STABILIZATION OF PHOSPHATIC CLAY USING LIME COLUMNS

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STABILIZATION OF PHOSPHATIC CLAY USING LIME COLUMNS

FINAL REPORT

by

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STABILIZATION OF PHOSPHATIC CLAY USING LIME COLUMNS

ABSTRACT

The phosphate mining industry has created over 85,000 acres of phosphatic waste clay ponds in central Florida, with approximately 5,000 acres of additional ponds created annually. Techniques have been developed to drain, crust, and reclaim these areas; however, these reclaimed areas are generally only suitable for agriculture or highly specialized use (such as wastewater effluent disposal areas). Construction of buildings or utilities on these lands by conventional methods is not possible because, just a few feet below the surface crust, the low strength clay remains very soft and highly compressible due to a high water content. For this reason, a need exists to develop economical and practical techniques to remediate these areas to a level at which the land can be utilized for a broad range of purposes, such as suburban housing, light commercial building, and utilities.

The lime column method has been used in other countries, primarily in Scandinavia and Japan, to provide additional bearing capacity and reduced settlements for soft clays, and appears to be suitable for use with phosphatic waste clay. Lime columns are constructed <u>in-situ</u> by intimate mixing of clay and finely pulverized quicklime (CaO). These columns reduce plasticity, increase permeability and strength, and lower the water content through hydration and pozzolanic reaction.

In this report, field scale experimental programs that were done on two 40 metre by 40 metre (125 feet by 125 feet) test plots, are described. The field test program was completed to compare the settlement magnitudes and rates of the phosphatic clay due to surface loadings for plots with and without lime columns, as well as demonstrate the feasibility of dry mixing lime with very soft soils.

Strength measurements of the lime columns correlated well with the laboratory data obtained from BCI's study in 1987. Results show that the shear strength of lime columns has increased more than ten times over untreated clay within 300 days of mixing. The solids content of the lime columns has increased significantly from about 30 percent up to 65 percent, after being mixed with lime. The solids content of the clays between the columns has also increased from about 30 to 35 percent, after column installation. The permeability of amended clays increased one to two orders of magnitude as compared to untreated phosphatic clays. Consolidation of waste phosphatic clays appears to be accelerated by the installation of lime columns, while at the same time reducing the anticipated total magnitude of settlement.

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FIPR 91-02-088

1.0 INTRODUCTION

1.1   Statement of Problem

There are presently more than 34,000 hectares (85,000 acres) of phosphatic clay ponds and clay-filled mine cuts in central Florida, with approximately 2,000 hectares (5,000 acres) of additional ponds created each year by phosphate mining. Growth in the central Florida mining district has generally been constrained to unmined areas and reclaimed mined-out areas. Both residential and commercial developers have had to deal with the impacts of waste clay disposal. Further, the mining industry has viewed waste clay disposal areas and ponds as a long-term liability with development typically restricted to agricultural or habitat uses. As demonstrated by projects in the Lakeland area, the cost of development through or around areas underlain by phosphatic waste clays is significantly higher than non-clay filled areas.

Techniques have been developed to drain, crust, and reclaim these areas, although as presently reclaimed, these areas remain generally only suitable for agriculture or for highly specialized use (such as wastewater effluent disposal areas). Construction of buildings or utilities by conventional methods is generally not cost effective without extensive stabilization or excavation and replacement site work. This is because just a few feet below the surface crust, the low strength and highly plastic clays remain very soft and compressible. For this reason, a need has existed to develop economical and practical techniques to reclaim these areas to a level at which the land can be utilized for a broad range of purposes, including suburban housing or light commercial development.

The stabilization technique being evaluated in this study is the use of lime columns. The in-place mixing of dry lime with soft phosphatic waste clays was originally studied by BCI in 1987. Based on the results of that bench scale study, FIPR (Florida Institute of Phosphate Research) and ASCE's Civil Engineering Research Foundation (CERF) funded this field scale study to evaluate the field scale feasibility and effectiveness of the lime column technique.

The primary function of the lime columns, as it relates to development on phosphatic clays, is to reduce total settlement and accelerate consolidation due to surface loadings. Typical settlements in 7 to 14 metre (20 to 40 foot) thick phosphatic clay deposits are often on the order of tenths of metres, when subjected to surface loadings of 9.8 to 19.6 tons/m^2 (200 to 400 psf). These settlements often take several to tens of years to complete, resulting in long term maintenance for structures, roadways and utilities. The lime columns treatment is expected to reduce the total settlement to a few centimetres and increase the rate of completion to months rather than years.

Based on the utilization of lime columns outside the United States, it was presumed that this method could be used to treat areas underlain by phosphatic waste clays. Improvements to the ground strength and compressibility properties should allow these low utility areas to be used for transportation or utility corridors in addition to development sites. Once these areas can be used, their value to the owner is increased as well as increasing tax base for the municipalities.

1.2 The Lime Column Approach

The lime column method has been used in other countries, primarily in the Scandinavian countries and Japan, to provide additional bearing capacity and reduced settlements for soft clays. Based on the previous bench scale testing, it appears to be suitable for use with phosphatic waste clay as well. Lime columns are constructed in-situ by intimate mixing of clay and finely pulverized unhydrated lime, or "quicklime"

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(CaO). As shown in Figure 1, a drilling tool is augered into the ground to the desired depth, reversed, and as the rod is slowly retracted, quicklime is injected into the clay by compressed air through a hollow rod in the auger. The auger blades are turned slowly to mix the lime with the saturated soft clay, leaving behind a two to three foot diameter column of lime/clay mix. Once this column cures (dries) the clay/lime mixture has increased permeability, reduced plasticity, and much higher strength characteristics than unmixed clays because of the reduced water content caused by hydration and pozzolanic reactions.

The lime columns are installed at a spacing that treats about ten percent of the total surface area, with the interstitial areas between the columns remaining untreated.

1.3 Previous Studies

In 1987, BCI completed a laboratory study sponsored by FIPR (No. 85-02-056) on the effect of lime and other admixtures on the engineering properties of phosphatic clay. Results indicated that the mixing of quicklime with phosphatic clay reduced plasticity, increased permeability, lowered water content, and developed significantly higher strength characteristics than for unmixed clay.

Compressibility of clay admixtures was significantly reduced over unamended clay. This is primarily due to cementing/bonding in the clay admixtures that increases the strength and reduces the magnitude of deformations below the "apparent preconsolidation pressure" (the pressure at which the bonds begin to break down and deformation is increased). In practical terms, this means it takes more load or pressure on amended clay before "virgin" compression is induced. The result is a substantially reduced overall compression or volume change within the range of anticipated field pressure where lime columns might be used.

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Compressibility index values indicated that overall deformations of amended clays are on the order of 1/10th to 1/70th of unamended clay. This means that a house would have less settlement if it is founded on lime columns. A comparison of a clay with no lime added to the same clay with ten percent lime added is shown in Figure 2. Substantial reduction in overall deformations can be seen on the consolidation curve for clay with ten percent lime.

Laboratory determined permeability values of phosphatic clays increased about one to two orders of magnitude when amended, depending on the type and amount of additive. Permeability of untreated clays averaged 6.3×10^{-8} cm/sec (1.8×10^{-4} ft/day). The average permeability of all treated clays was 5.2×10^{-7} cm/sec (1.5×10^{-3} ft/day), an increase of eight to ten times. Although the permeability of lime columns is still low compared to most soils, it is higher than the clay that surrounds the column; therefore it acts as a vertical drain.

1.4 Study Objectives

Laboratory measurements of strength, compressibility, and permeability can be of great value if they can be related to in-situ conditions. To our knowledge, application of the lime column method to soft ground stabilization/reclamation had not been made in the United States. It was the objective of this study to demonstrate that lime columns could be installed on an existing clay pond and that the assumptions of increased permeability and strength and decreased compressibility are valid at field scale. If the field scale results confirm the laboratory testing conclusions, the feasibility of using lime columns as an alternative to other stabilization techniques is greatly enhanced.

2.0 LITERATURE REVIEW

2.1   Soil Stabilization with Lime

Lime has been used for centuries for the stabilization of clays. For example, lime was used along with alabaster (gypsum) for mortar and plaster to build the huge limestone pyramids of ancient Egypt (Boynton, 1980). Since around 1900, progressively larger quantities of lime have been used in industry as a chemical reagent. Currently, more than 90 percent of the total amount of lime produced is sold as a chemical in its oxide and hydroxide form. Lime is the principal and lowest cost alkali available.

Recent figures show that approximately 17 percent of the lime produced in the United States is used for construction purposes, with the rest used for agriculture and chemical/industrial purposes. The percentage for construction is growing as new applications for lime are discovered. Lime stabilization methods for road and soil stabilization are widely used to permanently consolidate soils and base materials. The methods result in a significant increase in soil strength and bearing capacity and decrease in water sensitivity and volume change during wet/dry cycles. Many states have written standard procedures for lime stabilization of roads (i.e. Alabama State Department of Transportation, 1984).

The properties of soil-lime mixtures depend on: 1) the properties of the soil, 2) the properties of the lime (chemical composition and gradation), 3) lime content, 4) method of mixing, 5) duration of "mellowing" period (time between mixing and placement, 6) curing environment (moisture conditions, chemistry, and temperature), and 7) age.

In general, highly plastic (CH) clays are quite reactive or pozzolanic. Alkaline soils are usually more responsive than acidic soils. Sulfate has been reported to have a detrimental effect on lime stabilization due to the formation of the highly expansive

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mineral ettringilite. There are contradictory findings in the literature regarding the role of organics. Townsend and Donaghe (1976) report that soils with more than one percent organic content do not usually respond well to lime treatment. Sabry and Parcher (1979) report favorable response in a clay with 1.5 percent organics. Mitchell and Hooper (1961) found satisfactory performance with an expansive clay having eight percent organic content. Arman and Munfakh (1972) also report improved behavior in eight of the 11 organic clays tested, with organic contents as high as 20 percent.

Regarding lime properties, Remus and Davidson (1961) presented results of three montmorillonitic clay soils treated with various limes at a dosage of six percent. The strengths (at seventh and 28-day cured) of the soil treated with dolomitic monohydrate lime were significantly higher than the strengths of the soil treated with calcitic slaked lime. Alexander et al. (1972) found that unslaked lime was more effective than hydrated lime in improving strength. At lime contents above two percent, the coarser unslaked limes were more effective because the fine limes caused a significant flocculation, resulting in a reduction in the density of the soil.

The amount of lime to be added depends on the intended design improvement. Typically, there are no established mix design procedures for determining optimum lime content for soil modification. Criteria for selecting lime content are often performance based, and often include requirements such as no reduction in plasticity index, or increase in strength or final pH. Typical lime additions for modification of high plasticity clay are approximately three to ten percent, by dry weight basis (Boyton, 1980). Hydrated lime (slaked) typically is used at slightly higher amounts than unslaked lime for stabilizing high plasticity clays.

One example of performance based lime mixing is presented by Eades and Grim (1966) and consists of adding increasing amounts of lime to a 20 percent solids content soil slurry. The optimum lime content is then taken to be the lowest

percentage of lime that produces a slurry pH of 12.4, one hour after mixing. While this procedure ensures sufficient free lime for pozzolanic reaction to occur, it cannot be used to predict exactly how much strength gain will occur.

A reduction in the plasticity of the clay is reported when clay is mixed with lime (Broms and Bowman, 1978). The plasticity is reduced through the physio-chemical phenomenon of cation exchange (Roads and Streets, 1979). The addition of lime to reactive soil causes an immediate reduction in the plasticity index (PI). According to Brandl (1981), the plastic limit always increases, while the liquid limit either remains unchanged or sometimes decreases, depending on the amount and activity of the colloidal clay minerals.

2.2   Stabilization of Phosphatic Clay with Lime

Very little previous research has been done on stabilization of phosphatic clay with lime. Other potential stabilizers that have been investigated include phosphogypsum and flyash (Barwood, 1986).

Zellars-Williams, Inc. (1983) performed laboratory strength tests on mixes of slaked lime and phosphatic clay at initial clay solids contents less than or equal to 42 percent, and also investigated the effect of lime on the flocculation of dilute clays. The majority of the vane shear strength readings was zero, although strengths as high as 22 kPa (0.23 tsf) were recorded. The authors concluded that the effectiveness of the addition of lime to phosphatic clays was dependent on the amount of water present in the system, and that treatment of massive volumes of fresh waste clays was not economical.

Selfridge (1985) investigated the consolidation and curing strength behavior of phosphatic clay mixed with lime and gypsum. Clays from several different central Florida mines were tested at initial clay solids contents ranging from 12 to 14 percent with 4, 8, and 12 percent lime added. Twenty-eight day undrained strengths up to

1.2 kPa (25 psf) were obtained, with strengths as much as nine times the initial strength of the untreated clay. The immediate strength of the treated clay was nearly twice that of the untreated clay in many tests. Selfridge found a significant decrease in the time rate of consolidation of the treated clay as well as a decrease in the overall amount of consolidation. These results were attributed to flocculation and agglomeration of the clay/lime particles which make them behave more like sand and less like clay.

An in-house study was completed by FIPR on strength of phosphatic clay mixed with various quantities of lime, phosphogypsum, and other additives (Barwood, 1986). Phosphatic waste clay samples were prepared with clay solids content of 5, 10, 20, and 30 percent. Lime was then added to these samples at 5, 15, 35, 50, and 100 percent by weight. Also some mixes of lime and gypsum were prepared at a 1:5 ratio of lime to gypsum. Temperatures up to 90 degrees Celsius were used to accelerate the curing process on some samples.

The tests performed by FIPR indicate that there was little strength gain for any mixes with clay at an initial solids content of five to ten percent. Moderate to high strength gains were observed on clays at 20 percent solids content with a minimum of seven percent lime and 35 percent phosphogypsum. Samples with clays at 30 percent solids content exhibited similar trends to those at 20 percent solids content, but had greater strength gains for comparable additions of lime.

2.3   The Lime Column Method

The lime column method, where unslaked lime or quicklime (CaO) is mixed in-situ with very soft clay, has been and is currently used extensively in Sweden, Finland, and Norway to stabilize roads and excavations and as foundation preparation for light structures (Broms, 1984). A mixing tool shaped like a large dough mixer with a 0.5 m (20.0 inches) diameter is used to mix in-situ the lime with the clay. The

length of the columns is typically 15 m (50 feet). The powdered lime is forced down the Kelly bar of the lime column machines to the mixing tool using compressed air.

