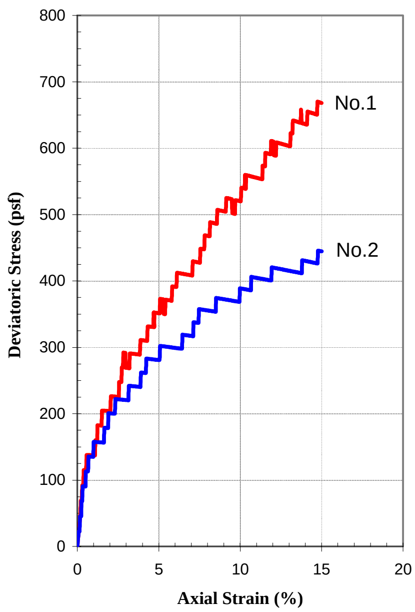


Sample	1	
Diameter (in)	2.83	
Length (in)	5.69	
Weight (lb)	2.57	
Moisture Content (%)	25.3	
Wet Unit Weight (pcf)	124	
Dry Unit Weight (pcf)	99	
Strain rate (%/min)	1	
Confining Pressure (psi)	2.5	
Dev. Failure Stress (psf)	2565	
Shear Stress (psf)	1282	
Average Shear Stress	***1282 psf***	

Project: **Red Clay**
Description: **11/24/2003 Sampling**
Date: **1/12/2004**

Triaxial Test (UU)
(ASTM D-2850)

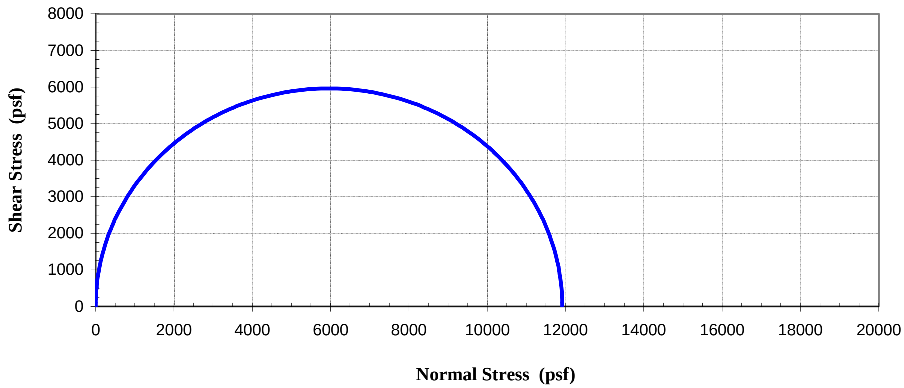


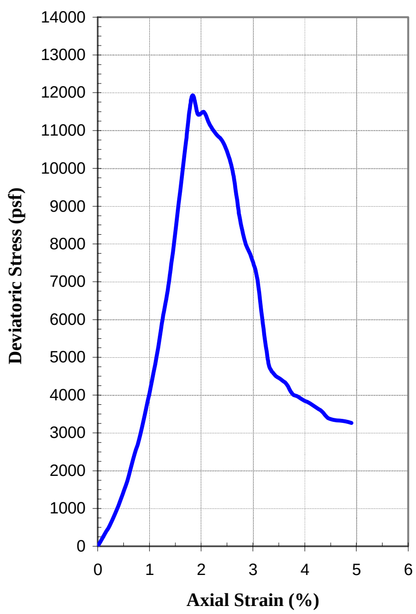


Sample	1	2
Diameter (in)	2.82	2.84
Length (in)	5.75	5.72
Weight (lb)	2.52	2.50
Moisture Content (%)	31.6	31.5
Wet Unit Weight (pcf)	122	119
Dry Unit Weight (pcf)	92	91
Strain rate (%/min)	1	1
Confining Pressure (psi)	2.5	5.0
Dev. Failure Stress (psf)	670	445
Shear Stress (psf)	335	222
Average Shear Stress	***279 psf***	

Project: **Red Clay**
Description: **11/05/2003 Sampling**
Date: **11/12/2003**

Unconfined Compression Test
(ASTM D-2166)

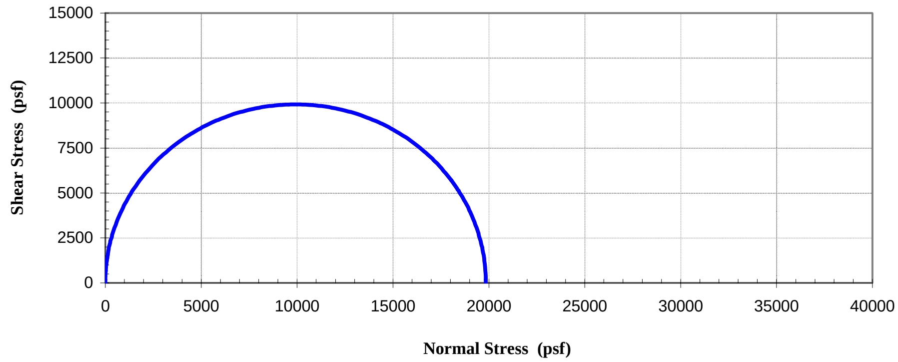


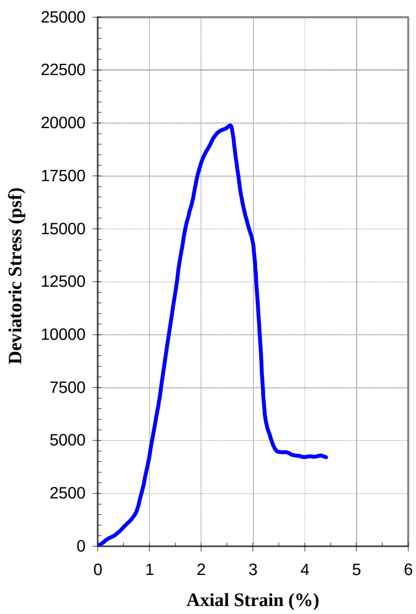


Sample	1	
Diameter (in)	2.18	
Length (in)	4.39	
Weight (lb)	1.13	
Moisture Content (%)	8.3	
Wet Unit Weight (pcf)	119	
Dry Unit Weight (pcf)	110	
Strain rate (%/min)	1	
Length / Diameter ratio	2.0	
Failure Stress (psf)	11918	
Shear Stress (psf)	5959	
Average Shear Stress	***5959 psf***	

Project: **Red Clay**
Compaction: **Modified Proctor**
Moisture: **8 %**

Unconfined Compression Test
(ASTM D-2166)



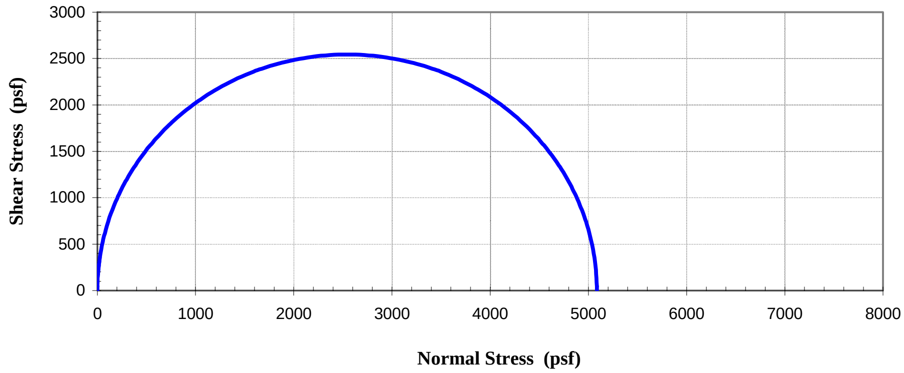


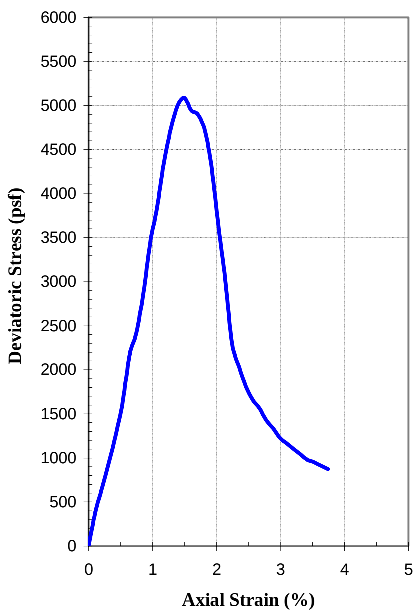
Sample	1	
Diameter (in)	2.33	
Length (in)	4.65	
Weight (lb)	1.42	
Moisture Content (%)	11.6	
Wet Unit Weight (pcf)	125	
Dry Unit Weight (pcf)	112	
Strain rate (%/min)	1	
Length / Diameter ratio	2.0	
Failure Stress (psf)	19844	
Shear Stress (psf)	9922	
Average Shear Stress	***9922 psf***	

Project: **Red Clay**
Compaction: **Modified Proctor**
Moisture: **12 %**

Unconfined Compression Test

(ASTM D-2166)

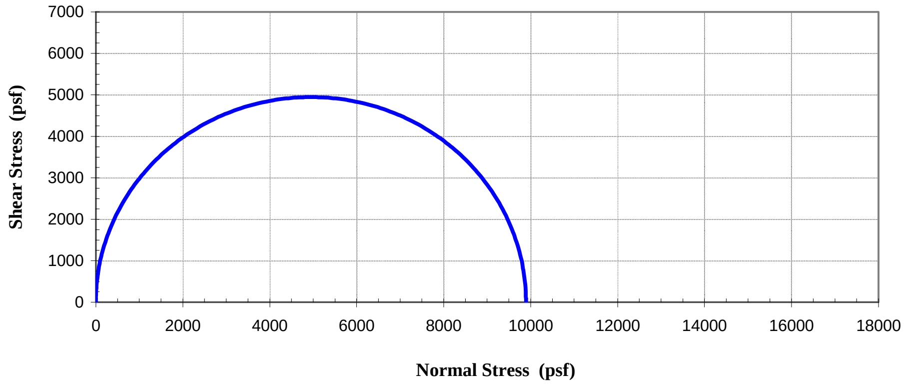


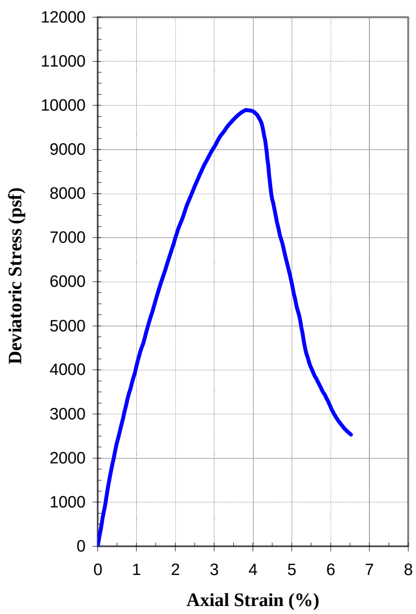


Sample	1	
Diameter (in)	2.25	
Length (in)	4.68	
Weight (lb)	1.22	
Moisture Content (%)	11.5	
Wet Unit Weight (pcf)	113	
Dry Unit Weight (pcf)	101	
Strain rate (%/min)	1	
Length / Diameter ratio	2.1	
Failure Stress (psf)	5086	
Shear Stress (psf)	2543	
Average Shear Stress	***2543 psf***	

Project: **Red Clay**
Compaction: **Standard Proctor**
Moisture: **12 %**

Unconfined Compression Test
(ASTM D-2166)