In Scandinavia, specially designed truck-mounted carriers or standard front wheel loaders are used for the installation of the columns. The lime is stored in a 2.5 m^3 (88 cu ft.) container pulled by the rig or the loader. Previous production rates for lime columns were reported to be about 40 to 50 columns in eight to ten hours under favorable conditions. Recent conversations with Dr. K. Rainer Massarsch of GEO Engineering AB (Sweden) indicate they have increased production rates to as much as 3,000 metres per day. However, rates of 750 to 1,500 metres per day are still typical of on-going construction projects. The cost of lime columns (based on about 1,000 m/day) in Sweden is reported to be about $3.30 per metre ($1.17 per foot, $US), which makes the method very competitive, compared with steel or precast concrete piles or soil improvement methods (preloading, stone columns, embankment piles, etc.).

In Scandinavia, specially designed truck-mounted carrier (Linden-Alimac LPS 4) or a standard front wheel loader (e.g. Volvo M LM 641) are used for the installation of the lime columns. The LPS 4 machine can be used in weak soil conditions due to the low contact pressure (30 kPa/625 psf). The minimum required shear strength to carry the machine is about 6 kPa (125 psf). Since a 0.75 to 1.0 metre (two to three feet) thick fill is often required to site grading, heavier equipment can often be used.

The LPS 4 has a strip chart recorder where the amount of lime injected into each column is plotted as a function of the depth. A permanent record is thus obtained for each column.

The lime column method is mainly used to stabilize very soft inorganic clays with a liquid limit less than 100 percent, an organic content less than three percent, and an undrained shear strength less than about 20 kPa (400 psf). The method has,

however, also been used successfully in soft organic clay with a liquid limit of up to 180 percent.

The response of the clay with lime has been found to vary depending on the properties of the clay. The shear strength generally increases with increasing solid content and with decreasing plasticity index. Clay mineralogy is also important.

2.4   Laboratory Testing Program (BCI, 1988)

In 1988, BCI completed a laboratory investigation to find the effect of unhydrated lime (CaO) on phosphatic waste clays having a wide range of plasticity. The parameters tested were plasticity, shear strength, hydraulic conductivity, compressibility, compaction, and pH. Laboratory controlled variables, which affected the engineering properties, were the initial strength of untreated clay (determined by the initial water content or solids content), the percentage of admixture (lime), and the curing time.

Samples were prepared at several initial clay strengths to show the change in properties of clay admixtures over a wide range of initial conditions in the field. Clays were prepared at strengths of 2, 4, 8, and 12 kPa (42, 84, 167, and 250 psf) by air drying to the correct water content. The lime was then mixed with the clay for at least five minutes with a large commercial mixer.

After sitting undisturbed for approximately five minutes (curing time), the clay mix was then compacted with a wooden tamper into 30 cm (12 inch) long sections of 7.5 cm (3 inch) diameter PVC pipe. The maximum lift thickness allowed was 3.75 cm (1.5 inches). Each pipe was filled with 25 cm (10 inches) or more with the clay/additive mixture. Once compacted, all samples were stored submerged in a water bath at 72 degrees, the approximate ground temperature in central Florida.

Each mixture was tested for water content and strength at zero to 360 elapsed days after preparation. The majority of the strength tests were run with a fall cone penetrometer. In addition to the fall cone method, shear strengths were measured by vane shear and unconfined compression methods for comparison purposes.

BCI (1988) found that the shear strength of phosphatic clay was greatly increased when amended with various amounts of lime. The amount of strength gained depends on the initial strength of the clay, the amount of lime, the amount of time the clay is allowed to cure, and the chemical properties of the clay itself. In general, the benefit of increasing the lime content appeared to peak between 15 and 20 percent lime. The initial water content of the clay is also a significant factor controlling the strength of the lime columns. The undrained shear strength increased 30 times the original strength within about 180 days. An additional increase in strength of about ten percent was measured from the 180-day strengths to 300-day strengths.

3.0 TEST PLOTS

3.1 Site Selection

BCI received a signed contract from FIPR to do this field scale study of the stabilization of phosphatic clays with lime columns on March 23, 1992.

The initial task for this study was the selection of an appropriate test site for field installation of the lime columns. It was expressed by FIPR that the selection of a test site should be a clay settling area belonging to or operated by an active phosphate mining company. Under this condition, BCI visited several industry sites and met with mining representatives in Polk County.

After extensive review of in-house maps, aerial photographs, and our general knowledge of the central phosphate district, BCI determined that the IMC Haynsworth Mine, southwest of Bradley, Florida, would be the most appropriate area for the study. Several meetings were held with the reclamation staff of IMC Fertilizer, who operated the Haynsworth facilities, and with the property owner, American Cyanamid Company. The outcome of these meetings was to narrow selection of possible sites to three areas, known as areas M-1, M-2, and M-3. Each of these areas is an above grade clay settling area, which is currently undergoing mandatory reclamation efforts under the regulations of the Florida Department of Environmental Protection (FDEP), Bureau of Mine Reclamation. These three areas are shown in Figure 3 (pocket aerial map)

BCI initiated a preliminary depth probing and clay sampling program to evaluate each of these three areas. Area M-1 was found to have clay depths in virtually all accessible areas in excess of 10 metres (30 feet). Due to constraints of the lime column's installation equipment at the time of this study, the maximum treatment depth was 9 metres (27 to 28 feet). Thus, Area M-1 was considered not suitable for the study. Area M-3 was found to be of adequate depth, specifically less than 9

metres (27 to 28 feet). However, solids content profiles within the portions of Area M-3 tested indicated a solids content profile averaging less than 20 percent by weight. This solids content profile was not suitable for support of the fill materials necessary for operation of the drill equipment and application of the test load and gradually below the desired starting point of 30 to 40 percent. With clay depths typically less than 9 metres (27 to 28 feet) and clay solids averaging 30 percent or slightly higher, it was determined that Area M-2 would be the most appropriate for the test plot location. Figure 3 shows the general site location with Area M-2 highlighted.

The basic field test program involved the comparison of settlement of the phosphatic clays due to surface loadings for a plot with lime columns and a plot without lime columns. A 1 to 1.3 metres (3 to 4 foot) thick fill pad was used to provide equipment access and to simulate the surface loadings due to site grading and low pressure floor loads typical of slab-on-grade construction for residential and light commercial structures (about 20 kPa/400 psf).

Each field plot was sized to be about 40 metres by 40 metres (125 feet by 125 feet). About 1.3 metres (4 feet) of fill was placed over dewatered and partially reclaimed waste clays in area M-2 for the lime column plot (Plot A). Due to near-surface bearing capacity failures at the time of backfill loading application, only about 0.8 to 1 metre (2.5 to 3 feet) of fill was placed on the control plot (Plot B). The fill was placed directly over the vegetation to help provide surface stability for earthmoving equipment. A schematic of the test pad areas and their relative location and size within area M-2 is shown in Figure 4.

The lime columns were constructed in one of the test plots with spacing and column length using guidelines established design methods (Broms, 1984). This spacing was typically designed to be 1.5 to 1.8 metres (4.5 to 5.5 feet) on center. The second plot, adjacent to the first, was left unaltered (no lime columns installed) as a reference.

3.2 Phosphatic Clay Sampling

Prior to the column installation, each test plot was probed and sampled to define the existing conditions and extent of the clays within the test area. Laboratory tests (solids content, percent passing No. 200 sieve and Atterberg limits) were completed to define the properties of the clay. The test results showed that for a depth of more than 1.5 metres (5 feet), the clay in both plots have solid contents of about 25 to 35 percent with an average of 98 percent passing No. 200 sieve. Figures 5 and 6 show the initial solids content profiles. The clay is highly plastic with a plastic limit of about 73 to 77 percent and plasticity index (PI) ranging from 129 to 151 percent. It is classified as CH in Unified Soil Classification System (USCS).

In addition, BCI completed a series of vane shear tests at various depths and locations within each plot to determine existing peak (undisturbed) and remolded shear strength profiles with depth. Vane shear test results for each test plot are provided in Figures 7 through 10.

3.3 Contractual Services Coordination

Concurrently with the site selection efforts, BCI prepared a request for proposal for a specialty geotechnical contracting firm to provide equipment fabrication, mobilization, and lime column installation at the test site. This proposal request was delivered to three contracting firms known to BCI for their geotechnical capabilities and which had expressed interest in the study.

Based on the responses received, BCI selected Hayward Baker, Inc. (HB) of Odenton, Maryland to provide the specialty contractor services. HB also has offices and personnel in Tampa, Florida. HB and its parent company GKN Keller are recognized worldwide as a leader in subsurface soil remediation and specialty geotechnical contracting. Through negotiation, a detailed scope of services and a contract budget was established.

As part of an effort to reduce costs and obtain in-kind services, BCI negotiated for the donation of 20,000 pounds of quicklime from Allied Lime Company of Montgomery, Alabama. Lime transportation to the test site required contracted trucking. This effort was scheduled by HB to coordinate with their mobilization schedule.

BCI contracted McDonald Construction Company of Lakeland, Florida, to place overburden fill soil over each of the two designated test plot areas, with each test plot receiving approximately 0.9 to 1.2 metres (3 to 4 feet) of fill over a 40 metre by 40 metre (125 foot by 125 foot) square area.

During the course of fill placement, it was observed that the clays beneath the extreme eastern edge of the control pad were experiencing localized shearing failure due to the rapid loading of the fill and vibration from earthmoving equipment. It was decided to restrict further equipment operations from this area and limit additional fill placement to the remaining stable area. As a result, the lime column plot received 1.5 metres (4.5 feet) of fill and the control plot received approximately 1 metre (3 feet) of fill.

3.4 Lime Column Installation

HB mobilized their lime column installation equipment on September 12, 1992. Over a period of three weeks, 163 columns with a diameter of 0.5 metre (1.6 foot) were installed. The typical depth for the columns was a nominal nine metres (27 to 28 feet) below the fill pad. The columns were installed in a 25 metre by 25 metre (75 foot by 75 foot) test plot area using a nominal 1.6 metre (5.3 foot) spacing center-to-center. The general procedure for column installation was described previously in Section 1.2 of this report. Figure 11 provides a diagram of the installation process. The actual column installation is shown in Figures 12 to 14.

Column installation was accomplished using a KBO hydraulic rotary drill with a specially developed, 0.5 metre (1.6 foot) diameter mixing tool to blend the materials. A high pressure (170 kPa/25 psi), low air volume injection system was used to inject the dry quicklime through the drill string into the clays. Various combinations of mixing rate, injection rate, and pressure settings were tried in a series of preliminary test columns to determine which installation settings would result in the best clay/lime mixing. In general, columns were installed with about 15 percent lime mixture by weight.

3.5 Monitoring Efforts

Immediately following the installation of the lime columns and demobilization from the site by HB, BCI installed a series of 32 settlement monuments within the two test plot areas (Figure 15). Concurrently, BCI also installed a series of 18 piezometers at varying depths within both the lime column plot and the untreated control plot. The settlement monuments were used to monitor relative settlement of each test area while the piezometers were used to measure pore pressure levels and changes at different depths in the clay profile.

Monitoring efforts following lime column installation included settlement measurements of all settlement monuments twice monthly, reading of piezometer pore pressure levels twice monthly, and visual record of obvious changes in site conditions during each site visit. Additionally, BCI has established a sampling and testing program to collect clay profile samples for solids content testing, and vane shear testing of both the treated and untreated clay areas. The lime column test plot was tested for shear strength both within the columns and directly adjacent to the columns.

4.0 RESULTS AND DISCUSSION

4.1   Settlement

Settlement of lime column and control plots was monitored in the field using surveying equipment.   Sixteen settlement monuments were placed and evenly distributed on each plot. Two reference monuments were placed on stable dike areas, located about 150 feet from the plots. The results of averaged settlements for both lime column and control plots are shown in Figure 16 (Time versus Settlement Plot). The predicted settlements beyond the current date are also illustrated in these curves.

Figure 16 shows that at 300 days following lime column installation, the amount of settlement of the lime column plot was higher than that of the control plot by approximately 50 percent. The lime column plot settled about 38 cm (15 inches) and the control plot settled about 28 cm (11 inches).

Theoretically, it was expected that immediate settlement would control the total settlement at the lime column plot and its secondary settlements would be minimal. The control plot (without columns) was expected to consolidate slower than the lime column plot. Figure 16 shows that the control plot is consolidating slower than the lime column plot. This is because the lime columns have higher permeability than the surrounding clay and function as vertical drains. These vertical drains help accelerate the process of consolidation.

The lime column plot received somewhat more fill and thus more surface loading than the control plot. The lime column plot received about 1.5 metres (4.5 feet) of fill and the control plot received only about 1 metre (3 feet) of fill due to bearing failure at the time of the placement of fill material. This difference in loadings resulted in higher settlements and is probably the reason the lime column plot is showing more deformation.   To try and account for the loading difference, we

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computed the theoretical settlement of the control plot for a thickness of fill equal to the lime column plot. The adjusted settlement graphs are shown in Figure 17.

Figure 17 shows that the settlement of the control plot exceeded that of the lime column plot at about day 220 after the columns were installed. It was expected that the control plot will continue to consolidate. Based on finite strain based consolidation of the untreated clay area, the settlements measured to date represent only about 50 percent of the total primary consolidation anticipated.

It was initially anticipated that the primary settlement of the lime column plot would have stopped within about six months after loading and column installation. However, based on the data collected at day 300, the lime column plot still appears to be consolidating, however at a rate slower than that of the control plot.

4.2 Porewater Pressure Measurements

A total of 18 piezometers were installed in the lime column and control plots; six in the control plot and 12 in the lime columns plot, respectively. The piezometers were placed near the top, at mid-depth, and near the bottom of each location to monitor porewater pressure variation across the entire clay profile. Figure 18 shows a typical piezometer location profile. Figures 19 and 20 show the excess pore pressure data points at different times for the lime column and the control plot, respectively.

Figure 19 shows that the porewater pressure has been dissipating with time since the columns were installed. At a depth of 2.5 metres (8 feet) below the top of the pad, the porewater pressure has dissipated completely which is an indication of the end of primary consolidation. However, at a depth of 4 to 7 metres (12 to 20 feet), the porewater pressure still exists, while at about 8 metres (25 feet) depth, negative pore pressures were recorded both initially (at 20 days) and after 300 days.

The pore pressure data results from the control plot show smaller differences between the 20 day and 300 day readings. Again, readings from the eight foot depth are at hydrostatic as with the lime column plot. However, the readings at 6 metres (18 feet) show some positive pore pressures. The 300-day reading of the bottom piezometer in the control plot also showed negative pore pressure values, similar to the lime column plot, probably due to bottom drainage into underlying sandy spoil materials.

4.3 Shear Strength

Shear strengths of the amended and unamended clays were measured using a field vane shear device, laboratory torvane, the unconfined compression test, and the triaxial shear test.

Field vane shear tests were completed weekly, immediately following lime column installation for a six-week period, followed by monthly thereafter. Results were recorded and compared to changes in shear strength with time and depth.

Figures 21 and 22 show the comparison of average peak and remolded shear strength with depth for the lime column plot before lime columns and after lime columns were installed. Forty-three days after lime column installation, the effort required to measure the shear strength in the lime columns increased significantly to the point that hand operated vane shear equipment could not be advanced into the column. Due to this condition, Shelby tube samples from various depths were obtained from lime columns using a truck-mounted drill rig. Vane shear tests were performed in the laboratory on these relatively undisturbed samples.

Results show that the shear strength of the column increased by greater than 50 percent over untreated clays within seven days of mixing. Within 300 days of mixing, the shear strength of lime columns has increased more than ten times over

untreated clay. It was also observed that the shear strength of the clay profile between columns in the treated area also increased.

Unconfined compression tests run on undisturbed samples obtained from a lime column resulted in a compression strength of about 13 kPa (270 psf). This result is lower than that obtained from vane shear tests performed in the laboratory. The triaxial tests performed on the undisturbed sample of lime columns result in a friction angle of about 25 to 34 degrees and a cohesion of about 10 kPa (200 psf). The results of the laboratory strength testing of clays and lime column materials are presented in the Appendix of this report.

Figures 23 and 24 show the average peak and remolded strength versus depth for the control plot (Plot B) for before lime column installation, 7, 43, and 310 days after the columns were installed in Plot A. These data show no increases in strength over the time of the study in the control plot.

4.4 Solids Content

Plots of solids content versus depth before and after lime column installation for Plots A and B are shown in Figures 25 and 26. Figure 25 shows that at 318 days after column installation, the solids content of the clays between the lime columns has increased from about 30 to 35 percent. The solids content of the lime columns themselves have increased significantly from a starting point of about 30 percent to up to 65 percent, after being mixed with lime.

Figure 26 shows that for the control plot, the solids content values increased from about 30 percent to about 35 percent during the study period.

4.5   Permeability

The permeability tests were run with flexible wall permeameter on Shelby tube samples obtained from the lime columns and with rigid wall permeameter for remolded

unamended phosphatic clay samples. The tests were run using falling head method. A gravity applied hydraulic gradient of 10 to 15 was used for the tests using the rigid wall permeameter. For the flexible wall permeameter, a hydraulic gradient of 20 to 30 was used by applying hydraulic pressure through a burette panel.

The permeability of untreated clays averaged 1.8×10^{-7} cm/sec (5.1×10^{-4} ft/day). The average permeability of the lime columns was 5.7×10^{-6} cm/sec (1.6×10^{-2} ft/day), an increase of more than one order of magnitude of the unamended clays.

5.0 COST OF LIME COLUMNS

The cost of lime columns is dependent on the cost of lime and the rate of installation.   Publications from a lime column contracting company in Sweden estimates the cost of lime columns at \$3 to \$4.50 per metre (\$1.00 to \$1.50 per linear foot), U.S. currency. This cost includes materials and installation, based on a production installation rate of 40 to 50 columns or about 750 to 1,500 metres per day using the specialized installation equipment.

In order to relate the cost of lime columns to conventional construction methods, a preliminary economic analysis is necessary. For example: assume that a 25 metre by 25 metre (75 foot by 75 foot) one-story building is proposed on a very soft clay with a depth of 7 metres (20 feet). Conventional practice would likely involve the excavation of clay materials and replacement with select materials (sands). Local experience with this type of construction has shown that the cost for excavation and replacement are highly dependent on the proximity of both borrow material and a dump site for the clay, but they generally range between \$5.85/m^3 (\$4.50/cu yd) to \$8.45/m^3 (\$6.50/cu yd) for excavation of the clay and \$3.25/m^3 (\$2.50/cu yd) to \$5.85/m^3 (\$4.50/cu yd) for sand fill material. The cost for excavation of waste clays is typically much higher than for conventional excavation of sands and natural clays.   There is also the disposal expense and logistical difficulties associated with eliminating the waste phosphatic clays when a removal and replace operation is chosen. Ranges of costs are presented in Figure 27 for a remove and replace scenario.

The cost of lime columns depends on the cost of lime, amount of lime required (based on percent lime added and spacing of columns), and the rate of installation. Generally, it is assumed that 10 to 15 percent of the area is treated which equates to an average column spacing of about 1.5 metres (4.5 feet), when a nominal 0.6 metre (2 foot) diameter mixing tool is used. For example, it was assumed that 256

columns are installed in a 25 metre by 25 metre (75 foot by 75 foot) grid pattern, each with a depth of 7 metres (20 feet). It is further assumed that columns can be installed at a rate of 10 to 17 metres (30 to 50 feet) per hour, and at a cost for equipment (including operator) of $125 to $145 per hour. This analysis results in a much higher per foot price than stated in the Scandinavian literature source.

Low and high costs for installed lime columns have been estimated and are shown on Figure 27. The production rates cited above are estimated assuming field production equipment and personnel are properly adapted and trained for lime column installation. Production rates for the test plots, once the drill rig and liming station equipment were fully operational were on the order of 15 metres (45 feet) per hour. Because this field study involved the setup and operation of prototype equipment, we would expect actual field production rates to be faster.

As discussed above and shown in Figure 27 the use of lime columns at a nominal spacing of 1.5 metres (4.5 feet) is very competitive with the remove and replace option. It should be restated, however, that some surcharging time is required for the lime columns options which may not be available in certain situations.

6.0 CONCLUSIONS AND RECOMMENDATIONS

From the analyses of the data obtained to date, the following conclusions are presented:

- The installation of lime columns in phosphatic clays can be accomplished without significant changes to existing soil modification equipment available in the United States. Though there are safety concerns in handling unslaked lime, procedures were developed during the field study to provide a reliable supply of lime to the drill rig and the delivery system.

- The shear strength measurements of the columns correlate well with the laboratory data obtained during the previous study. The solids content and shear strength of the lime columns increased significantly compared to untreated clays.

- The permeability of amended clays also increased one to two orders of magnitude as compared to untreated phosphatic clays. Though a comparatively small increase, this improvement allows the columns to act as vertical drains, and thereby enhance the rate of settlement.

- This field scale study utilized a lime addition of about 15 percent (by dry weight). Based on the strength gain of the lime columns no additional lime is probably required for phosphatic waste clays.

- The spacing and size of the lime columns for this study was about seven percent (163, 0.5 metre (1.6 foot) diameter) columns over an area 625 square metres (5,625 square feet) in size. This spacing and coverage is on the lower end of the range discussed by other investigators. A closer spacing, larger diameter tool, and tighter coverage, probably about 1.5 metres (4.5 feet),

center to center, would likely result in faster and less consolidation than experienced in this study.

- Production rates for 10 to 12 metre long lime columns in Scandinavia are reported to be 500 to 1,500 metres (1,500 to 4,500 feet) per day, which are considerably better than were experienced in this study and assumed in our cost estimate. The Scandinavian production, if achievable on phosphatic clays would make lime columns a very cost competitive alternative for ground treatment.

- Research and production uses of lime columns in Scandinavia have progressed rapidly and they are now installing columns with mixtures of cement and flyash along with the lime.

- Consolidation of waste phosphatic clays appears to be accelerated by the installation of lime columns, while at the same time reducing the anticipated total magnitude of settlement that will occur under a given loading condition. This phenomenon is due to increased permeability of the clay lime mixtures and the columns acting as vertical drains, as well as pseudo-structural components. However, the total magnitude and rate of the settlement is still considered not impractical for building support purposes when the initial clay solids content averages about 30 percent, which was the case at the present test site. These results are consistent with the earlier laboratory study (Zellars-Williams, Inc., 1983; FIPR, 1988) which indicated that, typically, an average initial solids content of about 40 percent should be the starting point. Hence, practical application of lime columns in phosphatic clay will likely require that the clay be more aggressively dewatered than was possible at this test site. Or, alternatively, the rate of consolidation should be improved by increasing the proportion of treated area from the present value of about seven percent.

- Consequently, this present study has established a general lower bound for the clay solids content (32 percent) and the percentage of area treated (seven percent) for the practical application of lime columns in phosphatic clay.

- The use of pneumatic piezometers in the phosphatic clays give highly variable results even after several months of readings. These inconsistencies may be the result of plugging of the piezometer tips with the very low permeability clays and lack of or degradation of the soil/piezometer interface seal, allowing hydraulic connection to the surface.

The following general recommendations are presented based on our observations and conclusions:

- Since the rate of consolidation or settlement of the lime columns plot appears to be decreasing, the settlement plates should be monitored for the next few to several months to compare the movement of the two plots.

- Due to clay movement (mud waving) during fill placement, it may be desirable to place a geotextile material on the clay surface prior to placing fill materials.

- Production rates and utilization of lime columns in the United Stated would probably be enhanced significantly by encouraging future technology exchanges with Scandinavian researchers and contractors.

- Additional field studies, using closer spaced columns and/or higher solids content clays may prove beneficial in development of additional installation performance criteria.

ACKNOWLEDGEMENTS

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FIGURES

FIGURE 1. Graphical Representation of the Lime Column Installation Process
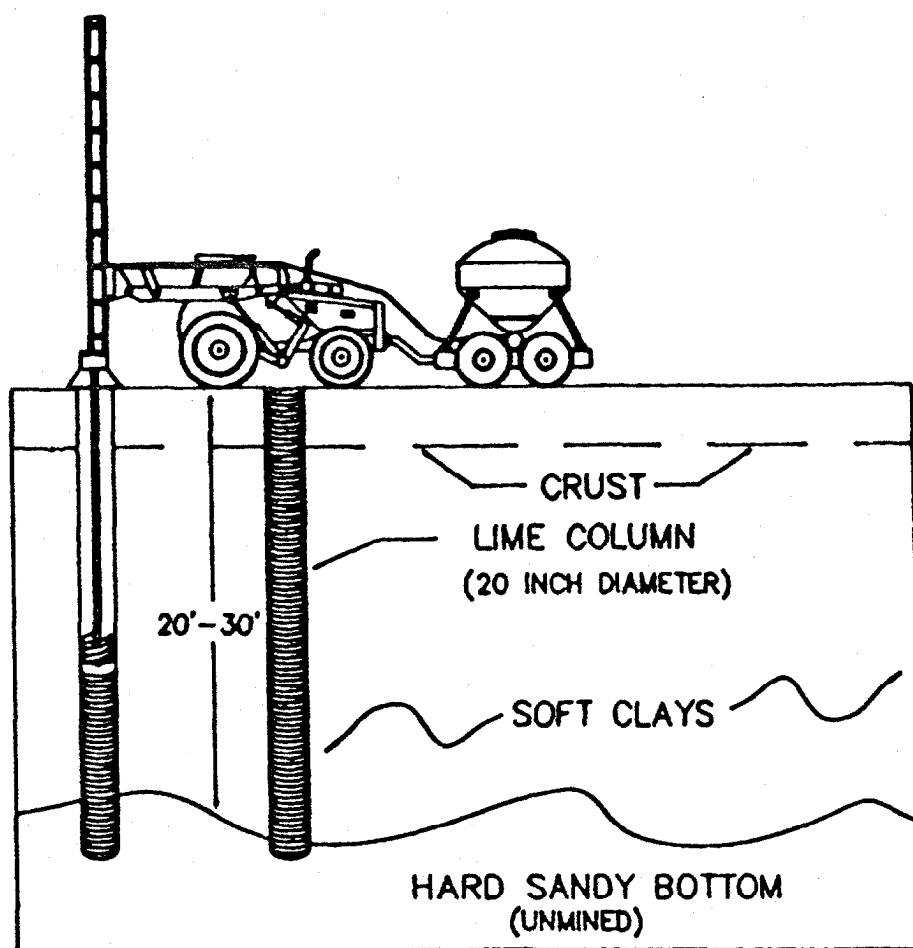
CONSOLIDATION TEST

SAMPLES A-2-0L & A-2-10L
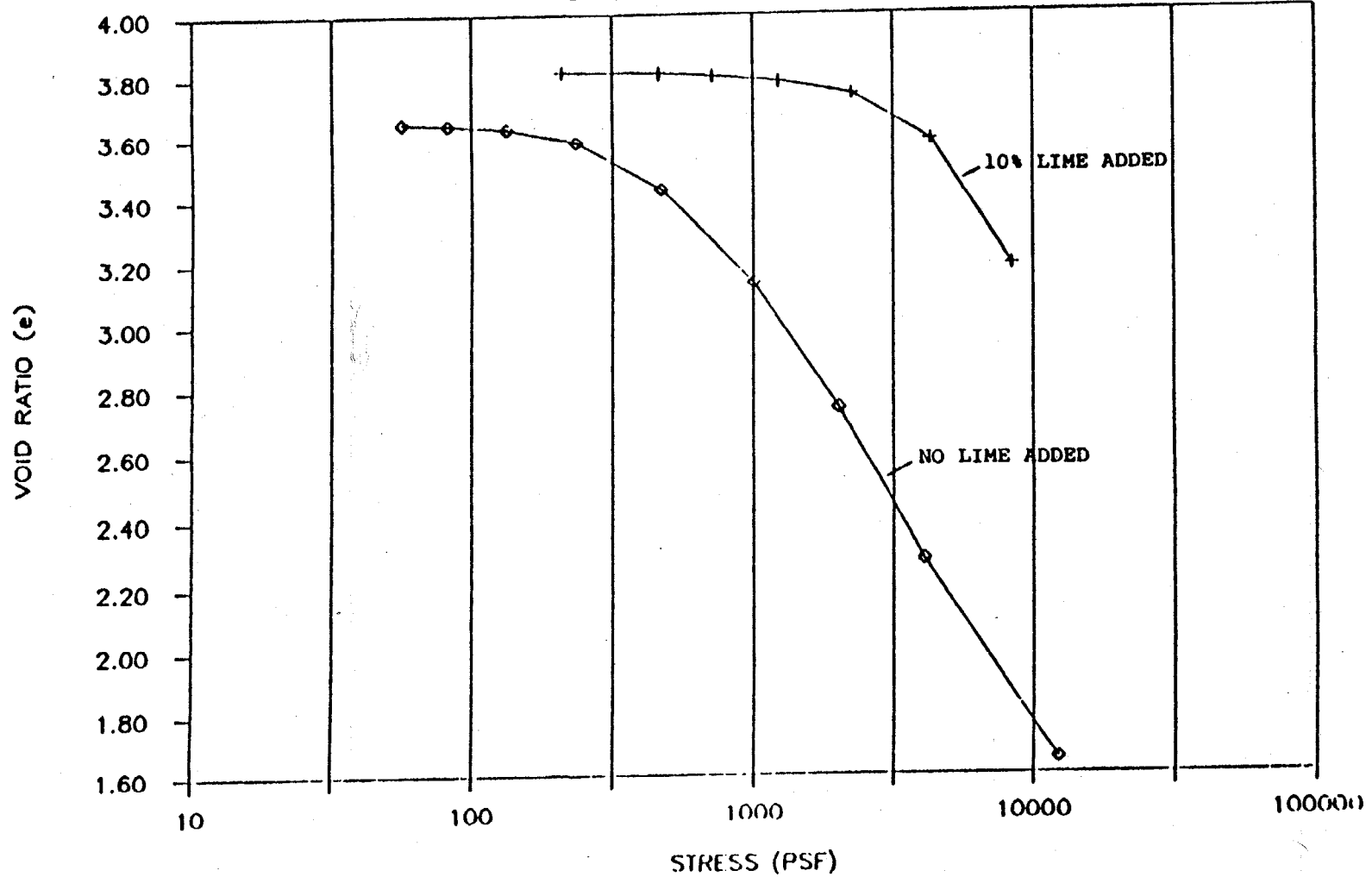
FIGURE 2: TYPICAL DEFORMATION CHARACTERISTICS OF PHOSPHATIC CLAY AND CLAY/LIME MIX