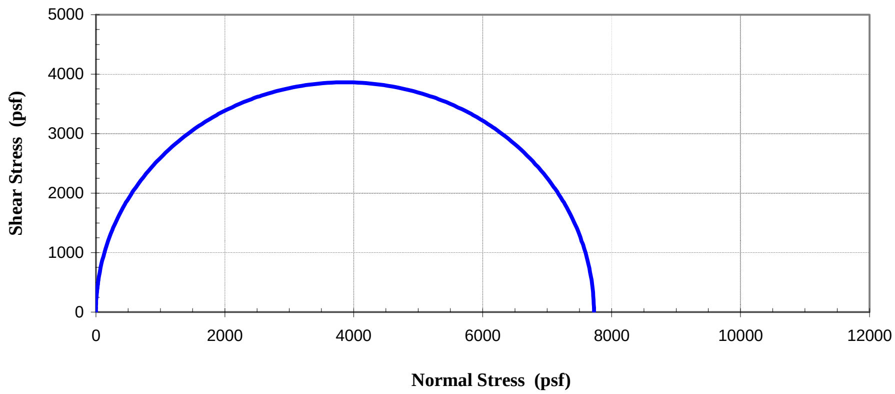


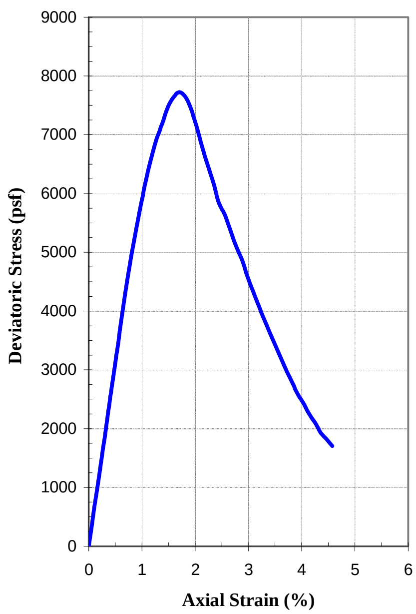


Sample	1	
Diameter (in)	2.31	
Length (in)	4.60	
Weight (lb)	1.41	
Moisture Content (%)	18.0	
Wet Unit Weight (pcf)	127	
Dry Unit Weight (pcf)	108	
Strain rate (%/min)	1	
Length / Diameter ratio	2.0	
Failure Stress (psf)	9894	
Shear Stress (psf)	4947	
Average Shear Stress	***4947 psf***	

Project: **Red Clay**
Compaction: **Modified Proctor**
Moisture: **17 %**

Unconfined Compression Test
(ASTM D-2166)

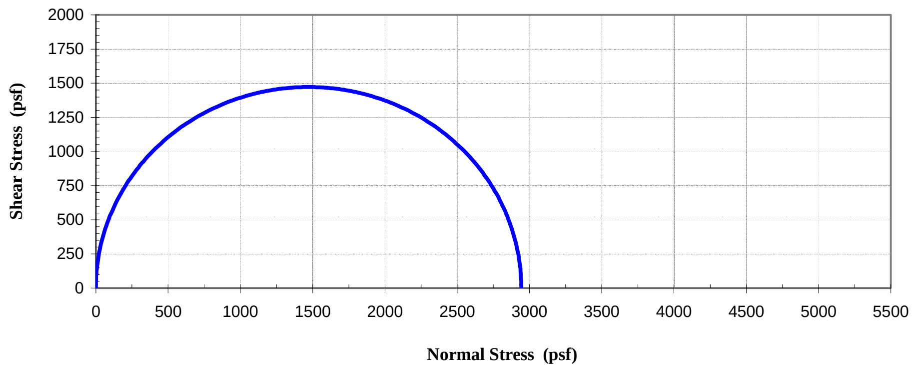


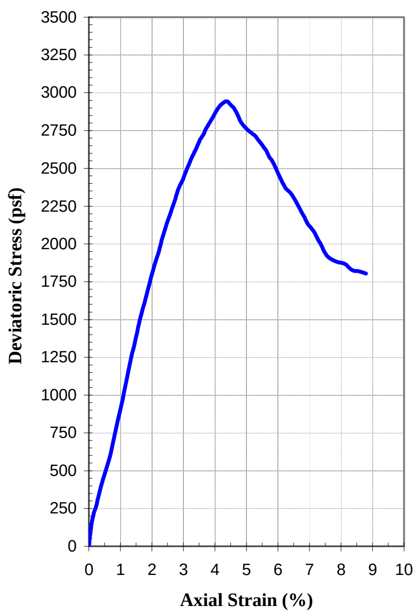


Sample	1	
Diameter (in)	2.35	
Length (in)	4.70	
Weight (lb)	1.41	
Moisture Content (%)	16.4	
Wet Unit Weight (pcf)	120	
Dry Unit Weight (pcf)	103	
Strain rate (%/min)	1	
Length / Diameter ratio	2.0	
Failure Stress (psf)	7726	
Shear Stress (psf)	3863	
Average Shear Stress	***3863 psf***	

Project: **Red Clay**
Compaction: **Standard Proctor**
Moisture: **17 %**

Unconfined Compression Test
(ASTM D-2166)

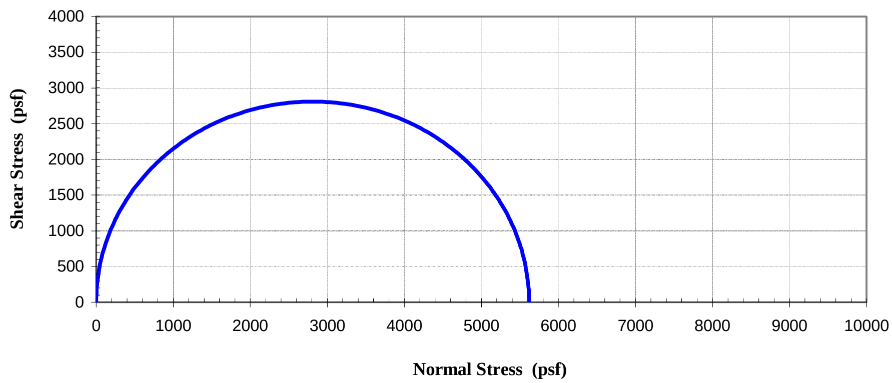


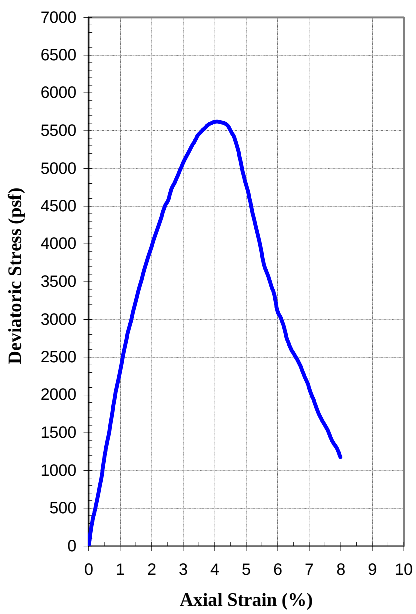


Sample	1	
Diameter (in)	2.26	
Length (in)	4.55	
Weight (lb)	1.30	
Moisture Content (%)	21.0	
Wet Unit Weight (pcf)	124	
Dry Unit Weight (pcf)	102	
Strain rate (%/min)	1	
Length / Diameter ratio	2.0	
Failure Stress (psf)	2944	
Shear Stress (psf)	1472	
Average Shear Stress	***1472 psf***	

Project: **Red Clay**
Compaction: **Modified Proctor**
Moisture: **21 %**

Unconfined Compression Test
(ASTM D-2166)

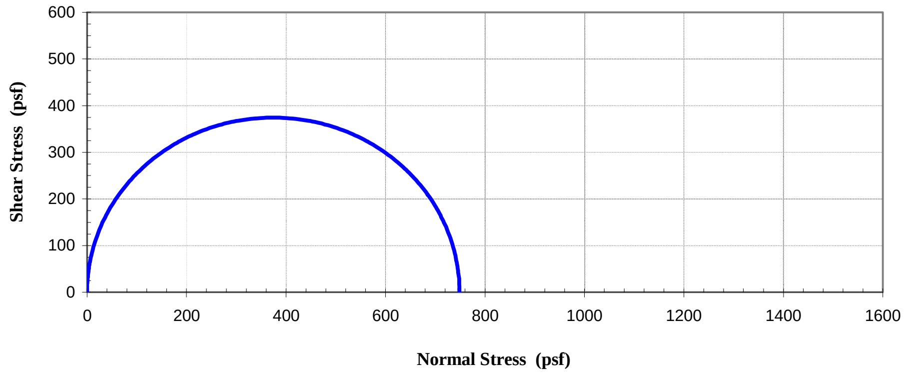


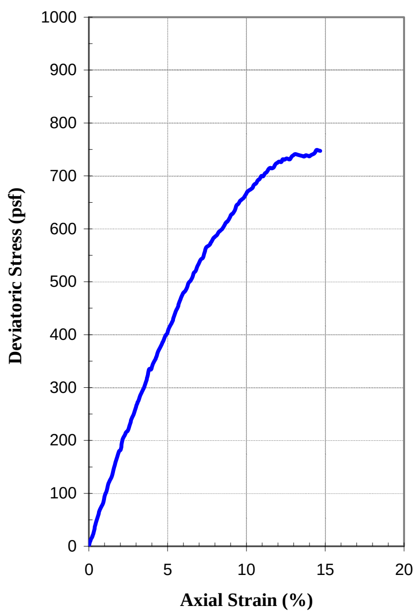


Sample	1	
Diameter (in)	2.32	
Length (in)	4.76	
Weight (lb)	1.41	
Moisture Content (%)	20.3	
Wet Unit Weight (pcf)	121	
Dry Unit Weight (pcf)	101	
Strain rate (%/min)	1	
Length / Diameter ratio	2.0	
Failure Stress (psf)	5618	
Shear Stress (psf)	2809	
Average Shear Stress	***2809 psf***	

Project: **Red Clay**
Compaction: **Standard Proctor**
Moisture: **21 %**

Unconfined Compression Test
(ASTM D-2166)

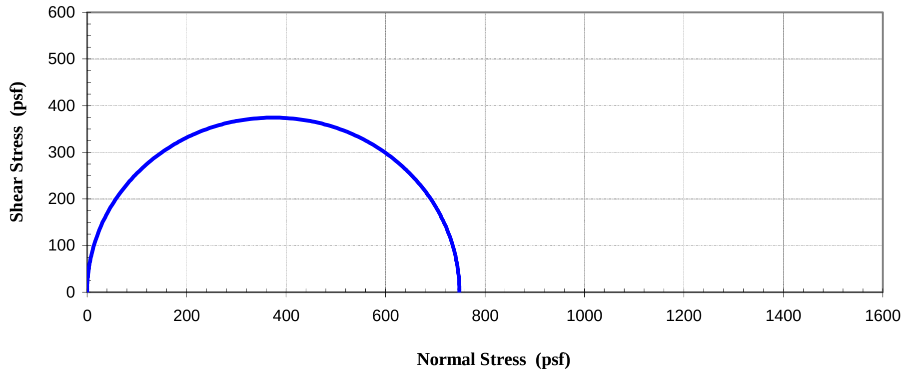


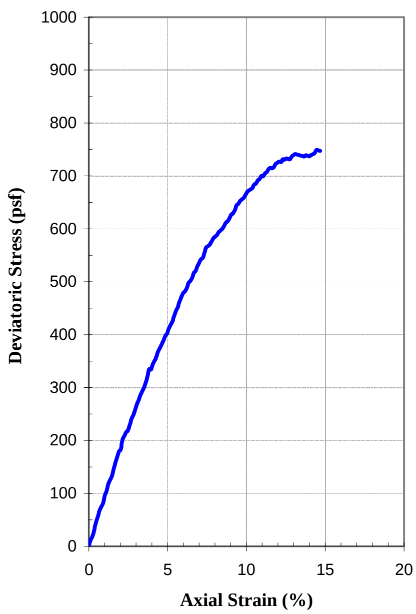


Sample	1	
Diameter (in)	2.21	
Length (in)	4.43	
Weight (lb)	1.14	
Moisture Content (%)	25.6	
Wet Unit Weight (pcf)	115	
Dry Unit Weight (pcf)	92	
Strain rate (%/min)	1	
Length / Diameter ratio	2.0	
Failure Stress (psf)	748	
Shear Stress (psf)	374	
Average Shear Stress	***374 psf***	