TEST PLOTS LOCATION

SCALE: 1 = 2000

FIGURE 3

PLOT B

CONTROL PLOT
NO LIME COLUMNS

APPROXIMATE
LIMITS OF
SURCHARGE FILL

PLOT A

LIME COLUMNS ONLY

EXPLORATORY
BORING
LOCATIONS
(TYPICAL)

75'
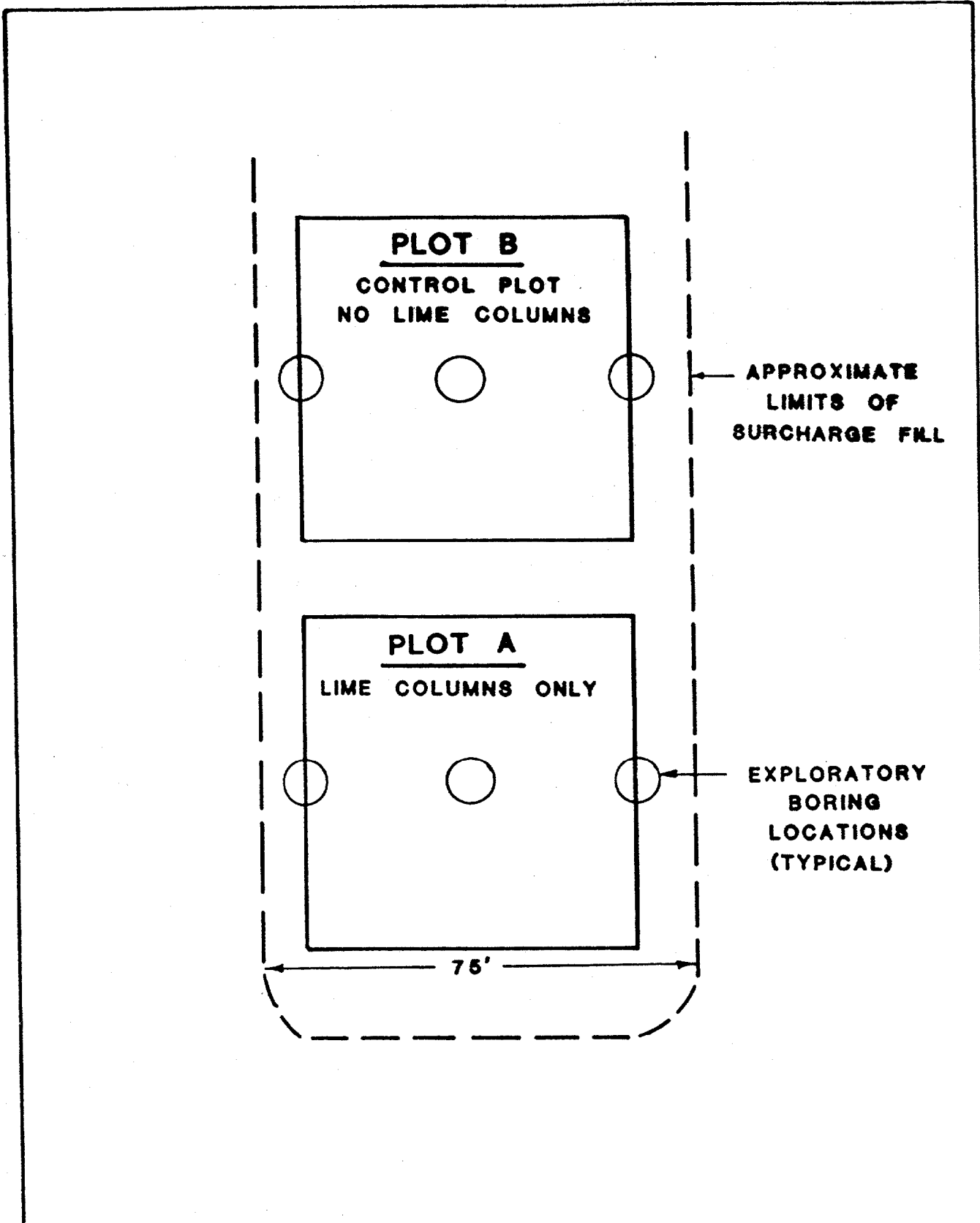
FIGURE 4:   PLAN VIEW OF
LIME COLUMN PLOTS

N0537

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DEPTH VS. SOLID CONTENT (PLOT A)
PRIOR TO LIME COLUMN INSTALLATION
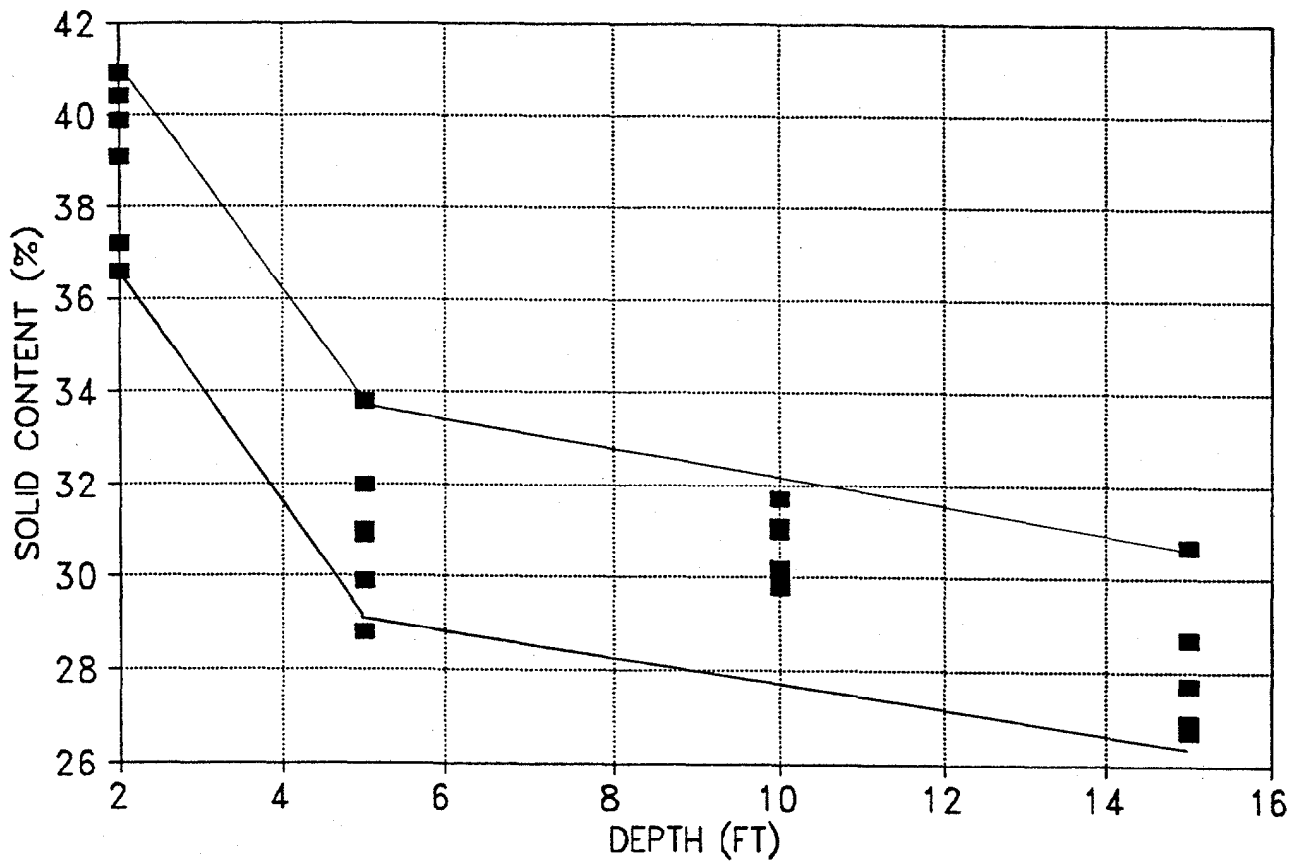
FIGURE 5