Project: **Red Clay**
Compaction: **Standard Proctor**
Moisture: **26 %**

Unconfined Compression Test
(ASTM D-2166)





Sample	1	
Diameter (in)	2.21	
Length (in)	4.43	
Weight (lb)	1.14	
Moisture Content (%)	25.6	
Wet Unit Weight (pcf)	115	
Dry Unit Weight (pcf)	92	
Strain rate (%/min)	1	
Length / Diameter ratio	2.0	
Failure Stress (psf)	748	
Shear Stress (psf)	374	
Average Shear Stress	***374 psf***	

Project: **Red Clay**
Compaction: **Standard Proctor**
Moisture: **26 %**

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/11/03 (Sample #1) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	6.14
Diameter (cm)	7.19
Moisture Content (%)	32.9
Dry Density (pcf)	89.4

Test Parameters					
Cell Pressure (psi):	82.1	Back Pressure (psi):	80	Hydraulic Gradient:	13.75
Influent Pressure (psi):	81.2	Effluent Pressure (psi):	80	Degree of Saturation:	100

Final Hydraulic Conductivity (corrected to 20^{o}C)

5.60E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/11/03 (Sample #2) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.81
Diameter (cm)	7.27
Moisture Content (%)	26.4
Dry Density (pcf)	100.3

Test Parameters					
Cell Pressure (psi):	84.5	Back Pressure (psi):	82	Hydraulic Gradient:	12.10
Influent Pressure (psi):	83	Effluent Pressure (psi):	82	Degree of Saturation:	99

Final Hydraulic Conductivity (corrected to 20^{o}C)

1.52E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project

Client:

Project Number:

Sample Identification: 11/11/03 (Sample #3)

Depth (ft):

Sample Description (Visual):

Test Method: ASTM D5084 Constant Head

Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	4.99
Diameter (cm)	7.45
Moisture Content (%)	30.3
Dry Density (pcf)	90.8

Test Parameters					
Cell Pressure (psi):	80.5	Back Pressure (psi):	78	Hydraulic Gradient:	14.10
Influent Pressure (psi):	79	Effluent Pressure (psi):	78	Degree of Saturation:	99

Final Hydraulic Conductivity (corrected to 20^{o}C)

3.62E-08 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/11/03 (Sample #4) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.12
Diameter (cm)	7.16
Moisture Content (%)	26.8
Dry Density (pcf)	96.2

Test Parameters

Cell Pressure (psi):	82.3	Back Pressure (psi):	79.8	Hydraulic Gradient:	16.48
Influent Pressure (psi):	81	Effluent Pressure (psi):	79.8	Degree of Saturation:	99

Final Hydraulic Conductivity (corrected to 20^{o}C)

1.80E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/13/03 (Sample #1) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.21
Diameter (cm)	7.15
Moisture Content (%)	32.3
Dry Density (pcf)	92.6

Test Parameters					
Cell Pressure (psi):	79	Back Pressure (psi):	75	Hydraulic Gradient:	27.02
Influent Pressure (psi):	77.6	Effluent Pressure (psi):	75.6	Degree of Saturation:	99.1

Final Hydraulic Conductivity (corrected to 20^{o}C)

2.65E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project   Client:
Project Number:

Sample Identification: 11/13/03 (Sample #2)   Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.72
Diameter (cm)	7.01
Moisture Content (%)	28.6
Dry Density (pcf)	96.3

Test Parameters					
Cell Pressure (psi):	79.1	Back Pressure (psi):	75	Hydraulic Gradient:	24.60
Influent Pressure (psi):	77.6	Effluent Pressure (psi):	75.6	Degree of Saturation:	99.1

Final Hydraulic Conductivity (corrected to 20^{o}C)
1.35E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project   Client:
Project Number:

Sample Identification: 11/17/03 (Sample #1)   Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.46
Diameter (cm)	7.14
Moisture Content (%)	31.9
Dry Density (pcf)	95.4

Test Parameters

Cell Pressure (psi):	79	Back Pressure (psi):	76.9	Hydraulic Gradient:	12.89
Influent Pressure (psi):	77.9	Effluent Pressure (psi):	76.9	Degree of Saturation:	98

Final Hydraulic Conductivity (corrected to 20^{o}C)

1.66E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/17/03 (Sample #2) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.28
Diameter (cm)	7.18
Moisture Content (%)	30.5
Dry Density (pcf)	99.4

Test Parameters					
Cell Pressure (psi):	80.9	Back Pressure (psi):	78	Hydraulic Gradient:	17.32
Influent Pressure (psi):	79.3	Effluent Pressure (psi):	78	Degree of Saturation:	99

Final Hydraulic Conductivity (corrected to 20^{o}C)
2.62E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/24/03 (Sample#1) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	6.27
Diameter (cm)	7.16
Moisture Content (%)	29.6
Dry Density (pcf)	94.9

Test Parameters					
Cell Pressure (psi):	74.3	Back Pressure (psi):	70.8	Hydraulic Gradient:	11.20
Influent Pressure (psi):	71.8	Effluent Pressure (psi):	70.8	Degree of Saturation:	98

Final Hydraulic Conductivity (corrected to 20^{o}C)

8.40E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 12/04/03 (Sample #1) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.92
Diameter (cm)	7.21
Moisture Content (%)	26.9
Dry Density (pcf)	100.5

Test Parameters					
Cell Pressure (psi):	78.7	Back Pressure (psi):	73.6	Hydraulic Gradient:	13.10
Influent Pressure (psi):	74.7	Effluent Pressure (psi):	73.6	Degree of Saturation:	99

Final Hydraulic Conductivity (corrected to 20^{o}C)

5.10E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/05/03 (Sample #1) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	7.26
Diameter (cm)	7.28
Moisture Content (%)	31.9
Dry Density (pcf)	87.4

Test Parameters

Cell Pressure (psi):	72.3	Back Pressure (psi):	69.8	Hydraulic Gradient:	4.84
Influent Pressure (psi):	70.3	Effluent Pressure (psi):	69.8	Degree of Saturation:	99

Final Hydraulic Conductivity (corrected to 20^{o}C)

2.12E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/24/03 (Sample#2) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.92
Diameter (cm)	7.16
Moisture Content (%)	27.5
Dry Density (pcf)	98.5

Test Parameters					
Cell Pressure (psi):	78.4	Back Pressure (psi):	75.9	Hydraulic Gradient:	13.05
Influent Pressure (psi):	77.0	Effluent Pressure (psi):	75.9	Degree of Saturation:	99

Final Hydraulic Conductivity (corrected to 20^{o}C)

1.11E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 12/04/03 (Sample #2) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	6.17
Diameter (cm)	7.19
Moisture Content (%)	24.9
Dry Density (pcf)	103.3

Test Parameters					
Cell Pressure (psi):	75.0	Back Pressure (psi):	71.4	Hydraulic Gradient:	10.25
Influent Pressure (psi):	72.3	Effluent Pressure (psi):	71.4	Degree of Saturation:	95

Final Hydraulic Conductivity (corrected to 20^{o}C)

6.90E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project

Client:

Project Number:

Sample Identification: 11/05/03 (Sample #2)

Depth (ft):

Sample Description (Visual):

Test Method: ASTM D5084 Constant Head

Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	6.20
Diameter (cm)	7.26
Moisture Content (%)	31.5
Dry Density (pcf)	84.9

Test Parameters					
Cell Pressure (psi):	83.3	Back Pressure (psi):	80.7	Hydraulic Gradient:	5.67
Influent Pressure (psi):	81.2	Effluent Pressure (psi):	80.7	Degree of Saturation:	96

Final Hydraulic Conductivity (corrected to 20^{o}C)

5.27E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project   Client:
Project Number:

Sample Identification: 11/24/03 (Sample#3)   Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.46
Diameter (cm)	7.21
Moisture Content (%)	25.2
Dry Density (pcf)	99.8

Test Parameters					
Cell Pressure (psi):	78.3	Back Pressure (psi):	75.1	Hydraulic Gradient:	12.87
Influent Pressure (psi):	76.1	Effluent Pressure (psi):	75.1	Degree of Saturation:	95

Final Hydraulic Conductivity (corrected to 20^{o}C)

1.19E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project   Client:
Project Number:

Sample Identification: 12/04/03 (Sample #3)   Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.69
Diameter (cm)	7.21
Moisture Content (%)	25.2
Dry Density (pcf)	103.1

Test Parameters					
Cell Pressure (psi):	78.3	Back Pressure (psi):	75.1	Hydraulic Gradient:	12.36
Influent Pressure (psi):	76.1	Effluent Pressure (psi):	75.1	Degree of Saturation:	95

Final Hydraulic Conductivity (corrected to 20^{o}C)

5.47E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project   Client:
Project Number:

Sample Identification: 11/13/03 (Sample #3)   Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.26
Diameter (cm)	6.99
Moisture Content (%)	31.3
Dry Density (pcf)	93.5

Test Parameters					
Cell Pressure (psi):	76.1	Back Pressure (psi):	73.0	Hydraulic Gradient:	12.06
Influent Pressure (psi):	73.9	Effluent Pressure (psi):	73.0	Degree of Saturation:	96

Final Hydraulic Conductivity (corrected to 20^{o}C)

3.38E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project   Client:
Project Number:

Sample Identification: 11/17/03 (Sample #4)   Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	6.22
Diameter (cm)	7.16
Moisture Content (%)	28.9
Dry Density (pcf)	93.6

Test Parameters					
Cell Pressure (psi):	76.6	Back Pressure (psi):	73.0	Hydraulic Gradient:	11.31
Influent Pressure (psi):	74.0	Effluent Pressure (psi):	73.0	Degree of Saturation:	100

Final Hydraulic Conductivity (corrected to 20^{o}C)

1.39E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: 11/24/03 (Sample #4) Depth (ft):
Sample Description (Visual):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.26
Diameter (cm)	6.99
Moisture Content (%)	31.3
Dry Density (pcf)	93.5

Test Parameters					
Cell Pressure (psi):	76.1	Back Pressure (psi):	73.0	Hydraulic Gradient:	12.06
Influent Pressure (psi):	73.9	Effluent Pressure (psi):	73.0	Degree of Saturation:	96

Final Hydraulic Conductivity (corrected to 20^{o}C)

3.38E-06 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project | Client:
Project Number:

Sample Identification: Standard Compaction | Depth (ft):
w= 12%

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	7.45
Diameter (cm)	7.13
Moisture Content (%)	13.3
Dry Density (pcf)	101.3

Test Parameters					
Cell Pressure (psi):	76.6	Back Pressure (psi):	70	Hydraulic Gradient:	18.87
Influent Pressure (psi):	75.3	Effluent Pressure (psi):	73.3	Degree of Saturation:	98

Final Hydraulic Conductivity (corrected to 20^{o}C)
1.45E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project
Client:
Project Number:

Sample Identification: Standard Compaction
w= 17%
Depth (ft):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	6.05
Diameter (cm)	7.14
Moisture Content (%)	16.4
Dry Density (pcf)	102.6

Test Parameters

Cell Pressure (psi):	74.3	Back Pressure (psi):	70.6	Hydraulic Gradient:	24.43
Influent Pressure (psi):	72.7	Effluent Pressure (psi):	70.6	Degree of Saturation:	100

Final Hydraulic Conductivity (corrected to 20^{o}C)

1.29E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project

Client:

Project Number:

Sample Identification: Standard Compaction
w= 18%

Depth (ft):

Test Method: ASTM D5084 Constant Head

Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.52
Diameter (cm)	7.02
Moisture Content (%)	18.9
Dry Density (pcf)	105.6

Test Parameters					
Cell Pressure (psi):	74.6	Back Pressure (psi):	70	Hydraulic Gradient:	25.48
Influent Pressure (psi):	73	Effluent Pressure (psi):	71	Degree of Saturation:	96

Final Hydraulic Conductivity (corrected to 20^{o}C)

9.64E-08 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project

Client:

Project Number:

Sample Identification: Standard Compaction
w= 21%

Depth (ft):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.76
Diameter (cm)	7.12
Moisture Content (%)	20.1
Dry Density (pcf)	101.1

Test Parameters					
Cell Pressure (psi):	75.3	Back Pressure (psi):	72.3	Hydraulic Gradient:	24.42
Influent Pressure (psi):	74.3	Effluent Pressure (psi):	72.3	Degree of Saturation:	94

Final Hydraulic Conductivity (corrected to 20^{o}C)

1.25E-07 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: Standard Compaction Depth (ft):
w= 26%

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	6.09
Diameter (cm)	6.96
Moisture Content (%)	26.4
Dry Density (pcf)	93.2

Test Parameters					
Cell Pressure (psi):	75.4	Back Pressure (psi):	70.0	Hydraulic Gradient:	23.09
Influent Pressure (psi):	74.0	Effluent Pressure (psi):	72.0	Degree of Saturation:	97

Final Hydraulic Conductivity (corrected to 20^{o}C)
7.89E-08 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project
Client:
Project Number:

Sample Identification: Modified Compaction
w= 18%
Depth (ft):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.68
Diameter (cm)	7.17
Moisture Content (%)	18.0
Dry Density (pcf)	110.3

Test Parameters					
Cell Pressure (psi):	74	Back Pressure (psi):	70.8	Hydraulic Gradient:	24.77
Influent Pressure (psi):	73.0	Effluent Pressure (psi):	71.0	Degree of Saturation:	97

Final Hydraulic Conductivity (corrected to 20^{o}C)

5.09E-08 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project
Client:
Project Number:

Sample Identification: Modified Compaction
w= 8%
Depth (ft):

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.92
Diameter (cm)	7.14
Moisture Content (%)	8.7
Dry Density (pcf)	113.3

Test Parameters					
Cell Pressure (psi):	74.6	Back Pressure (psi):	70.0	Hydraulic Gradient:	23.77
Influent Pressure (psi):	73.0	Effluent Pressure (psi):	71.0	Degree of Saturation:	95

Final Hydraulic Conductivity (corrected to 20^{o}C)

8.01E-08 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: Modified Compaction Depth (ft):
w= 12%

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	5.31
Diameter (cm)	7.16
Moisture Content (%)	12.1
Dry Density (pcf)	116.4

Test Parameters					
Cell Pressure (psi):	73.9	Back Pressure (psi):	70.4	Hydraulic Gradient:	26.50
Influent Pressure (psi):	73	Effluent Pressure (psi):	71	Degree of Saturation:	99

Final Hydraulic Conductivity (corrected to 20^{o}C)

4.73E-08 cm/sec

Hydraulic Conductivity Test - Flexi-wall
ASTM D5084

Project: Red Clay Project Client:
Project Number:

Sample Identification: Modified Compaction Depth (ft):
w= 15%

Test Method: ASTM D5084 Constant Head
Permeant Type: Tap Water

Sample Dimensions	
Length (cm)	6.00
Diameter (cm)	7.18
Moisture Content (%)	15.8
Dry Density (pcf)	114.2

Test Parameters					
Cell Pressure (psi):	74.5	Back Pressure (psi):	70.5	Hydraulic Gradient:	23.46
Influent Pressure (psi):	73.5	Effluent Pressure (psi):	71.5	Degree of Saturation:	98

Final Hydraulic Conductivity (corrected to 20^{o}C)

4.38E-08 cm/sec

Appendix B

Field Test Results

Test data - Bay Shore Recycling								
11/17/2003								
	Denstiy (pcf)			Percent Compaction		Notes		
Test No.	Wet	Dry	Water	Modified	Standard	Depth	Thickness	Location
1	121.1	100.6	20.4	86.0	95.4	10"	1'	1
2	122.2	101.3	20.7	86.6	96.0	8"	1'	1
3	122.6	101.7	20.6	86.9	96.4	6"	1'	1
4	123.2	101.5	21.3	86.8	96.2	4"	1'	1
5	123.3	102.9	19.8	87.9	97.5	2"	1'	1
6	126.0	105.1	19.9	89.8	99.6	12"	1'	2
7	126.6	104.4	21.3	89.2	99.0	10"	1'	2
8	126.2	104.4	20.9	89.2	99.0	8"	1'	2
9	124.6	103.0	21.0	88.0	97.6	6"	1'	2
10	124.5	103.1	20.8	88.1	97.7	4"	1'	2
11	124.6	102.9	21.1	87.9	97.5	2"	1'	2
12	123.6	101.6	21.6	86.8	96.3	10"	1'	3
13	124.1	102.7	20.8	87.8	97.3	8"	1'	3
14	124.9	103.6	20.5	88.5	98.2	6"	1'	3
15	125.2	103.3	21.2	88.3	97.9	4"	1'	3
16	126.1	104.7	20.4	89.5	99.2	2"	1'	3
17	126.7	105.0	20.6	89.7	99.5	12"	1'	4
18	126.3	104.7	20.6	89.5	99.2	10"	1'	4
19	124.9	103.2	21.1	88.2	97.8	8"	1'	4
20	124.9	102.7	21.6	87.8	97.3	6"	1'	4
21	123.8	101.9	21.4	87.1	96.6	4"	1'	4
22	123.9	101.4	22.1	86.7	96.1	2"	1'	4
23	125.4	103.4	21.3	88.4	98.0	8"	1'	5
24	125.6	103.8	21.0	88.7	98.4	6"	1'	5
25	123.1	100.9	22.0	86.2	95.6	4"	1'	5
26	123.5	101.6	21.5	86.8	96.3	2"	1'	5
27	120.0	98.2	22.2	83.9	93.1	12"	2'	6
28	120.2	98.5	22.0	84.2	93.4	10"	2'	6
29	121.4	99.9	21.6	85.4	94.7	8"	2'	6
30	122.0	100.4	21.5	85.8	95.2	6"	2'	6
31	123.0	101.3	21.4	86.6	96.0	4"	2'	6
32	123.6	101.8	21.4	87.0	96.5	2"	2'	6
33	119.0	94.6	25.9	80.9	89.7	12"	2'	7
34	119.4	95.8	24.7	81.9	90.8	10"	2'	7
35	119.2	95.3	25.1	81.5	90.3	8"	2'	7
36	120.1	95.5	25.8	81.6	90.5	6"	2'	7
37	120.6	96.3	25.3	82.3	91.3	4"	2'	7
38	121.4	96.9	25.4	82.8	91.8	2"	2'	7
39	121.8	98.4	23.4	84.1	93.3	12"	2'	8
40	122.1	98.6	23.8	84.3	93.5	10"	2'	8
41	123.7	100.7	22.9	86.1	95.5	8"	2'	8
42	121.7	98.5	23.5	84.2	93.4	6"	2'	8

Test No.	Density (pcf) Wet	Density (pcf) Dry	Water	Percent Compaction Modified	Percent Compaction Standard	Notes Depth	Notes Thickness	Notes Location
43	121.6	98.2	23.8	83.9	93.1	4"	2'	8

11/24/2003

Test No.	Density (pcf)		Water	Percent Compaction		Notes		
	Wet	Dry		Modified	Standard	Depth	Thickness	Location
1	124.0	100.4	23.6	85.8	95.2	12"	1'	1
2	124.3	101.4	22.5	86.7	96.1	10"	1'	1
3	126.2	104.0	21.3	88.9	98.6	8"	1'	1
4	126.0	104.3	20.7	89.1	98.9	6"	1'	1
5	128.2	106.0	20.9	90.6	100.5	4"	1'	1
6	129.2	106.9	20.9	91.4	101.3	2"	1'	1
7	126.3	102.0	23.8	87.2	96.7	8"	1'	*2*
8	126.0	102.5	22.9	87.6	97.2	6"	1'	*2*
9	127.6	103.7	23.0	88.6	98.3	4"	1'	*2*
10	128.1	104.6	22.4	89.4	99.1	2"	1'	*2*
11	122.9	100.6	22.1	86.0	95.4	12"	1'	*3*
12	126.5	103.8	21.9	88.7	98.4	10"	1'	*3*
13	128.5	105.8	21.5	90.4	100.3	8"	1'	*3*
14	130.0	106.8	21.7	91.3	101.2	6"	1'	*3*
15	129.5	107.6	21.1	92.0	102.0	4"	1'	*3*
16	127.3	105.6	21.2	90.3	100.1	2"	1'	*3*
17	134.0	110.3	21.4	94.3	104.5	12"	1'	*4*
18	131.1	106.7	22.8	91.2	101.1	10"	1'	*4*
19	127.3	103.3	23.2	88.3	97.9	8"	1'	*4*
20	126.3	101.6	24.3	86.8	96.3	6"	1'	*4*
21	126.2	102.7	22.9	87.8	97.3	4"	1'	*4*
22	126.2	102.8	22.7	87.9	97.4	2"	1'	*4*
23	131.5	109.0	20.7	93.2	103.3	12"	1'	*5*
24	129.5	106.3	21.9	90.9	100.8	10"	1'	*5*
25	128.9	105.8	21.8	90.4	100.3	8"	1'	*5*
26	130.7	107.8	22.0	92.1	102.2	6"	1'	*5*
27	129.2	105.8	22.1	90.4	100.3	4"	1'	*5*
28	127.8	104.1	22.8	89.0	98.7	2"	1'	*5*
29	123.5	99.1	24.6	84.7	93.9	12"	2'	*6*
30	123.5	98.3	25.6	84.0	93.2	10"	2'	*6*
31	123.4	98.4	25.4	84.1	93.3	8"	2'	*6*
32	124.5	99.6	25.0	85.1	94.4	6"	2'	*6*
33	124.2	99.3	25.1	84.9	94.1	4"	2'	*6*
34	125.8	100.5	25.2	85.9	95.3	2"	2'	*6*
35	126.2	103.6	21.8	88.5	98.2	12"	2'	*7*
36	126.1	103.6	22.1	88.5	98.2	10"	2'	*7*
37	126.5	104.1	21.5	89.0	98.7	8"	2'	*7*
38	128.7	106.7	20.6	91.2	101.1	6"	2'	*7*
39	128.9	105.7	21.9	90.3	100.2	4"	2'	*7*
40	129.8	108.2	20.0	92.5	102.6	2"	2'	*7*

Type	Density			Percentage		Proctor	Location/ Notes		
	Wet (pcf)	H_20 (pcf)	Dry (pcf)	H_20	Density	(pcf)			
☒ Soil ❑ Asphalt ❑ Concrete	129.2	12.5	116.6	107.5	101.4	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 12 12"/ 60 Sec.
☒ Soil ❑ Asphalt ❑ Concrete	126.3	13.8	112.5	12.23	97.84	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 12 10"/ 60 Sec.
☒ Soil ❑ Asphalt ❑ Concrete	125.1	14.3	110.7	12.95	96.3	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 12 8"/ 60 Sec.
☒ Soil ❑ Asphalt ❑ Concrete	122.3	13	109.3	11.87	95.06	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 12 6"/ 60 Sec.
☒ Soil ❑ Asphalt ❑ Concrete	119.2	13.2	106	12.41	92.22	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 12 4"/ 60 Sec.
☒ Soil ❑ Asphalt ❑ Concrete	115.5	13.7	101.8	13.44	88.53	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 12 2"/ 60 Sec.
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	
❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	