DEPTH VS. SOLID CONTENT (PLOT B)
PRIOR TO LIME COLUMN INSTALLATION
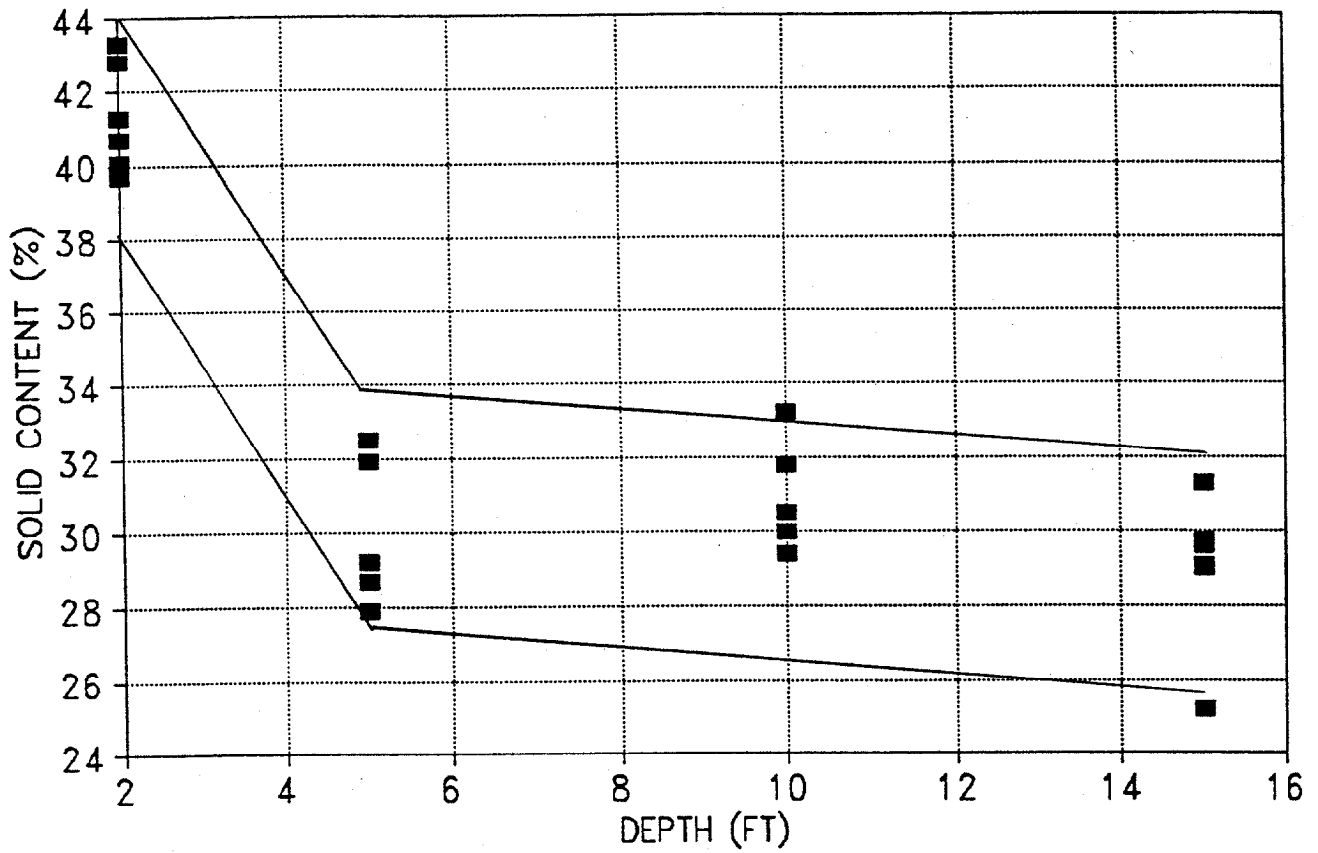
FIGURE 6

DEPTH VS. PEAK SHEAR STRENGTH (PLOT A)
BEFORE LIME COLUMN TREATMENT
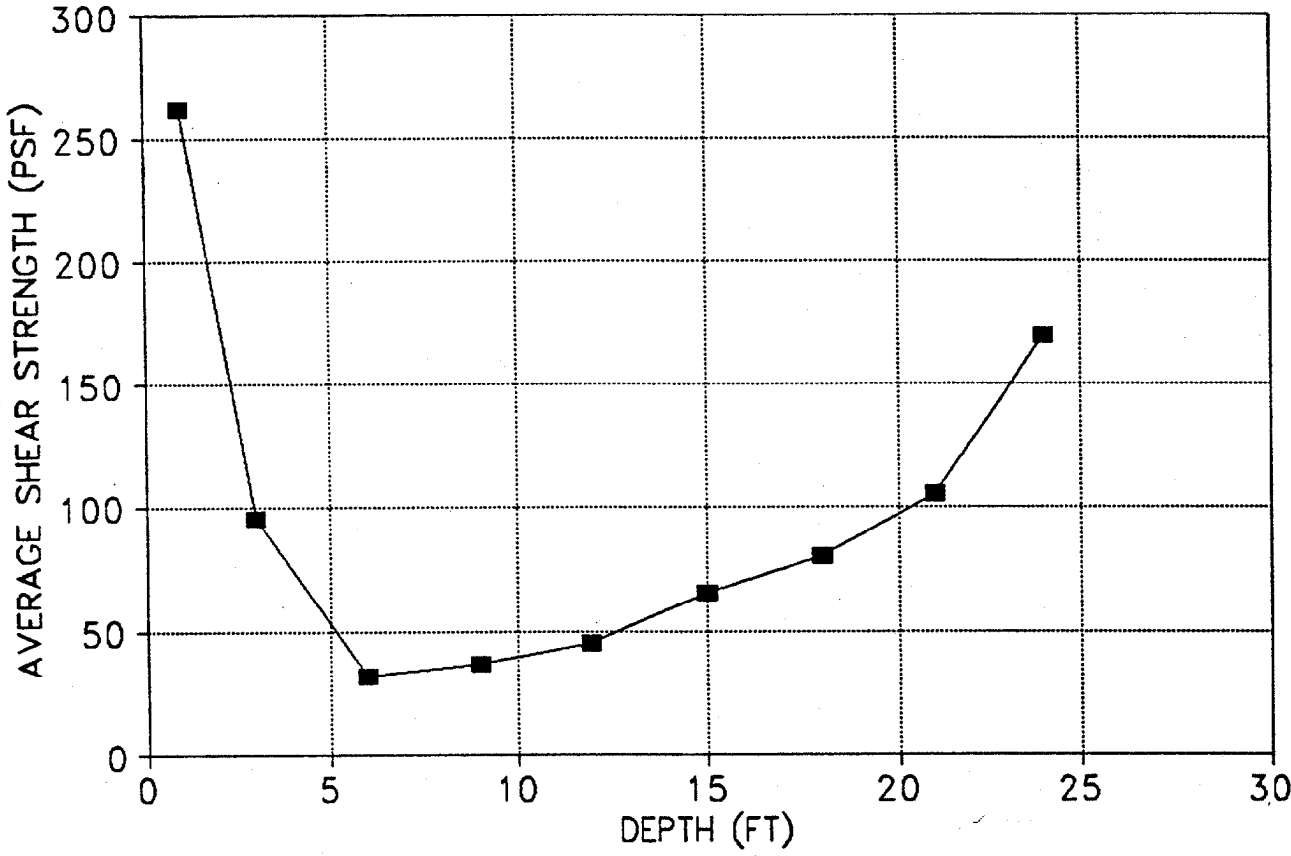
FIGURE 7

DEPTH VS. REMOLDED SHEAR STRENGTH
BEFORE LIME COLUMN (PLOT A)
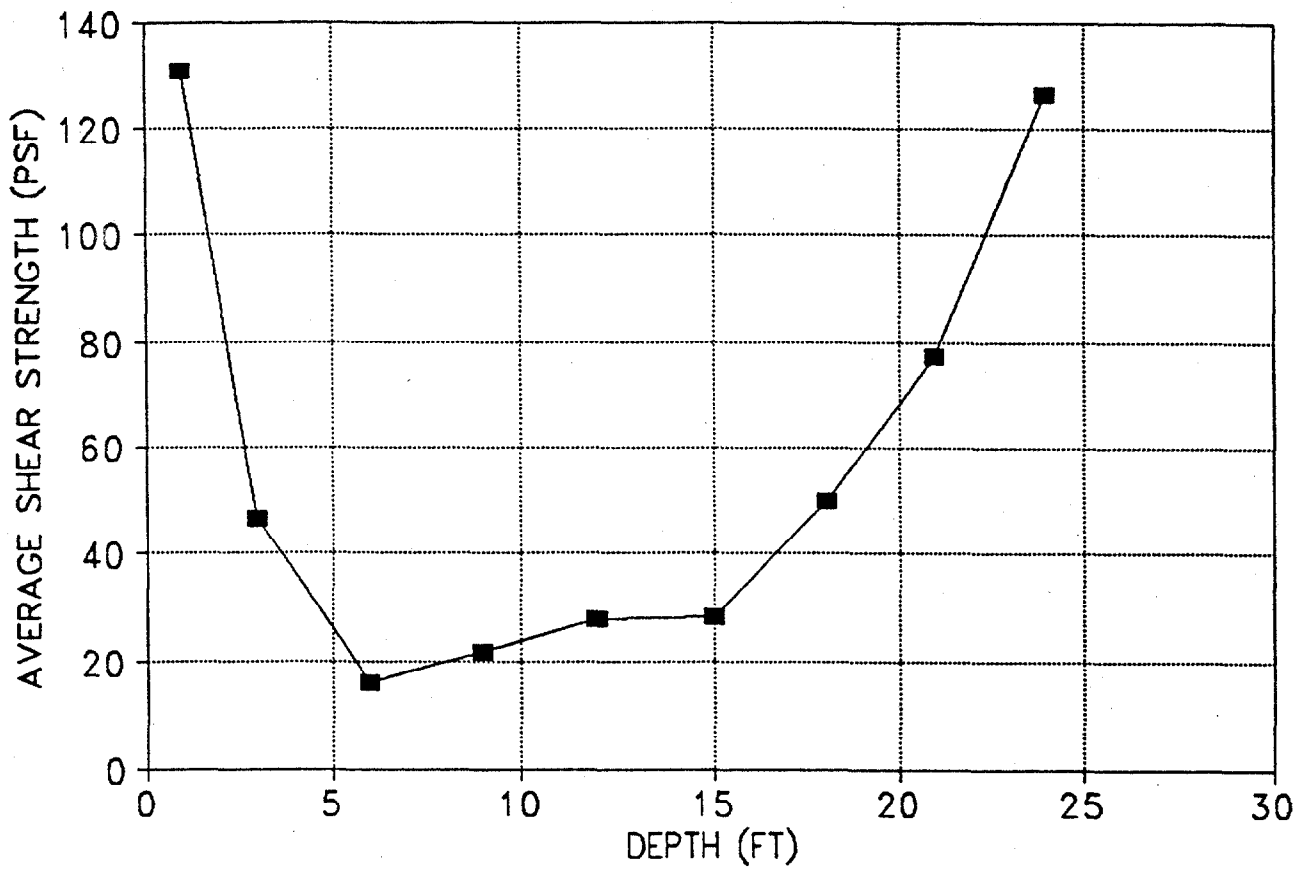
FIGURE 8

DEPTH VS. PEAK SHEAR STRENGTH (PLOT B)
BEFORE LIME COLUMN
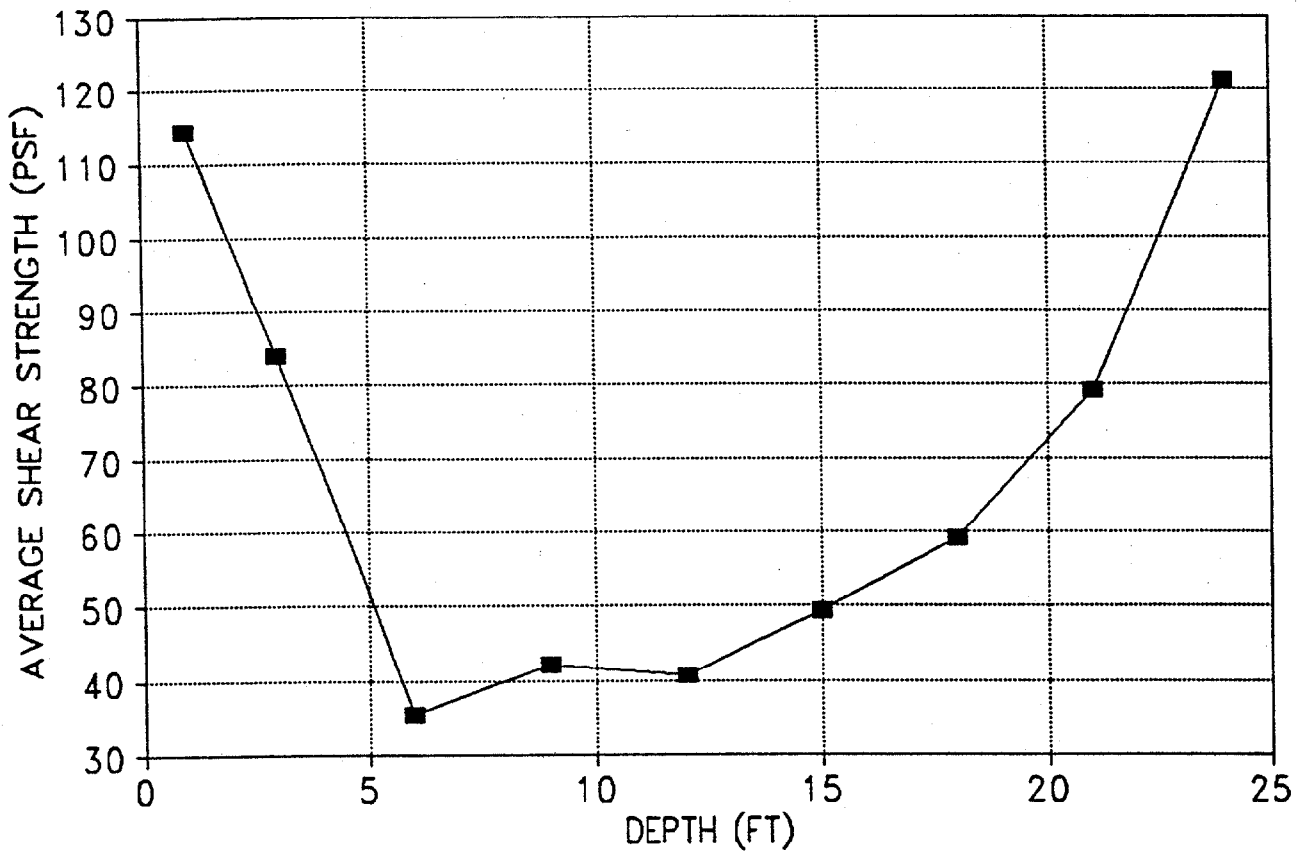
FIGURE 9

DEPTH VS. REMOLDED SHEAR STRENGTH
BEFORE LIME COLUMN (PLOT B)
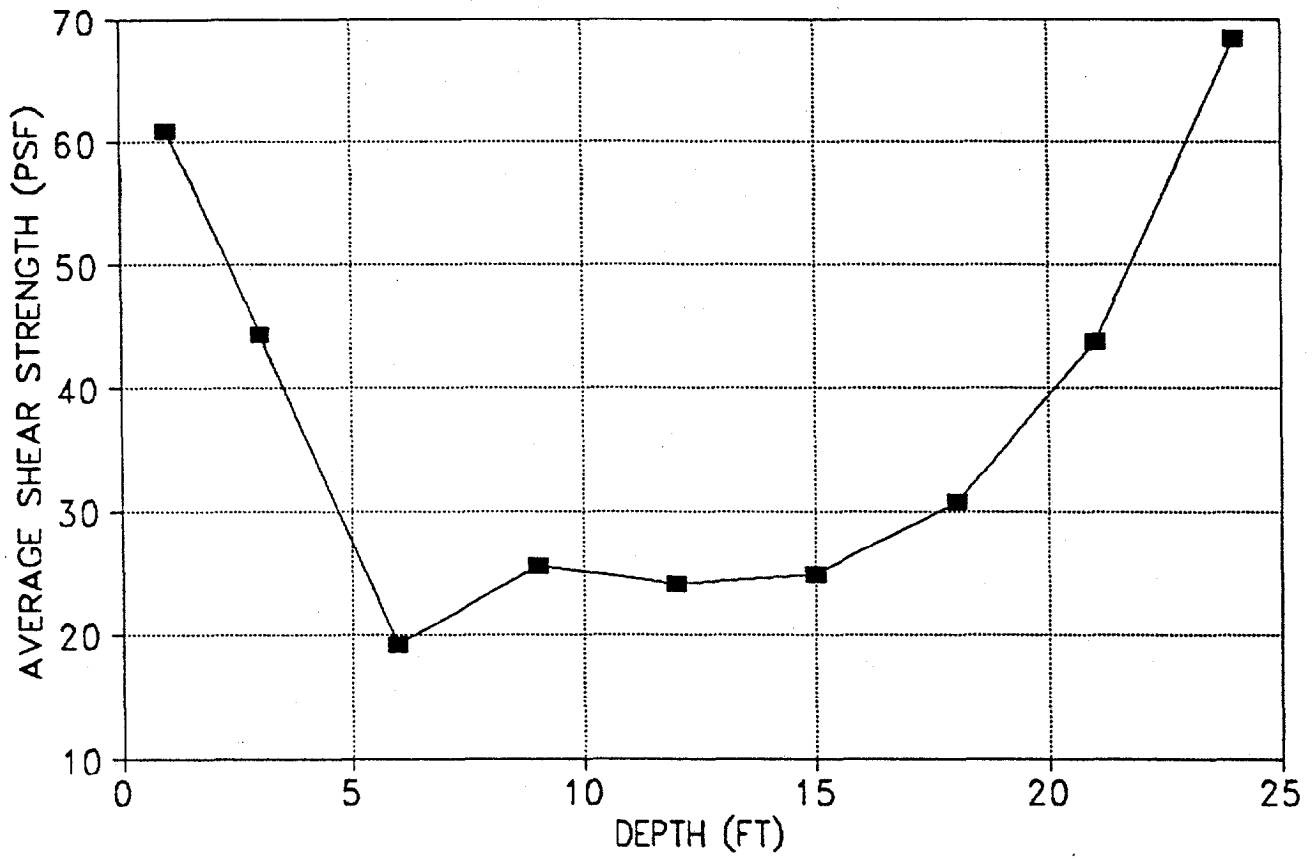
FIGURE 10

LIME COLUMN INSTALLATION
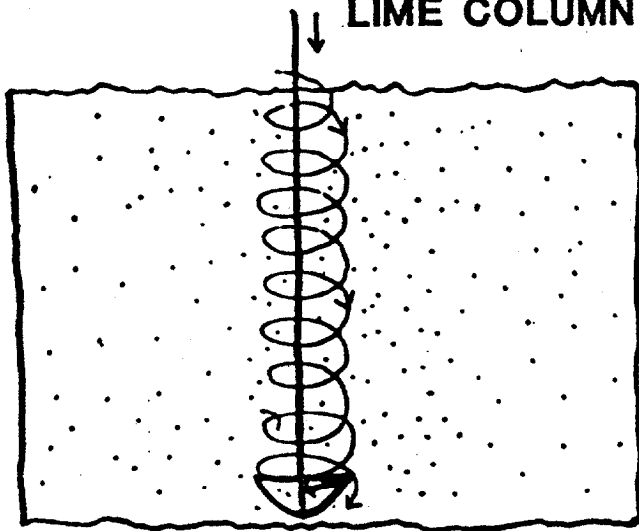
Screw down the mixer tool.