Test No.	Type	Density			Percentage		Proctor	Location/ Notes		
		Wet (pcf)	H_20 (pcf)	Dry (pcf)	H_20	Density	(pcf)			
17	☒ Soil ❑ Asphalt ❑ Concrete	130	13.5	116.6	11.54	101.4	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 3 12" / 60 Sec.
18	☒ Soil ❑ Asphalt ❑ Concrete	130.1	13.9	116.2	11.99	101	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 3 10" / 60 sec.
19	☒ Soil ❑ Asphalt ❑ Concrete	128.9	13.7	115.3	11.84	100.2	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 3 8" / 60 sec.
20	☒ Soil ❑ Asphalt ❑ Concrete	129.7	13.6	116	11.82	100.8	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 3 6" / 60 sec.
21	☒ Soil ❑ Asphalt ❑ Concrete	129.7	13.9	116	11.76	100.9	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 3 4" / 60 sec.
22	☒ Soil ❑ Asphalt ❑ Concrete	126.6	10.6	112.7	12.35	98.02	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 3 2" / 60 sec.
23	☒ Soil ❑ Asphalt ❑ Concrete	127.9	11	117.3	9.03	102	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 4 12" / 60 sec.
24	☒ Soil ❑ Asphalt ❑ Concrete	126.4	11	115.4	9.55	100.3	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 4 10" / 60 sec.
25	☒ Soil ❑ Asphalt ❑ Concrete	124.6	11.3	113.4	9.95	98.58	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 4 8" / 60 sec.
26	☒ Soil ❑ Asphalt ❑ Concrete	122.6	11.2	111.4	10.08	96.84	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 4 6" / 60 sec.
27	☒ Soil ❑ Asphalt ❑ Concrete	120.3	11.2	109.1	10.23	94.89	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 4 4" / 60 sec.
28	☒ Soil ❑ Asphalt ❑ Concrete	117	10.9	106	10.33	92.2	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 4 2" / 60 sec.
29	☒ Soil ❑ Asphalt ❑ Concrete	128.2	12.6	115.6	10.9	100.5	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 5 12" / 60 sec.
30	☒ Soil ❑ Asphalt ❑ Concrete	127.5	12.9	114.6	11.24	99.67	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 5 10" / 60 sec.
31	☒ Soil ❑ Asphalt ❑ Concrete	125.1	12.2	112.9	10.78	98.16	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 5 8" / 60 sec.
32	☒ Soil ❑ Asphalt ❑ Concrete	124.1	12	112.1	10.71	97.46	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 5 6" / 60 sec.
33	☒ Soil ❑ Asphalt ❑ Concrete	122.7	12.3	110.4	11.15	96.02	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 5 4" / 60 sec.
34	☒ Soil ❑ Asphalt ❑ Concrete	119.3	12.3	107	11.53	93.05	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 5 2" / 60 sec.

Test No.	Type	Density			Percentage		Proctor	Location/ Notes		
		Wet (pcf)	H_20 (pcf)	Dry (pcf)	H_20	Density	(pcf)			
37	☒ Soil ❑ Asphalt ❑ Concrete	129.1	13.1	116.1	11.26	100.9	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 8 12" / 60 Sec.
38	☒ Soil ❑ Asphalt ❑ Concrete	127.9	12.6	115.3	10.92	100.2	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 6 10" / 60 Sec.
39	☒ Soil ❑ Asphalt ❑ Concrete	126.3	13.4	112.9	11.89	98.19	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 6 8" / 60 Sec.
40	☒ Soil ❑ Asphalt ❑ Concrete	125.8	12.9	112.9	11.47	98.16	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 6 6" / 60 Sec.
41	☒ Soil ❑ Asphalt ❑ Concrete	124	12.5	111.5	11.23	96.96	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 6 4" / 60 Sec.
42	☒ Soil ❑ Asphalt ❑ Concrete	121.1	12.3	108.9	11.26	94.68	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 6 2" / 60 Sec.
43	☒ Soil ❑ Asphalt ❑ Concrete	131.8	12.6	119.2	10.53	103.7	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 7 12" / 60 Sec.
44	☒ Soil ❑ Asphalt ❑ Concrete	127.5	13.9	113.5	12.28	98.73	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 7 10" / 60 Sec.
45	☒ Soil ❑ Asphalt ❑ Concrete	128.2	13	115.2	11.3	100.2	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 7 8" / 60 Sec.
46	☒ Soil ❑ Asphalt ❑ Concrete	129.3	13.7	115.6	11.89	100.5	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 7 6" / 60 Sec.
47	☒ Soil ❑ Asphalt ❑ Concrete	127.1	13.3	113	11.66	98.96	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 7 4" / 60 Sec.
48	☒ Soil ❑ Asphalt ❑ Concrete	121.2	13.9	107.4	12.91	93.38	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 7 2" / 60 Sec.
49	☒ Soil ❑ Asphalt ❑ Concrete	129.5	12.6	116.9	10.9	101.7	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 8 12" / 60 Sec.
50	☒ Soil ❑ Asphalt ❑ Concrete	124.8	13.6	111.2	12.26	96.69	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 8 10" / 60 Sec.
51	☒ Soil ❑ Asphalt ❑ Concrete	125.5	12.2	113.3	10.8	98.5	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 8 8" / 60 Sec.
52	☒ Soil ❑ Asphalt ❑ Concrete	124.6	12.9	111.7	11.54	97.17	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 8 6" / 60 Sec.
53	☒ Soil ❑ Asphalt ❑ Concrete	123.9	13.1	110.8	11.82	96.37	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 8 4" / 60 Sec.
54	☒ Soil ❑ Asphalt ❑ Concrete	115.6	12.9	102.7	12.55	89.31	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 8 2" / 60 Sec.
	❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	

Test No.	Type	Density			Percentage		Proctor	Location/ Notes		
		Wet (pcf)	H_20 (pcf)	Dry (pcf)	H_20	Density	(pcf)			
55	☒ Soil ❑ Asphalt ❑ Concrete	128.7	12.6	116.1	10.84	101	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 9 12" / 60 Sec.
56	☒ Soil ❑ Asphalt ❑ Concrete	125.1	11.3	113.8	9.97	98.94	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 9 10" / 60 Sec.
57	☒ Soil ❑ Asphalt ❑ Concrete	123.5	11.8	111.7	10.58	97.13	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 9 8" / 60 Sec.
58	☒ Soil ❑ Asphalt ❑ Concrete	123.3	10.9	112.4	9.68	97.78	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 9 6" / 60 Sec.
59	☒ Soil ❑ Asphalt ❑ Concrete	121.3	11.6	109.7	10.57	95.39	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 9 4" / 60 Sec.
60	☒ Soil ❑ Asphalt ❑ Concrete	119.5	12.1	107.4	11.26	93.37	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 9 2" / 60 Sec.
61	☒ Soil ❑ Asphalt ❑ Concrete	133.8	11	122.7	8.99	106.7	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 10 12" / 60 Sec.
62	☒ Soil ❑ Asphalt ❑ Concrete	131.9	12	119.8	10.03	104.2	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 10 10" / 60 Sec.
63	☒ Soil ❑ Asphalt ❑ Concrete	131.3	13.2	118.1	11.16	102.7	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 10 8" / 60 Sec.
64	☒ Soil ❑ Asphalt ❑ Concrete	129.4	12.4	116.9	10.64	101.7	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 10 6" / 60 Sec.
65	☒ Soil ❑ Asphalt ❑ Concrete	127.1	12.3	114.8	10.69	99.86	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 10 4" / 60 Sec.
666	☒ Soil ❑ Asphalt ❑ Concrete	122.4	12.1	110.3	10.97	95.95	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 10 2" / 60 Sec.
67	☒ Soil ❑ Asphalt ❑ Concrete	131.3	12.1	119.3	10.12	103.7	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 11 12" / 60 Sec.
68	☒ Soil ❑ Asphalt ❑ Concrete	127.8	12.5	115.3	10.82	100.3	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 11 10" / 60 Sec.
69	☒ Soil ❑ Asphalt ❑ Concrete	127.9	11.9	116	10.22	100.9	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 11 8" / 60 Sec.
70	☒ Soil ❑ Asphalt ❑ Concrete	128	11.9	116.1	10.23	101	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 11 6" / 60 Sec.
71	☒ Soil ❑ Asphalt ❑ Concrete	127.2	12.1	115.1	10.54	100.1	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 11 4" / 60 Sec.
72	☒ Soil ❑ Asphalt ❑ Concrete	120.2	11.3	108.9	10.36	94.67	115	❑ BS	☒ ***PASS*** ❑ ***FAIL***	Test Point 11 2" / 60 Sec.
	❑ Soil ❑ Asphalt ❑ Concrete							❑ BS	❑ ***PASS*** ❑ ***FAIL***	

Appendix C

Construction Photos

Photo #1. Transportation of Red Clay in Hopper Scows

Photo #2. Transportation of Red Clay in Hopper Scows

Photo #3. Unloading of the Red Clay

Photo #4. Transportation of the Red Clay Within the Bayshore Site

Photo #5. Spreading of the Red Clay at the Bayshore Site

Photo #6. Spreading of the Red Clay

Photo #7. Compaction of the Red Clay

Photo #8. Compaction of the Red Clay

Photo #9. Sampling of the Red Clay for laboratory Testing

Photo #10. Spreading of the Red Clay in 6-inch Layers at the ILR Landfill

Photo #11. Spreading of the Red Clay in 6-inch Layers at the ILR Landfill

Photo #12. Compaction of the Red Clay at the ILR Landfill

Photo #13. Compacted Red Clay

Photo #14. In-situ Density Testing of the Red Clay

Appendix D

Market Study

Dredged Red Clay

Market Analysis

Report Submitted to

Office of Maritime Resources
New Jersey Department of Transportation
Trenton, New Jersey

Prepared by

Sadat Associates, Inc.
Engineering and Environmental Science
1545 Lamberton Road • P.O. Box 4129
Trenton, NJ 08610 • 609-826-9600

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TABLE OF CONTENTS

APPENDICES

APPENDIX A

Landfill Questionnaire

TABLES AND FIGURES

1.0 Introduction

This report presents the findings of the market analysis performed by Sadat Associates Inc. (SAI) for the upland beneficial use of Dredged Red Clay (DRC) material generated from the dredging operations at the New York\ New Jersey navigational channels. The project was funded by a grant from the Office of Maritime Resources (OMR) of the New Jersey Department of Transportation (NJDOT).

Maintenance dredging and channel deepening projects along the New York / New Jersey navigational channels generate millions of cubic yards of dredged material that require management. While the dredged material generated from maintenance dredging consists mostly of silt and low percentages of clay and fine sand, the dredged material generated from channel deepening projects varies widely in composition and includes rock, glacial till, sand, gravel and virgin clay.

Most of the material generated by channel deepening projects (side slopes excepted) has never been exposed to industrial pollution and thus has been shown to be free from contamination. This clean virgin material meets the criteria for ocean disposal and is currently being disposed off at the Historic Area Remediation Sites (HARS). The HARS is currently being remediated to cap historically disposed silts from NY/NJ Harbor placed there over the past century. The material used for this purpose is clean material from dredging projects in the Harbor. It has been estimated that there is a need for 40 million cubic yards of clean capping material needed to achieve a 3-foot cap. To date approximately 25-28 million cubic yards have already been placed. It is in the Port's interest to reserve the remaining capacity for that clean material which has no potential for beneficial use. Materials such as rock and coarse sand are already used beneficially in either reefs or for construction aggregate. Other materials, such as the consolidated red clay which underlies Newark Bay may also have potential for beneficial use upland in remediation projects. Since the red clay has never been used at upland sites, there is a lack of experience in the handling, workability and the costs associated therewith. These issues, as well as the physical properties of the material, including the geotechnical characteristics and the in-situ hydraulic conductivity were studied under a separate demonstration project conducted by Soilteknik, Inc, of Basking Ridge, New Jersey.