The 0.5 m (1.6') wide mixer tool, that looks like a steel whisk, is screwed down into the soil, as deep as the desired pillar. Up to date, approx. 10 m (33'). ·
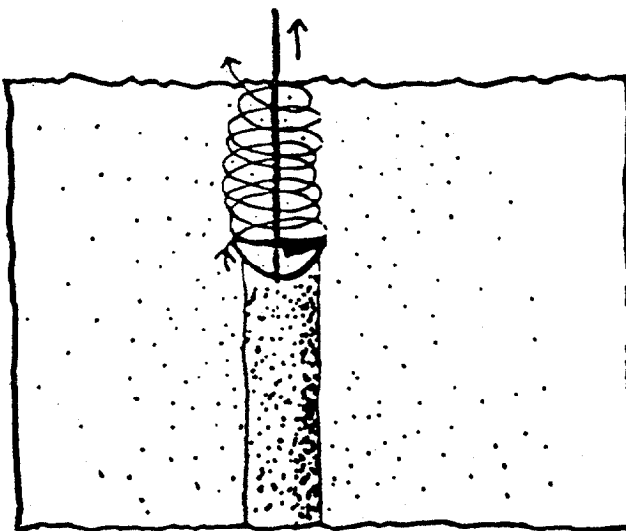
Add 3—8% quicklime and mix.

The quicklime is blown out by compressed air, via a jet nozzle on the tool.

The rotational speed is increased at the same time as the tool is drawn upwards, so that the lime and clay are well mixed. The water content of the clay is sufficient to start the reaction.
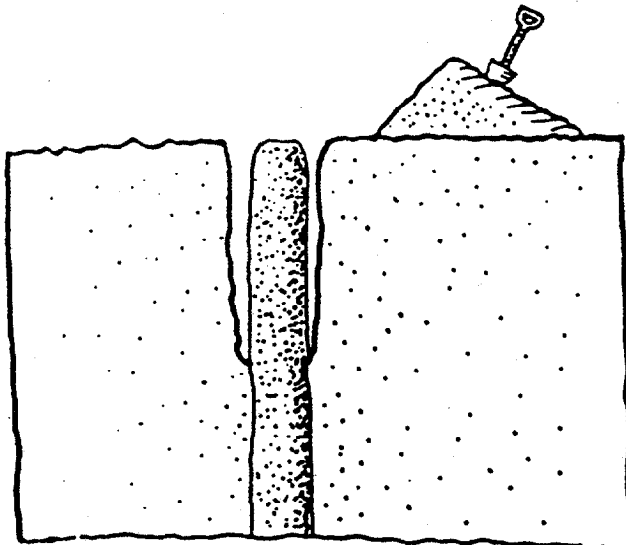
And you have a pillar that's up to ten times stronger than the surrounding clay.

Left in position is a uniform pillar with the same diameter as the tool. The stabilizing compound binds the water in the clay. An exchange of ions takes place and the shear strength can be increased more than tenfold in a few hours. A chemical reaction also occurs over a period of time, and further increases the shear strength. The pillars act as drains, and this means that soil stabilization is more rapid. The construction can be started immediately. After 30—90 days, the soil has full supporting capacity.

FIGURE 11

PLACEMENT OF FILL PAD
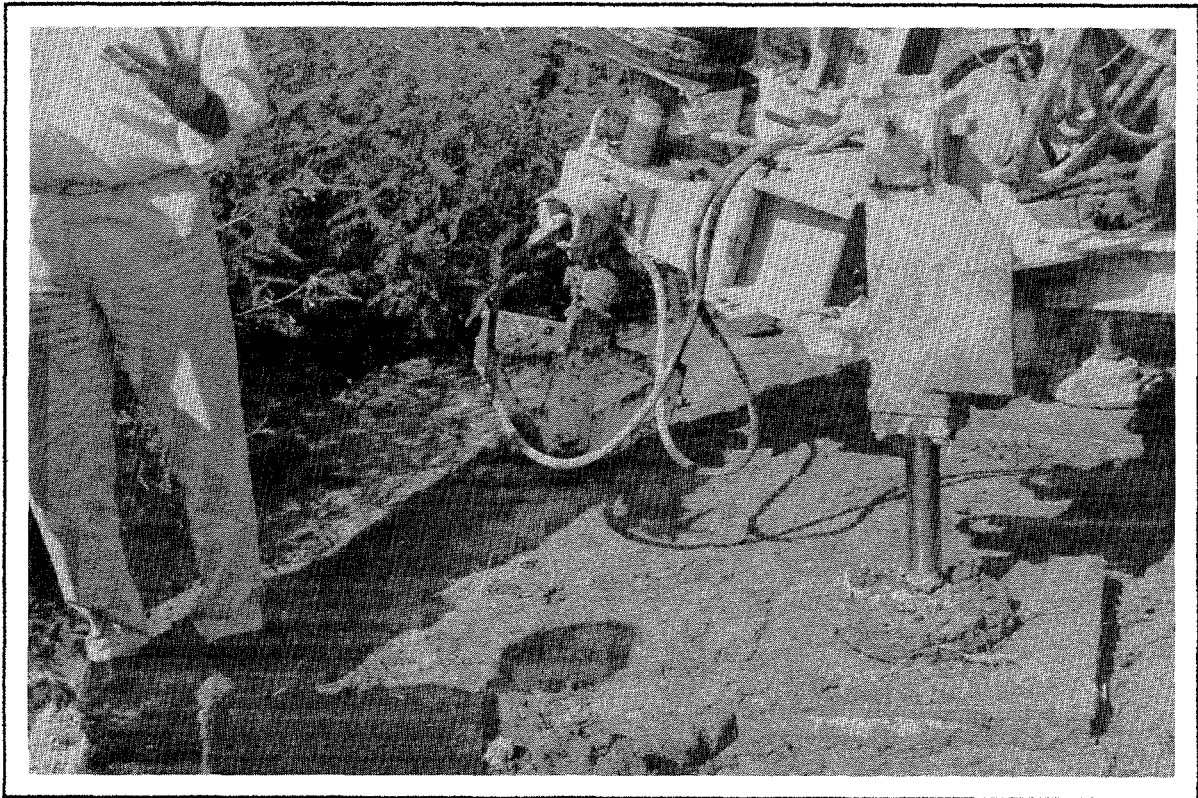
LIME COLUMN MIXER TOOL

FIGURE 12

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FIGURE 13
QUICKLIME PREPARATION AND
INJECTION USING COMPRESSED AIR
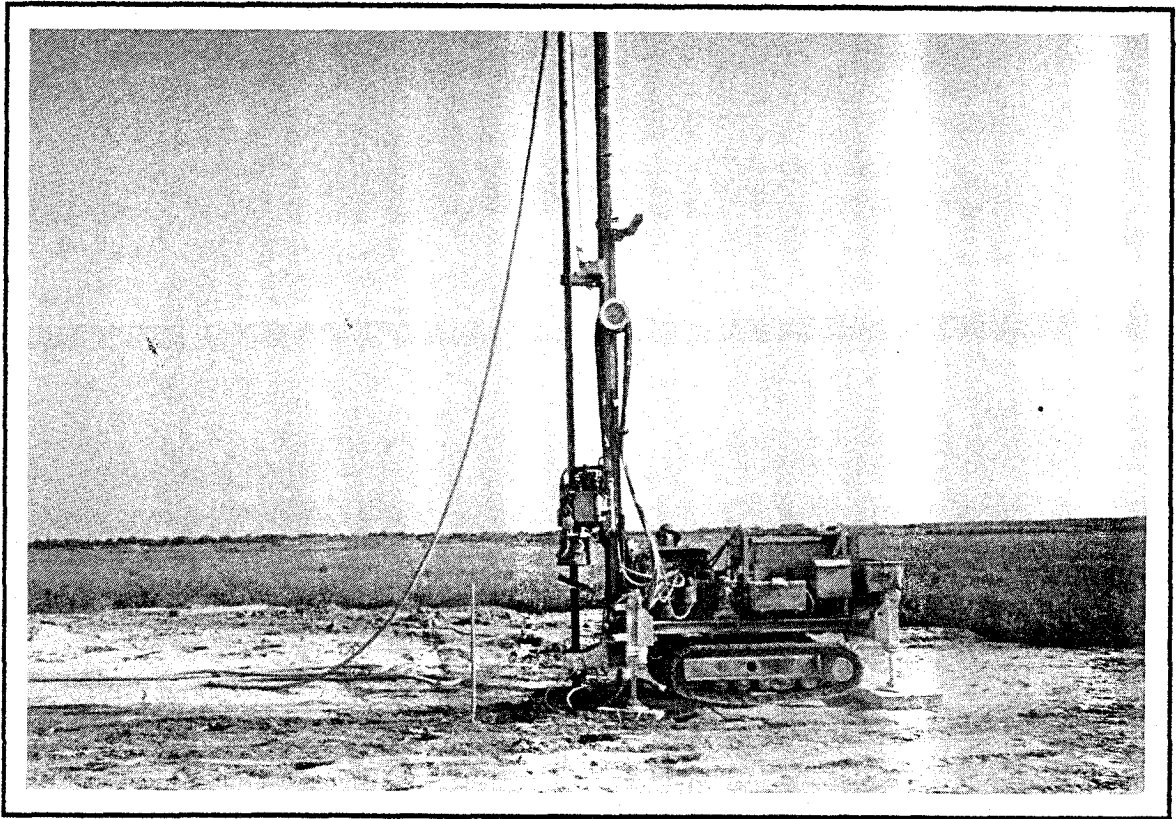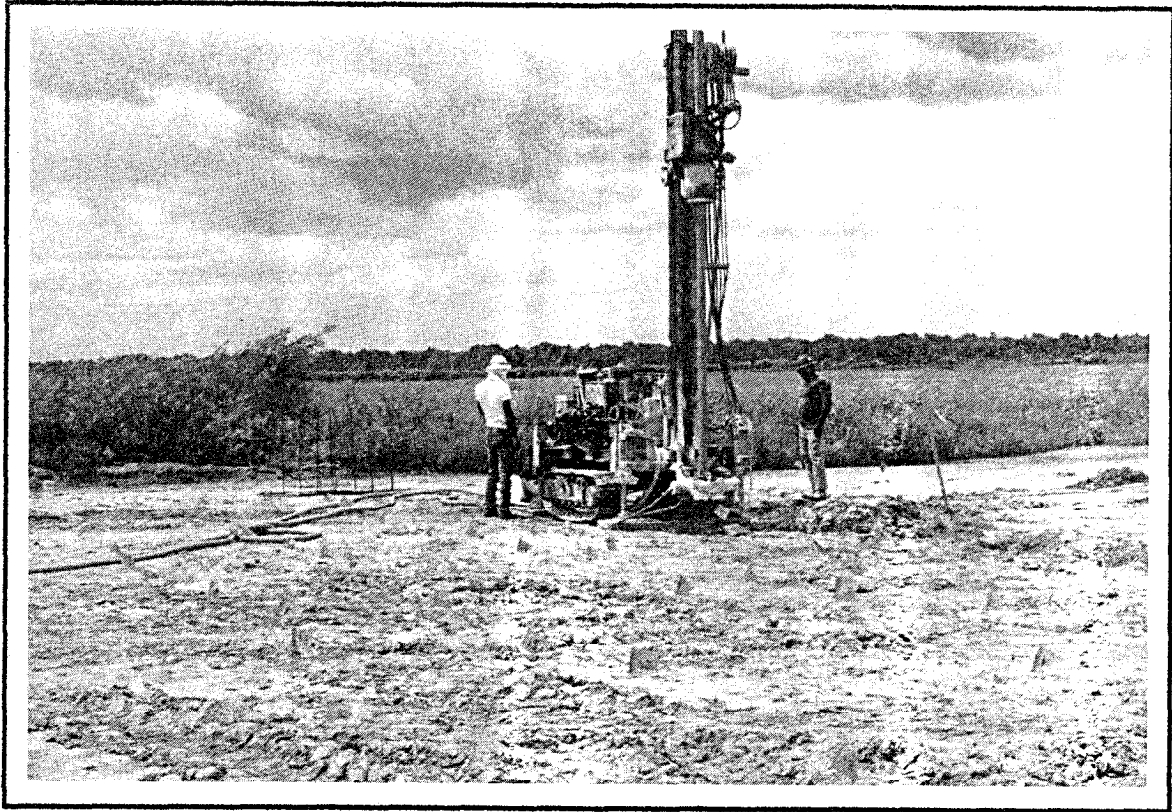
FIGURE 14

LIME COLUMN INSTALLATION

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5925 IMPERIAL PARKWAY, LAKELAND, FL 33860
PHONE (813) / 646-5601

8233F02A.DWG

FIGURE 15

SETTLEMENT MONUMENTS

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BROMWELL & CARRIER, INC.
5555 IMPERIAL PARKWAY, LAKELAND, FL 33800
PHONE (813) / 646-5001

TIME vs SETTLEMENTS
LIME COLUMN DEMONSTRATION PROJECT

FILL HEIGHT 3 FEET

FILL HEIGHT 4.5 FEET
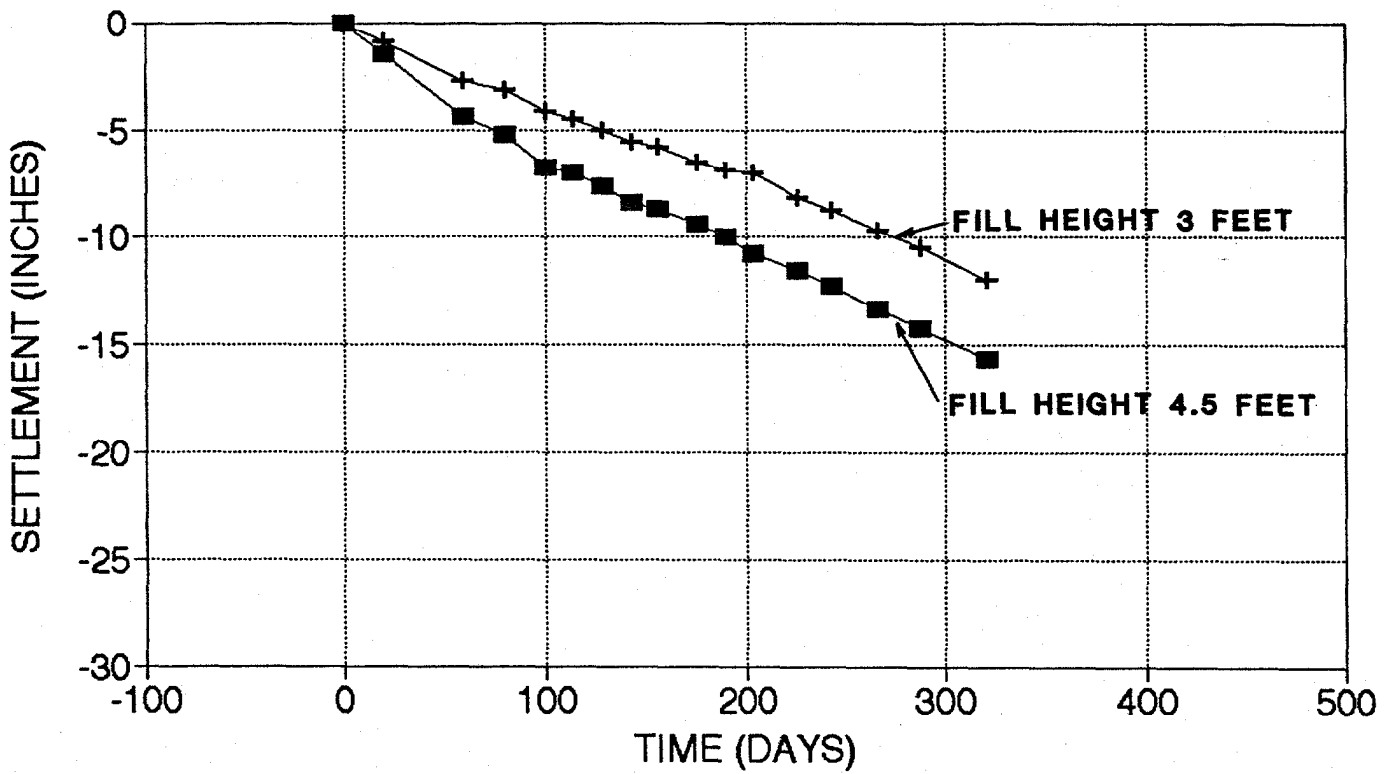
LIME COLUMN PLOT — CONTROL PLOT

FIGURE 16

TIME VS. ADJUSTED SETTLEMENT
LIME COLUMN PLOT AND CONTROL PLOT

FIGURE 17

INDICATOR AND RECORDER

FILL MATERIAL

P1

P4

TYPICAL PRESSURE TRANSDUCER

WASTE PHOSPHATIC CLAY

P2

P5

P3

P6

FIRM NATURAL MATERIAL
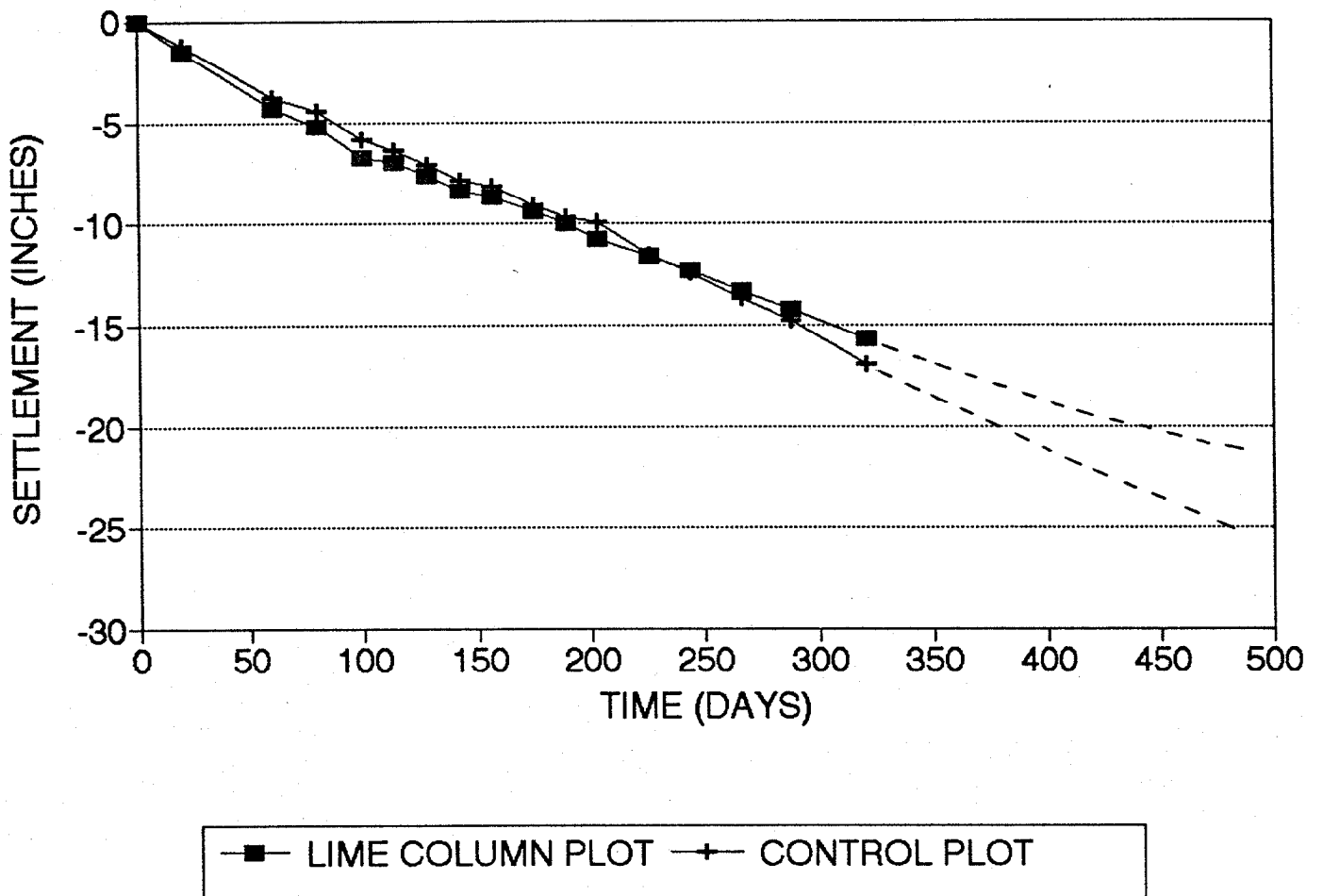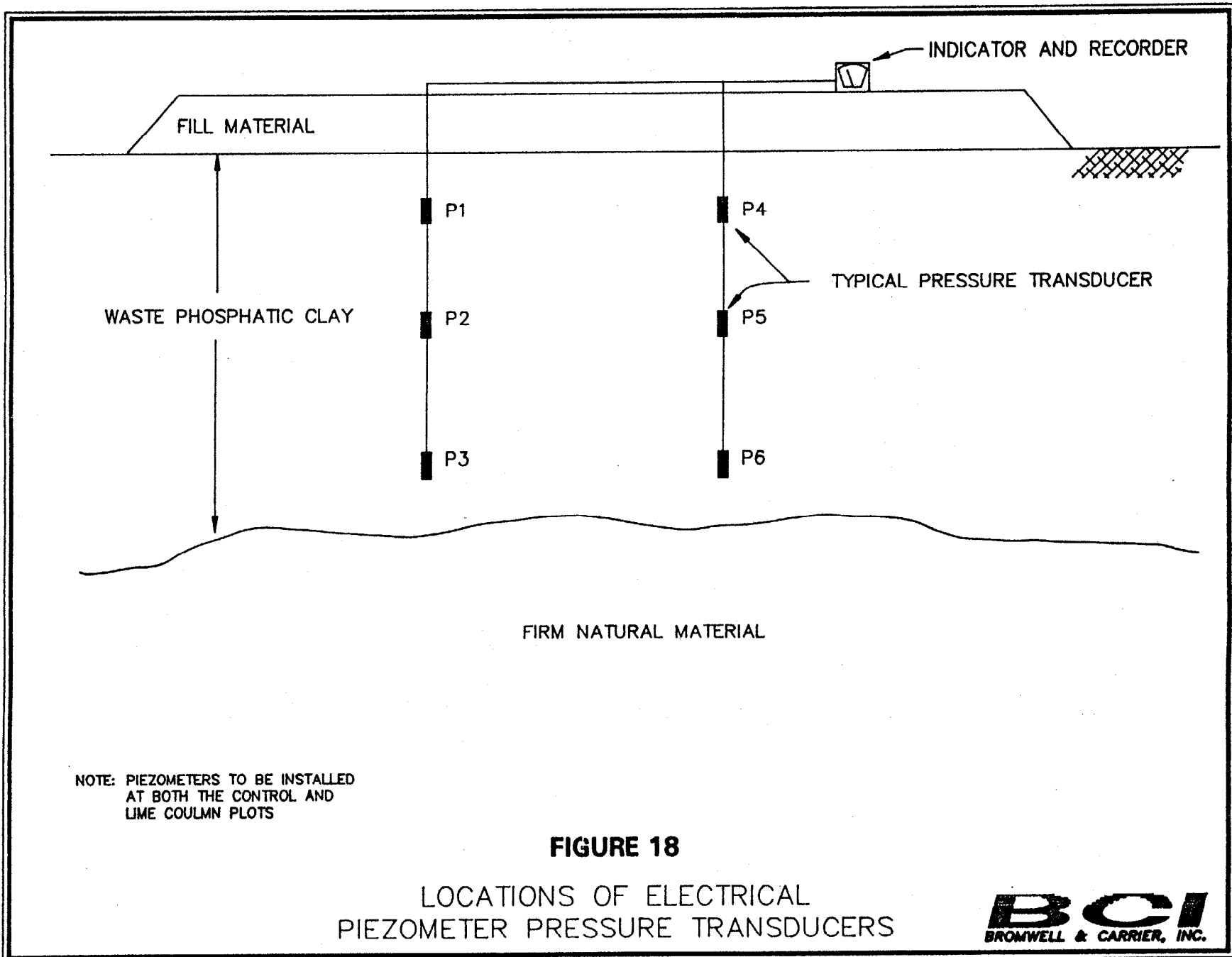
NOTE: PIEZOMETERS TO BE INSTALLED
AT BOTH THE CONTROL AND
LIME COULMN PLOTS