This report presents the findings of the study conducted by Sadat Associates, Inc., to identify and quantify the potential upland beneficial use markets for the dredged red clay. The following sections in this report present the potential DRC applications identified by the study. The engineering and regulatory concerns associated with each potential application, a market analysis and cost analysis are also included in this report.

2.0 DRC Quantity and Characteristics

2.1 Quantity of DRC Generated

In order to better understand the nature of the potential beneficial uses to be explored, data on the quantity of red clay generated by various dredging operations of the Port Authority of NY/NJ was obtained. The rate of red clay generation requiring disposal during the period from 2006 to 2013 is estimated by the Office of Maritime Resources as follows.

Table 2.1 - Projected Rate of DRC Generation

Year	2006	2007	2008	2009	2010	2011	2012	2013
Volume (1000 CY)	148	2,038	348	1,500	1,300	508	58	178

As seen from the table, it is estimated that a total of approximately 6 Million Cubic Yards (MCY) of red clay will be generated from the dredging operations over an 8-year period from 2006 to 2013 and will be available for various uses discussed in this report.

2.2 Engineering Characteristics

The engineering characteristics of DRC material have been evaluation by others and are presented in a separate report prepared by Rutgers University, which is submitted as part of this project.

2.3 Environmental Characteristics

The deposition of red clay at the New York/New Jersey navigation channels predates the industrial era and thus is not contaminated by industrial pollution. The material is found at depths below the recent sediments, which are sometimes contaminated. Analytical tests on the material were performed by various agencies including the Port Authority of New York and New Jersey. The results indicate that most of the analytical parameters included in the New Jersey Soil Cleanup Criteria are either not detected or are detected only in trace quantities. Based on the analytical test results, the material is believed to qualify for all the beneficial uses discussed later in this report. However, additional analytical testing will be necessary based on regulatory and/or site-specific requirements.

3.0 Regional Repository

The annual rate of DRC generation is believed to fluctuate from less than 100,000 CY to more than 2.0 Million CY during the next 8-year period. If the demand for DRC remains at a steady rate, a regional repository will have to be maintained to equalize this fluctuation in the rate of generation. Since the rate of future DRC demand is hypothetical, the repository will also help to offset the market instabilities and uncertainties.

3.1 Capacity of Regional Repository

The proposed DRC regional repository should be able to store the difference between the cumulative DRC generated and the cumulative DRC demand at any given time. Assuming that the approximately 6 Million CY of DRC generated during the period from 2006-2013 will be used up at a constant rate through the period, the rate of annual demand for DRC needs to be at least 760,000 CY. The cumulative quantities of DRC generated and the DRC demand are presented in Table 3.1 and the values are plotted in Figure 3.1. The required volume of storage is also presented in Table 3.1. As shown in the table, the required storage capacity of the regional repository is calculated as 1.5 Million CY. However, efforts can be made to increase the DRC use during years of increased DRC generation and this will substantially reduce the required storage volume of the repository. Considering that such efforts will be partially successful, the required storage volume is assumed to be one fourth of the quantity calculated in the table. Thus, the design storage volume of the repository is calculated as 380,000 (1.5 Million CY/4)

Table 3.1 - Regional Repository Capacity Calculations

Year	DRC Generated (1000CY)	DRC Generated - Cumulative (1000CY)	DRC Consumption Cumulative (1000CY)	Required Storage (1000CY)
2006	148	148	760	
2007	2038	2186	1520	
2008	348	2534	2276	
2009	1500	4034	3039	998
2010	1300	5334	3799	1535
2011	508	5842	4559	1288
2012	58	5900	5318	582
2013	178	6078	6078	

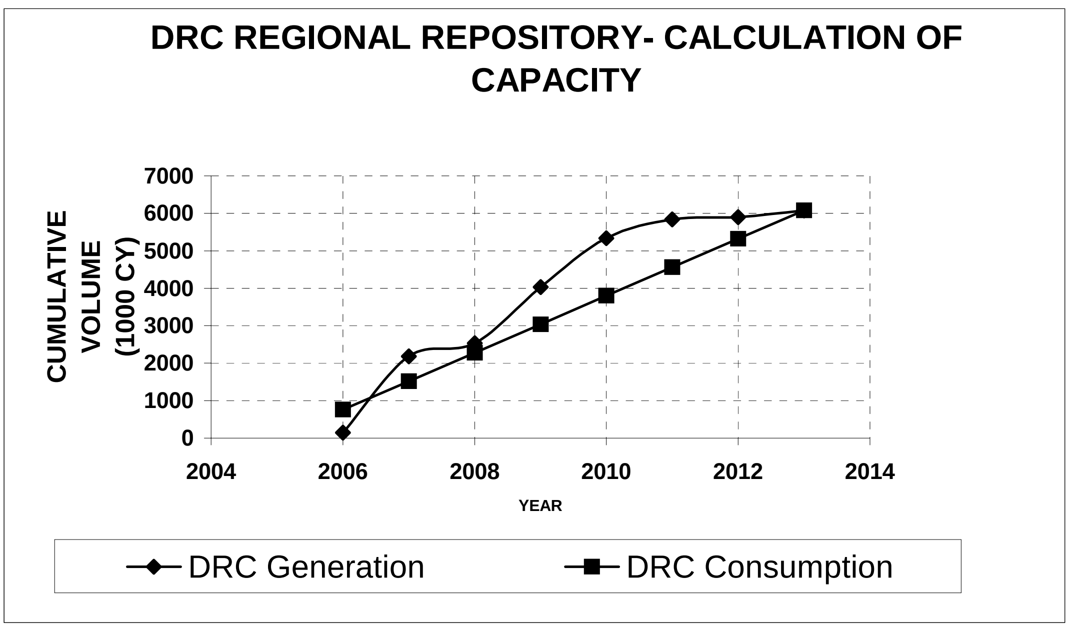

Figure 3.1 - Regional Repository Capacity Calculations

3.2 Repository Layout

A typical layout of the proposed repository would include a parcel located along a water body accessible by scows from the dredging locations. The site should have a bulkhead for unloading DRC from the scows and sufficient area for the storage of DRC to offset the fluctuations in supply and demand. Other features required for a typical facility include access roads, operation and maintenance areas, stormwater management facilities etc.

Based on the calculated storage capacity of 380,000 CY required for the repository and assuming a DRC stockpile height of 50 ft. and side slope of 1V: 3H, the required size of the storage area should be approximately 580 ft x 580 ft. This is approximately an area of 7.72 acres. Including additional area for access roads, operation and maintenance, and stormwater management, the total area required for the parcel will be approximately 10 acres.

3.3 Repository Sitting Considerations

The economic viability of using DRC as an alternative material to upland clay depends to a great extent on the transportation costs associated with delivering the DRC to a project site. The most effective means for upland delivery of DRC from the dredging operations is by hopper scow. This limits the potential sites for the DRC repository to areas accessible by water from locations where DRC is generated by dredging. Access to highways is also a major sitting consideration. Additional sitting criteria include avoidance of residential areas and local streets.

3.4 Repository Cost Analysis

The costs associated with maintaining a regional repository include the land leasing costs, the initial permitting costs, construction costs and operation costs. The land leasing costs will be the major share of these costs. The total costs for maintaining the facility at a location that meets the siting considerations discussed in Section 3.3 is estimated to be approximately $100,000 per acre per year. For a 10-acre facility, assuming an annual upland DRC usage of 760,000 CY, the costs associated with maintaining a regional repository will be $1.32/CY. The costs associated with the unloading of DRC is included in the cost estimates elsewhere. The costs associated with stockpiling can be considered as included in the efforts for size reduction and moisture conditioning which are included in other cost estimates.

4.0 DRC Applications

4.1 Containment Barrier Applications

The low hydraulic conductivity of DRC makes it an ideal material for the construction of low permeability containment barriers for contaminated sites. Low permeability barrier applications for landfills and land remediation projects have been identified as the most promising market for DRC. The prospects of using DRC in this market are discussed in detail in the following sections.

4.1.1 Engineering Concerns

The most critical geotechnical characteristic limiting the use of DRC as containment barrier layer is its hydraulic conductivity. The hydraulic conductivity of containment barrier layers in landfill and land remediation applications is stipulated by the NJDEP Solid Waste Regulations at N.J.A.C. 7:26- 2A. The maximum permissible hydraulic conductivity of clay containment layers after compaction, for landfill liners and cap layers is $1x10^{-7}$ cm/sec. For landfills without a low permeability bottom liner, NJDEP may approve a cap layer permeability of up to $1x10^{-5}$ cm/sec, on a case-by-case basis

The results from the demonstration project performed by Rutgers University, indicate that the DRC will meet or exceed the $1x10^{-7}$ cm/sec regulatory criterion for hydraulic conductivity for landfill caps and liners. The workability of DRC in regard to ease of construction and spreading in layers was also investigated as part of the demonstration project. The results indicate that DRC can be loaded, spread and compacted with standard construction equipment.

4.1.2 Environmental Concerns

DRC is currently being disposed at the Historic Area Remediation Sites. Environmental concerns associated with the use of DRC are not substantially different from that for the use of conventional upland clay sources. Analytical results on a composite sample of the DRC from Newark Bay, obtained from NJDOT/OMR, do not indicate any analytical parameter above the New Jersey Residential Direct Contact Soil Cleanup Criteria. Additional analytical testing may be required on a case by case basis to satisfy regulatory and\or site-specific concerns.

4.1.3 Permitting

Clay is accepted by the NJDEP Solid Waste Regulations at N.J.A.C. 7:26- 2A, as a liner/cap material for landfills. The use of DRC as containment layer at landfills or remediation sites is not believed to require any additional permitting. However, the use of DRC must be approved on a case-by-case basis as part permit process for landfills and as part of the Remedial Action Work Plan for remediation sites. All dredged material, including the DRC, must also have an Acceptable Use Determination (AUD) prior to its beneficial use.

4.1.4 Competing Products

During interviews conducted as part of the market survey, landfill managers were asked about alternative materials that they might want to consider for use at the landfills, as the containment barrier layer. The alternatives suggested were synthetic liners, locally available clay, and dredge materials other than DRC.

Synthetic liners are often preferred as containment barriers for their general ease of construction. They are readily available and are easy to handle, lay, load and store. The situation is different when clay is available onsite. Many landfills were sited at or near natural clay sources due the effectiveness of clay as a natural confining layer. If such local clay is available for use as cap or other containment layers, it may be viable to use local clay. A cost comparison of the above alternatives is discussed later in this report.

Dredged material other than DRC has been a more recent innovation as material for use as containment barriers. Dredged material is stabilized with suitable additives such as cement or lime, if necessary, to improve the geotechnical characteristics of the material, to form Stabilized Dredge Material (SDM). Dredged material used for the preparation of SDM is generally contaminated, and therefore is not suitable for HARS disposal. While SDM is attractive because of its revenue generating potential, SDM can be used only in conjunction with other materials like clay or synthetic liners, and cannot be used as the only containment barrier layer.

4.2 Civil Engineering Applications

Potential civil engineering applications for DRC include construction of pond liners and wetland restoration work in addition to structural fill applications. Although clay has traditionally been used for the construction of pond liners and for wetland restoration work, the use of clay as structural fill has not been very common. This is mainly due to non-availability of clay and cost concerns. If DRC can be made readily available at sufficient quantities, at costs comparable to common fill materials, then use of DRC as structural fill material for construction of berms and embankments and backfilling of abandoned pits could be a very promising bulk application for DRC. DRC is specifically suited for construction of berms and embankments for water retaining structures like dams and retention/detention ponds. The prospects of using DRC in potential civil engineering applications are discussed further in the following sections.

4.2.1 Engineering Concerns

The geotechnical concerns associated with the civil engineering applications of DRC are mainly its strength parameters, workability and compactibility. The workability and compactibility of DRC were investigated as part of the demonstration project. The results indicate that DRC can be loaded, spread and compacted with standard construction equipment. The reduced hydraulic conductivity is an added advantage when used appropriately in applications for water retaining structures. The results of the demonstration project including the strength parameters of DRC material are discussed in detail in a separate report submitted as part of this project.

4.2.2 Environmental Concerns

The DRC used for civil engineering applications may be required to meet the NJDEP Residential Direct Contact Soil Cleanup Criteria (RDCSCC). Considering the fact that DRC qualifies for HARS disposal and that the analytical testing on the DRC composite sample did not indicate any parameter above the NJDEP RDCSCC, it is believed that the material will qualify for all of the civil engineering applications discussed in this section. However, additional analytical testing may be required on a site-specific basis.

4.2.3 Permitting

The civil engineering applications discussed in this section are not believed to require any additional regulatory permitting. The use of DRC in land development projects will be reviewed as part of the stormwater review element of local, county and state permits. Use of DRC requires an Acceptable Use Determination (AUD) from NJDEP, before it can be used in upland civil engineering applications.

4.2.4 Competing Products

The materials used currently for civil engineering applications like the construction of pond liners, wetland restoration, and structural fill are local clay, synthetic liners and common fill. Among the above listed materials, synthetic liners can be used only for low permeability applications and common fill can be used only for structural fill applications. DRC when used as fill material for the construction of berms and embankments of water retaining structures will provide additional benefits as low permeability material. Upland clay and common fill are not always locally available. If a steady reliable source of DRC can be maintained, then civil engineering applications will be the most promising market for DRC material.

4.3 Manufacturing Applications

Potential ceramic manufacturing applications of DRC were investigated as part of the study. Use of DRC for the manufacture of bricks, tile and fine pottery was explored. A ceramic manufacturer in Hillsborough, New Jersey was contacted to study the feasibility of using DRC for the manufacture of bricks and tiles. The manufacturer currently uses onsite shale for the manufacture of bricks and tiles, and initially did not show interest in using imported material. However, after realizing the potential benefits of the material, the plant manager agreed to experiment with the use of DRC. A sample of the DRC was delivered to the manufacturing plant for test firing. The material was test fired and the brick was sent to a laboratory for testing. The laboratory testing indicated that excessive voids were created in the brick during the firing process, possibly due to high organic content. The brick was also found unusable due to color issues. Based on the determination, further investigations were not conducted.

To evaluate the potential for DRC in the manufacture of fine pottery and sculpturing, a sample of the material was provided to a professional artisan in Sergeantsville, New Jersey. Results indicate that the DRC material is not suitable for manufacture of fine pottery and sculpturing due to presence of coarse particles.

Results from the above two experiments indicate that the DRC material may have to be amended before it can be used in any manufacturing application. Since the associated costs are believed to be prohibitive for such applications, further studies and analyses were not conducted.

5.0 Market Analysis

Potential market for DRC applications has been estimated based on the best available information and prudent engineering assumptions. The estimated potential DRC market along with the adopted methodologies and the assumptions used for the estimation are discussed in the following sections.

5.1 Containment Barrier Applications

Several approaches were employed to estimate the available market for DRC as containment barrier layer in landfill and site remediation applications. Although the applications are similar, the markets for landfills and remediation sites were studied separately.

5.1.1 Landfills

Sadat Associates Inc. has unparalleled experience in the landfill engineering industry in New Jersey. The expertise in landfill closure and redevelopment projects in New Jersey were instrumental in making realistic assumptions, critical to the projection of DRC market for the landfill industry. In order to estimate the DRC market in the landfill industry, landfills were classified into the following categories; (1) operating regional landfills, (2) closed landfills that require capping and, (3) landfills under the NJDEP landfill remediation program. A fourth category includes landfills that can be considered as exceptions from the above general categories because they would require large quantities of capping material as part of their closure plan, about which SAI has specific information.

Questionnaires were sent to the landfill mangers of all the thirteen (13) regional landfills in New Jersey, requesting information regarding the potential market for low permeability material. The landfill managers were telephoned to follow-up on the questionnaire and interviewed on the proposed activities at the landfill that may require low permeability material. The letters and the questionnaire are attached in Appendix A. The responses did not lead to a conclusive estimate of the future demand scenarios. Therefore, a different approach was devised. The required future landfill capacity for each regional landfill was projected based on the population of the county from which the landfill receives solid wastes. The actual future volumes may be higher than the projections due to the fact that many of the landfills accept solid waste from municipalities in neighboring counties. The required number of landfill cells was then estimated using a typical landfill cell configuration. The required quantity of clay was then estimated based on the fact that a low permeability bottom liner and a top cap would be required for each cell that will be opened. The thickness of the clay layers was assumed as one (1) foot, based on the New Jersey Solid Waste Regulations.

The estimated potential market for clay and the assumptions used in the calculation of the potential market are shown in Table 5.1. As shown in the Table, the estimated potential market for DRC for use as containment layers at the thirteen (13) regional landfills, for the next ten years is approximately 5.25 Million CY. The contact details, the proposed year of final closing and the acreage of all the regional landfills in New Jersey are provided in Table 5.2. Additional information on all New Jersey landfills is available from the New Jersey Landfills Database, maintained by NJDEP.

Table 5.1 - Estimation of Potential DRC Market for Regional Landfills

	Year 2003 Population*	Pop. Growth Rate from 2000-'03	Annual % Growth Rate**	Jan 1, 2010 Projected Population	Required LF Volume (CY/Year)	Addl. Cells Required in a 10 YR Period	Required Vol. of Clay (CY) ***
Atlantic	263,410	4.30	1.304	286,550	561,863	10.74	346,423
Burlington	444,381	5.00	1.513	489,930	960,647	18.36	592,297
Camden	513,909	1.00	0.307	524,239	1,027,919	19.64	633,774
Cape May	101,845	-0.50	-0.154	100,829	197,704	3.78	121,897
Cumberland	149,306	2.00	0.611	155,338	304,584	5.82	187,795
Gloucester	266,962	4.80	1.453	293,205	574,913	10.99	354,468
Middlesex	780,995	4.10	1.244	846,349	1,659,509	31.71	1,023,188
Monmouth	632,274	2.80	0.853	668,177	1,310,151	25.03	807,787
Ocean	546,081	6.90	2.074	624,040	1,223,608	23.38	754,428
Salem	64,854	0.90	0.276	66,027	129,464	2.47	79,822
Sussex	151,146	4.80	1.453	166,004	325,499	6.22	200,690
Warren	109,219	6.60	1.986	124,112	243,356	4.65	150,044
			TOTAL	**4,344,801**	**8,519,217**	**163**	**5,252,613**

* US Census Bureau, 2003 Projected Population

** Based on US Census Bureau 2000-2003 Growth Rate

*** Assuming one foot thick cap and liner

Percapita SW Generated	2000	lb/yr	Area of Typical LF Cell	10	Acres
LF Compacted SW Density	1,200	lb/CY	Height of Typical LF Cell	50	Feet
Landfill Compaction Ratio	0.85		Side Slope of Typical Cell	3	H = 1V
			LF Volume of One Cell	523333	CY

Table 5.2 - New Jersey Regional Landfills Data

Facility Name	Facility Location	City	County	Mailing Name	Mail Contact	Mail Street	Mail City	Year of Closing	Acrage
Atlantic County Sanitary Landfill	Delilah Road	Egg Harbor Township	Atlantic	Atlantic County Utilities Authority	Richard S. Dovey, President	P.O. Box 996	Pleasantville, N.J. 08232	2022	308
Burlington County Resource Recovery Complex	Burlington-Columbus Road, Rte. 543	Florence and Mansfield Township	Burlington	Burlington County Board of Chosen Freeholders	Frederick F. Galdo, Clerk/Administrator	P.O. Box 6000	Mount Holly, NJ 08060	2015	496
Cape May County MUA Sanitary Landfill	Kearney Ave. & Route 610	Upper Twp. & Woodbine Borough	Cape May	Cape May County Municipal Utilities Authority	Charles M. Norkis,P.E., Chief Engineer	P.O. Box 610	Cape May Court House, NJ 08210	2039	372
Cumberland County Solid Waste Complex	Jesse's Bridge Road, Rt.636	Deerfield Township	Cumberland	Cumberland County Improvement Authority	Steven Wymbs, Executive Director	2 North High Street	Millville, NJ 08332	2021	300
Gloucester County Solid Waste Complex	Swedesboro-Monroeville Road	South Harrison Township	Gloucester	Gloucester County Improvement Authority	David Shields, Executive Director	109 Budd Blvd.	Woodbury, NJ 08096	2012	216
NJMC Erie landfill	Valley Brook Avenue	North Arlington	Bergen	New Jersey Meadowlands Commission	Thomas Marturano	Two DeKorte Park Plaza, P.O. Box 6	Lyndhurst, NJ 07071	2006	172
Middlesex County Sanitary landfill	Edgeboro Road	East Brunswick	Middlesex	Middlesex County Utilities Authority	Richard Fitamant, Executive Director	P.O. Box B-1	Sayreville, NJ 08872-0086	2015	932
Monmouth County Reclamation Center	Asbury Ave. & Shafto Rd.	Tinton Falls	Monmouth	Monmouth County Board of Chosen Freeholders	Robert J. Collins, County Administrator	Hall of Records, P.O. Box 1255	Freehold, NJ 07728-1255	2015	400
Ocean County Landfill Corp.	Route 70 & Route 571	Manchester	Ocean	Ocean County Landfill Corp.	Charles J Hesse	P.O. Box 207	Belford, NJ 08733	2016	992
Pennsauken Sanitary Landfill	9600 River Road	Pennsauken	Camden	Pollution Control Financing Authority of Camden Co	Rtd. John Jacobs, Deputy Director	729 Hylton Road	Pennsauken, NJ 08110	2013	432
Salem County Sanitary Landfill	Rt 540 & McKillip Rd.	Alloway Township	Salem	Salem County Utilities Authority	Michael Chapman, Executive Director	P.O. Box 674	Alloway, NJ 08801-0674	2018	156
Sussex County Sanitary Landfill	Rte 94 & 15	Lafayette Township	Sussex	Sussex County Municipal Utilities Authority	Frederick Vanderbeck, Chairman	RD#1, Box 900A	Lafayette, NJ 07848	2012	204
Warren County District Landfill	Edison Road	White Township	Warren	Pollution Control Financing Authority of Warren Co	John Carlton, Executive Director	P.O. Box 587	Oxford, NJ 07863-0587	2014	180

A different approach was used in estimating the potential market for DRC in closed industrial and sanitary landfills that require capping. There are about 500 landfills in New Jersey that are closed but are not properly capped. The major hurdle in capping these landfills is financing. Recent trends indicate that redevelopment opportunities are the most common incentive for the capping and closure of these types of landfills. Senior staff from the NJDEP Bureau of Landfills and Recycling Management (BLRM) and other sources were consulted to evaluate the frequency at which the abandoned landfills come up for capping and closure. It is estimated that the closure plans for about 5-10 old landfills are submitted each year for approval to the NJDEP. Average area of these landfills is assumed based on expert opinion as 10 acres. Some of the capped landfills are not redeveloped and some are redeveloped into residential/commercial facilities, golf courses etc. Thickness of the clay cap layer is assumed to be one (1) foot for estimation purposes, based on the NJ Solid Waste Regulations. In redevelopment projects involving buildings and infrastructure, the clay cap may be replaced by building slabs, pavements etc. However, this will be offset by the increased potential to use DRC as structural fill in such projects. Thus the potential market for use of DRC in capping closed New Jersey landfills, estimated at a rate of 5 landfills per year, for the next ten (10) years is approximately 0.8 Million CY.

New Jersey landfills that are being capped under the NJDEP site remediation program are not included in the above estimation. Based on information from the NJDEP site remediation program, a total landfill area of 335 acres is currently under the site remediation program. The list of landfills under the NJDEP site remediation program is provided in Table 5.3. It can be reasonably assumed that all these landfills will be capped within the next ten (10) years. Assuming a one (1) foot thick cap layer, the potential market for use of DRC in capping the landfills under NJDEP site remediation program is approximately 0.54 Million CY.

Table 5.3 - Potential DRC Market for Capping of Landfills Under NJDEP Site Remediation Program

Landfill Project	Landfill Area (Acres)	Required Volume of Cap Material (MCY)*

Fazzio Landfill	100	0.16
Winslow Landfill	95	0.15
James Landfill	21	0.03
Woodstown Landfill	44	0.07
Somerville Landfill	47	0.08
Harris Landfill	28	0.05
Total	**335**	**0.54**
* Estimated based on approximate area of the landfill and a one (1) foot thick cap		

Sadat Associates Inc. is familiar with several landfill projects that require large quantities of fill material, as part of their closure plan. Previous experiences with similar projects indicate that DRC material will be a potential alternative for those applications. Since the quantities of DRC material required for these landfill projects are substantially higher than the typical scenarios discussed above, the potential DRC market for these projects are estimated as a separate category. The landfill projects and the estimated quantity of required fill material are as shown in Table 5.4.

Table 5.4 - Potential DRC Market for Capping of Specific Landfills

Landfill Project	**Landfill Area (Acres)**	**Required Volume of Cap Material (MCY)***
EnCAP Golf, Inc.,	785	1.27
Overpeck Landfill	400	0.65
Wildwood Landfill	29	0.05
Stafford Landfill	60	0.10
Mall Landfill	30	0.05
Edgeboro Landfill	100	0.16
Keyport Landfill	34	0.05
Fresh Kills Landfill	460	0.74
Total		**3.07**

A summary of the estimated DRC market for landfill capping is provided in Table 5.5

Table 5.5 - Summary of Potential DRC Market Estimation for Landfill Capping

Description of Landfill Market	Estimated Market (Million CY)
Regional Landfills	5.25
Capping of Abandoned Landfills	0.80
Landfills Under NJDEP Site Remediation	0.54
Specific Landfills Listed in Table 5.5	3.07
TOTAL	**9.66**

5.1.2 Site Remediation

The first step in the estimation of DRC market for site remediation applications was an in-house evaluation of the site remediation projects performed by Sadat Associates Inc. Sadat Associates Inc., managed several site remediation projects ranging from Preliminary Assessments to Remedial Action Work plans. These projects were evaluated retrospectively for the potential to have used DRC at any stage of the project as part of site remediation.

The review revealed that there were 14 projects completed, which required soil remediation and backfill at the site. Out of this, 12 projects were small-scale projects, with the potential of using a quantity of DRC less than 10,000 CY. All the 12 small-scale projects together had only a potential of using approximately 900 CY. This is equivalent to a quantity of 75 CY of potential DRC market per one small-scale site remediation project.

Projects that had the potential to use more than 10,000 CY of DRC were classified as large-scale projects. Two projects were identified in this category, with a total potential for DRC usage of approximately 80,000 CY. This is equivalent to a quantity of 40,000 CY of potential DRC market per one large-scale site remediation project. However, considering that the estimate is based on a small sample size of only two projects in this category, the quantity was divided by a factor of 2, to make the estimate more conservative. Thus the potential DRC market per one large-scale site remediation project is estimated to be 20,000 CY.

The data available from the NJDEP known contaminated site database was analyzed to quantify the market for potential use of DRC. There are approximately 12,000 known contaminated sites listed in the NJDEP database for known contaminated sites. Out of this, approximately 3,500 sites have been identified by NJDEP as requiring multi-phased remedial action. The land area involved in the remedial action or other similar data valuable for estimation of potential DRC market associated with each site remediation project were not available from the NJDEP database or from other NJDEP sources. Therefore, using the same ratio derived from the SAI projects, to categorize the NJDEP projects into small/large scale projects, there will be 3000 small-scale and 500 large-scale projects that have the potential to use DRC as part of site remediation. Assuming that all the sites currently listed in the NJDEP known contaminated site database will be remediated during the next 10 years, the total estimated market for this application is 10.23 MCY. This estimate includes the potential market for use of DRC as containment barriers and as structural backfill for site remediation projects. The estimation of potential DRC market for site remediation is presented in Table 5.6.

Table 5.6 - Estimated Potential DRC Market for Site Remediation Projects

Category	SAI Projects			NJDEP Projects	
	No. of Projects	Ratio to Total	Potential for DRC Use (CY/project)	Number of Projects	Total DRC Market (Million CY)
Small-scale projects (< 10,000 CY)	12	0.86	75	3,000	0.225
Large-scale Projects (>10,000)	2	0.14	20,000	500	10.00

Total	**14**	**1.0**		**3,500**	**10.23**

5.2 Civil Engineering Applications

The DRC market in Civil Engineering applications depend primarily on the feasibility of using DRC in structural fill applications. The potential market for use of DRC as pond liners and in wetland restoration work is estimated based on the construction activity in New Jersey. Based on the most recent data available from the New Jersey Department of Community Affairs, construction of about 35,000 residential units, 10 Million Sq. ft. of office space and 6 Million square feet of retail space was authorized in the year 2003. Data for the year 2004 is not available at this time. Assuming an average floor area of 1,500 Sq. ft. per housing unit, the total building area is approximately 86 Million Sq. ft. Assuming a Floor Area Ratio (FAR) of 1.5; this is equivalent to construction in a total land area of approximately 3,000 acres. It can be reasonably assumed that approximately 2.5% of the total land area will be used for stormwater retention facilities or wetland restoration, requiring low permeability liners. Thus the total area requiring low permeability liners will be approximately 75 acres. Assuming a 1 foot thick low permeability liner, the potential market for DRC for this application is approximately 0.12 Million CY per year and amounts to 1.2 Million CY during a 10 year period. Additional Civil Engineering applications like the construction of berms, embankments and backfills are not included in this estimate.

Potential market for use of DRC as backfill and for construction of berms and embankments was not quantified under this study. This market offer immense potential for use of DRC, especially large scale applications, which are economically more viable. Sadat Associates Inc. is specifically aware of several such projects where quantities over 0.5M Million CY each will be required for backfill applications as part of site remediation activities.

5.3 Manufacturing Applications

The brick manufacturing facility in Hillsborough, New Jersey manufactures about 35 Million bricks per year. This amounts to a total volume of 0.1 Million CY of clay per year and 1.0 Million CY for a 10-year period. However, the applicability studies indicate that the DRC will require some amendment prior to use in manufacturing applications.

6.0 Cost Analysis

The incremental costs associated with the use of DRC for upland applications include the offshore transportation costs, unloading, and material placement costs. These costs were estimated based on the actual costs incurred during the demonstration projects and are discussed in detail in a separate report prepared by Soilteknic, Inc. Table 6.1 presents a cost comparison for the use of DRC and other products for applications discussed under Section 4.0. The costs associated with DRC and upland clay applications are based on data available from the Soiltecknic, Inc. report. Other cost estimates are based on in-house expertise at Sadat Associates Inc. and on industry standard cost data publications like the RS Means.

Table 6.1 - Cost Comparison of DRC and Other Materials

Material Type / Construction Item	Mined Clay ($/CY)	Synthetic Liners ($/CY equivalent) (4)	Common Fill ($/CY)	Dredged Red Clay ($/CY)
Material Purchase (1)	$15	$17.98	$12.10	None
Offshore Transportation	None	None	None	$1
Unloading (2)	None	Included	Included	$5
Bulkhead Usage	None	None	None	$0.50
Reloading/Upland Transportation	Same as other Materials	Included	Same as other Materials	Same as other Materials
Moisture Adjustment (3)	None	None	None	$5
Placement/ Spreading and Compaction	$2.30	24.17	$2.30	$2.30
Regional Repository	None	None	None	$1.27
Total	**$17.30**	**42.15**	**$14.40**	**$15.07**

(1) Current market price
(2) Unloading of dredged red clay to trucks
(3) Moisture conditioning using farming disks or other means
(4) Costs associated with 27 sq. ft. of liner, which will replace 1 CY of clay in a 1ft. thick layer.

7.0 Conclusions

The investigations conducted as part of this study indicate that there is sufficient and viable market for the upland use of DRC. The estimated potential market for the upland use of DRC for the next 10 years is approximately 22 MCY. Out of this, the potential market for use as containment barriers for landfill capping is 9.66 MCY and for use in site remediation projects is 10.23MCY. The potential market for Civil Engineering applications like pond liners, wetland restoration etc. is estimated as 1.2MCY. Additional market exists for use of DRC as structural backfill material in civil engineering applications. The market for use of clay in ceramic manufacturing industry is estimated as 1.0 MCY. However, the DRC material will require amendment before it can be used for ceramic manufacture.

The cost comparisons demonstrate that the costs associated with the use of DRC material for all upland applications are comparable to those of the competing products. The DRC costs associated with containment barrier applications show substantial advantage over costs of competing products. The financial viability of using DRC as an alternative to conventional upland clay, synthetic liners or common fill depends heavily on the applicable transportation costs. If DRC can be transported via scows directly to the site of application, there will be substantial cost savings.

Table 7.1 - Summary of Estimated DRC Market

Potential Use	Estimated Market (Million CY)
Containment Barrier Applications	
Landfills	**9.66**
Site Remediation	**10.23**
Civil Engineering Applications	**1.2**

Manufacturing Applications	**1.0**
TOTAL	**22.09**

8.0 Recommendations

This study demonstrates that there is sufficient, financially viable market for the use of DRC in upland applications. Therefore, it is recommended that a detailed marketing and implementation plan be developed to further define the operations of a repository and a marketing program to secure outlets for the material. The marketing and implementation plan should include detailed plans for the following:

- Identify and develop potential specific DRC application markets through discussions with landfill managers, builders engineers and contractors.
- Improve awareness among the professional and regulatory community about the potential applications.
- Identify projects with potential for large scale DRC application.
- Identify potential projects that the State (DEP/DOT) can influence.
- Detailed feasibility study for a repository including alternative sites and costs.
- Technical specifications and work plans for typical DRC applications like landfill cap, structural fills etc.

APPENDIX A

Landfill Questionnaire

FILL MATERIAL DEMAND ESTIMATION QUESTIONNAIRE

1) Name of Facility: ____

2) Contact Person: Mr./Ms.____

3) a) Phone #: _______________________b) Fax #:_________________

4) Address: ____

5) Type of Facility:
a) Public Sanitary Landfill b) Private Sanitary landfill
c) Industrial Landfill d) Private Remedial Site
e) Public Remedial Site f) Other_________________

6) Total Property Area of the Landfill\Remediation Site: ____________(acres)

7) Actual Landfilled\Remediated Area: ____________(acres)

8) Estimated Demand for Low Permeability Fill Material:

Year					
Quantity (CY)					

9) Criteria for Acceptance as Low Permeability Fill Material:

a) Analytical Criteria: ____

b) Engineering Criteria: ____

10) Estimated Demand for Structural Fill Material (if clay is a potential alternative):

Year					
Quantity (CY)					

11) Criteria for Acceptance as Structural Fill Material:

a) Analytical Criteria: ____

b) Engineering Criteria: ____

12) Current Use of Fill Material:

	Material Used	Costs at Site ($)	Placement Costs ($)
Low Permeability Fill			
Structural Fill			

13) Remarks:____

____

____

Sadat Associates, Inc.
Engineering and Environmental Science
1545 Lamberton Road • P.O. Box 4129
Trenton, NJ 08610 • 609-826-9600