FIGURE 18

LOCATIONS OF ELECTRICAL
PIEZOMETER PRESSURE TRANSDUCERS

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FMT8121A

SUMMARY GRAPH
DEPTH VS. POREWATER PRESSURE
PLOT A - LIME COLUMN PLOT
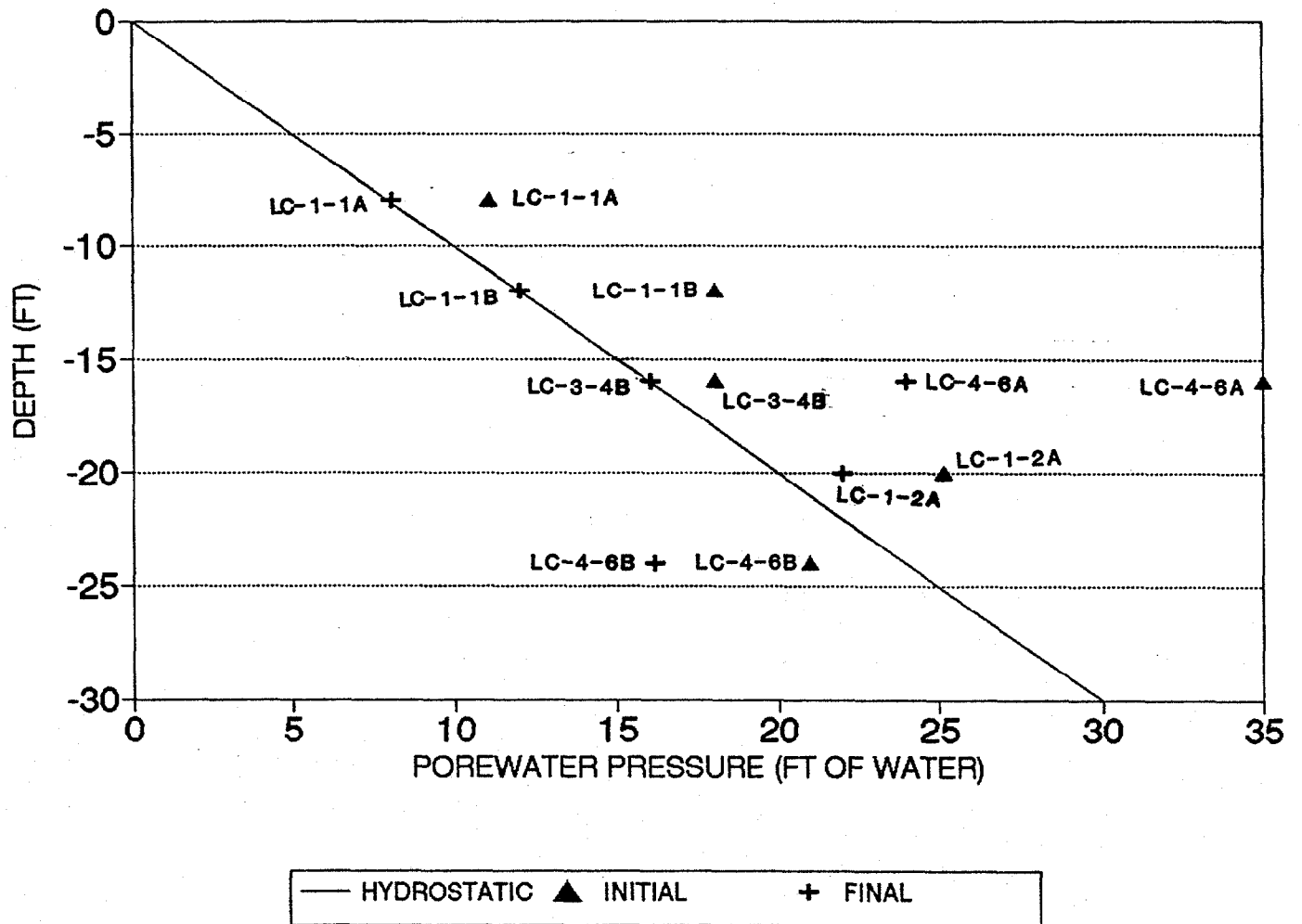
FIGURE 19

SUMMARY GRAPH
DEPTH VS. POREWATER PRESSURE
PLOT B - CONTROL PLOT
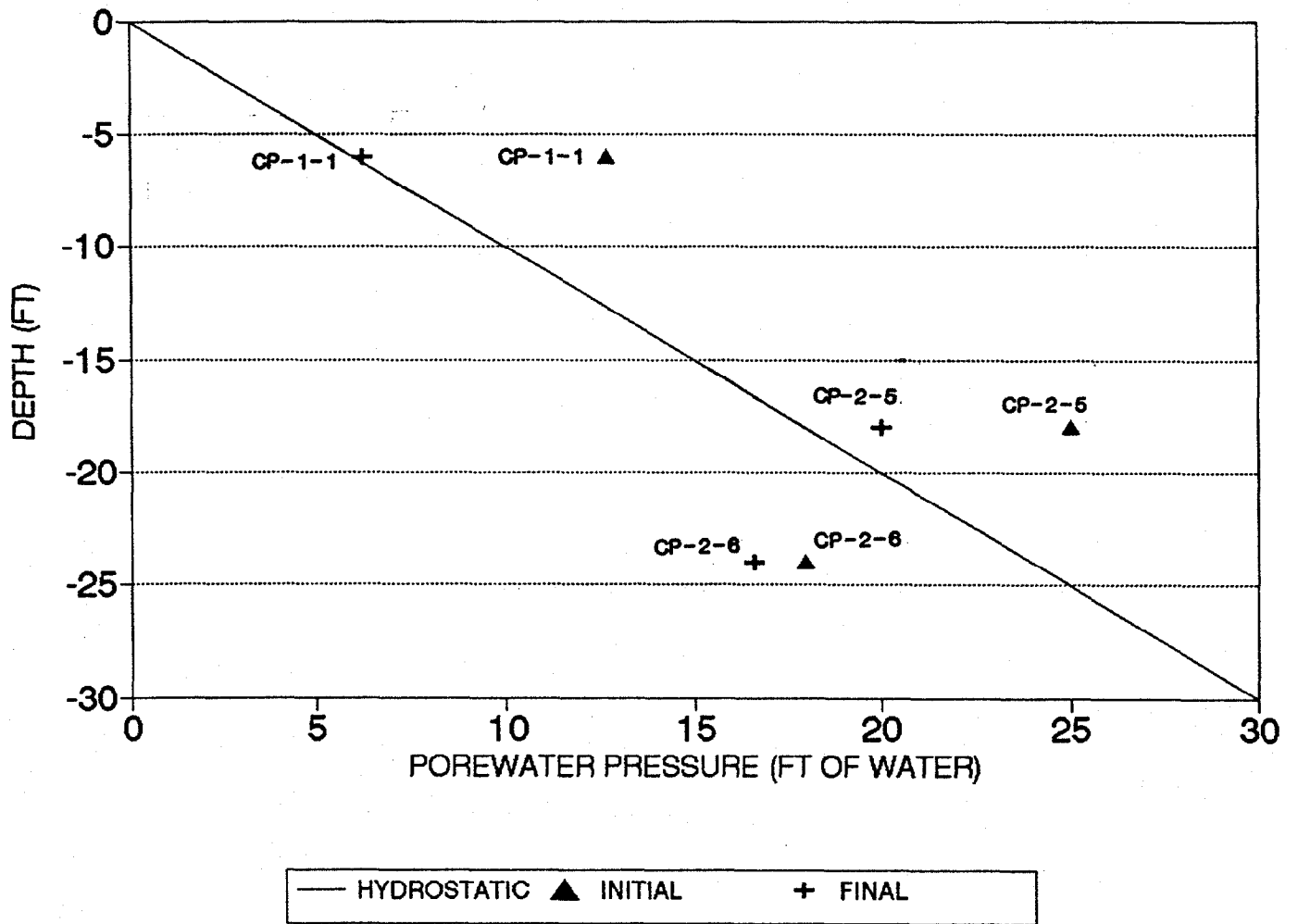
FIGURE 20

DEPTH VS. PEAK SHEAR STRENGTH (PLOT A) BEFORE AND AFTER LIME COLUMN
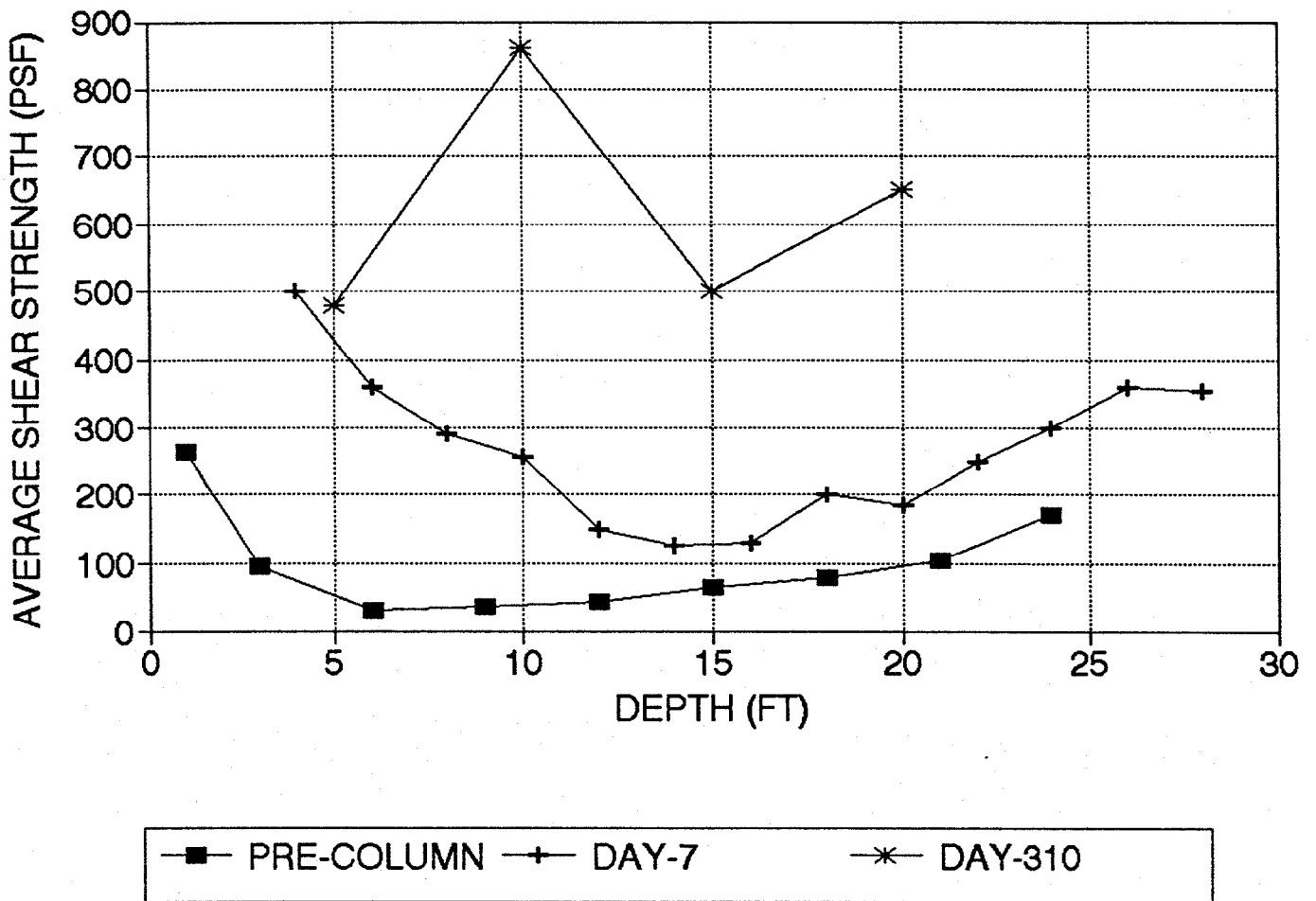
FIGURE 21

DEPTH VS. REMOLDED SHEAR STRENGTH
BEFORE AND AFTER LIME COLUMN (PLOT A)

PRE-COLUMN   POST-COLUMN (DAY-7)
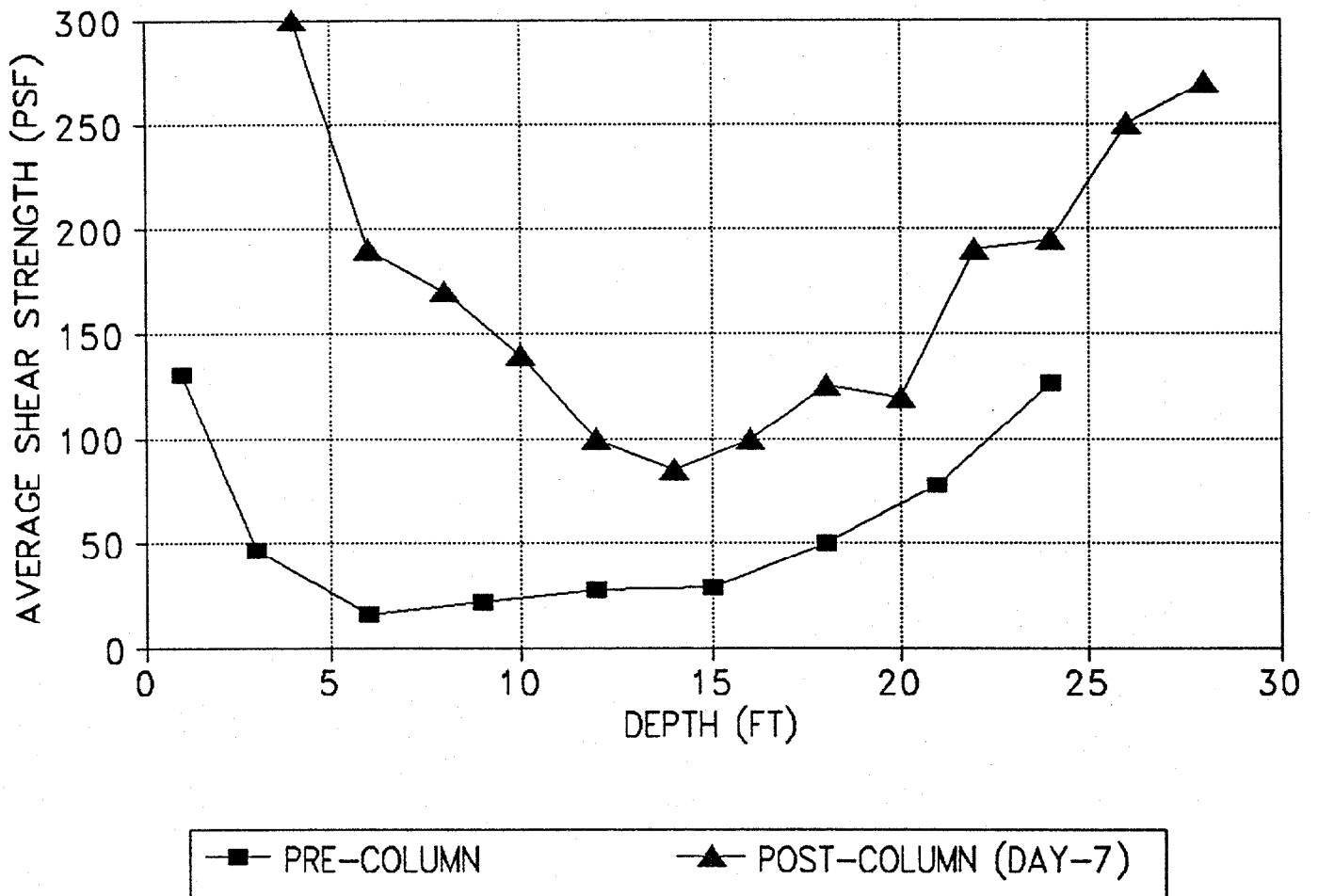
FIGURE 22

DEPTH VS. PEAK SHEAR STRENGTH
DAY 0, 7, 43, AND 310 (PLOT B)
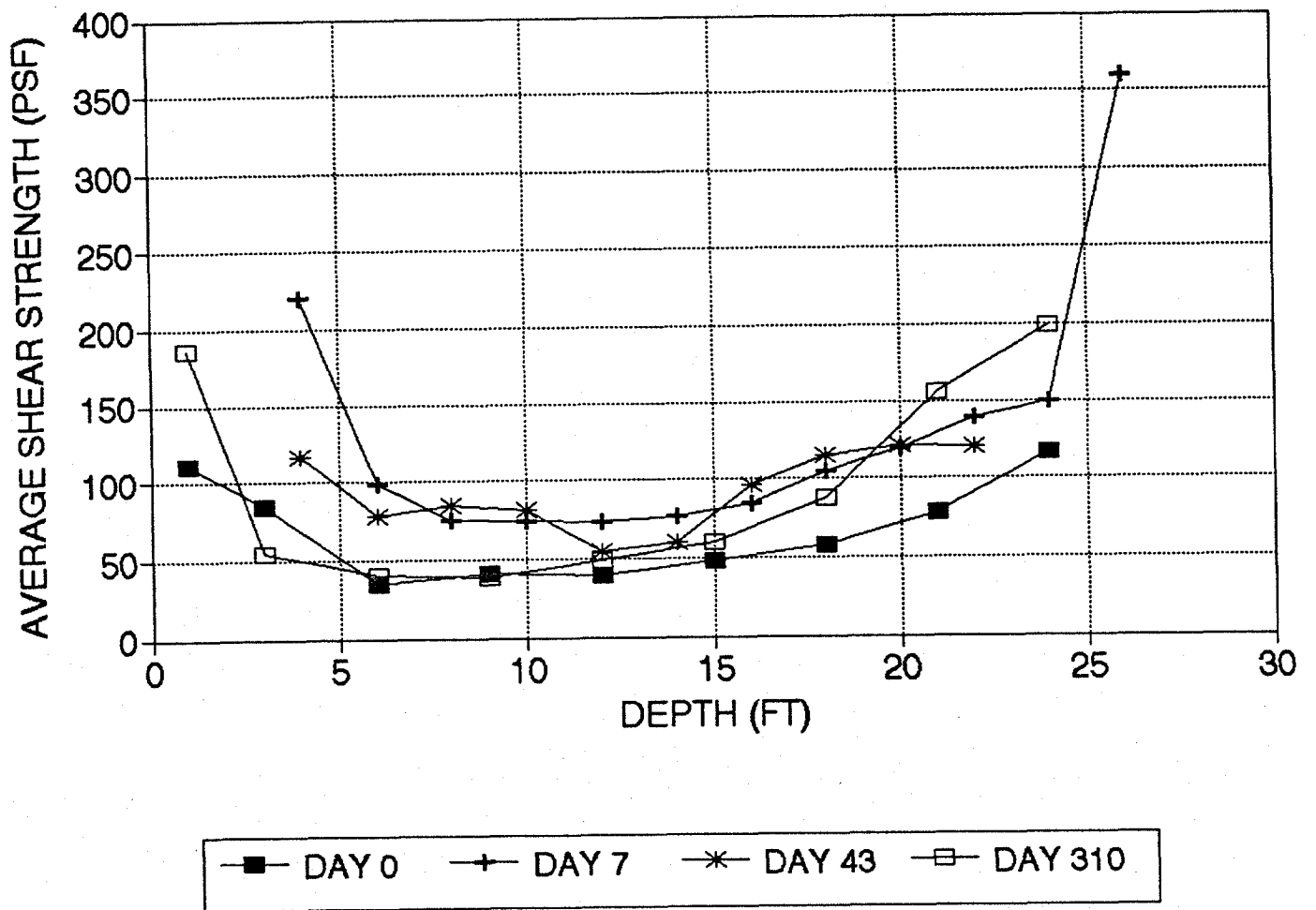
FIGURE 23

DEPTH VS. REMOLDED SHEAR STRENGTH
DAY 0, 7, 43, AND 310 (PLOT B)
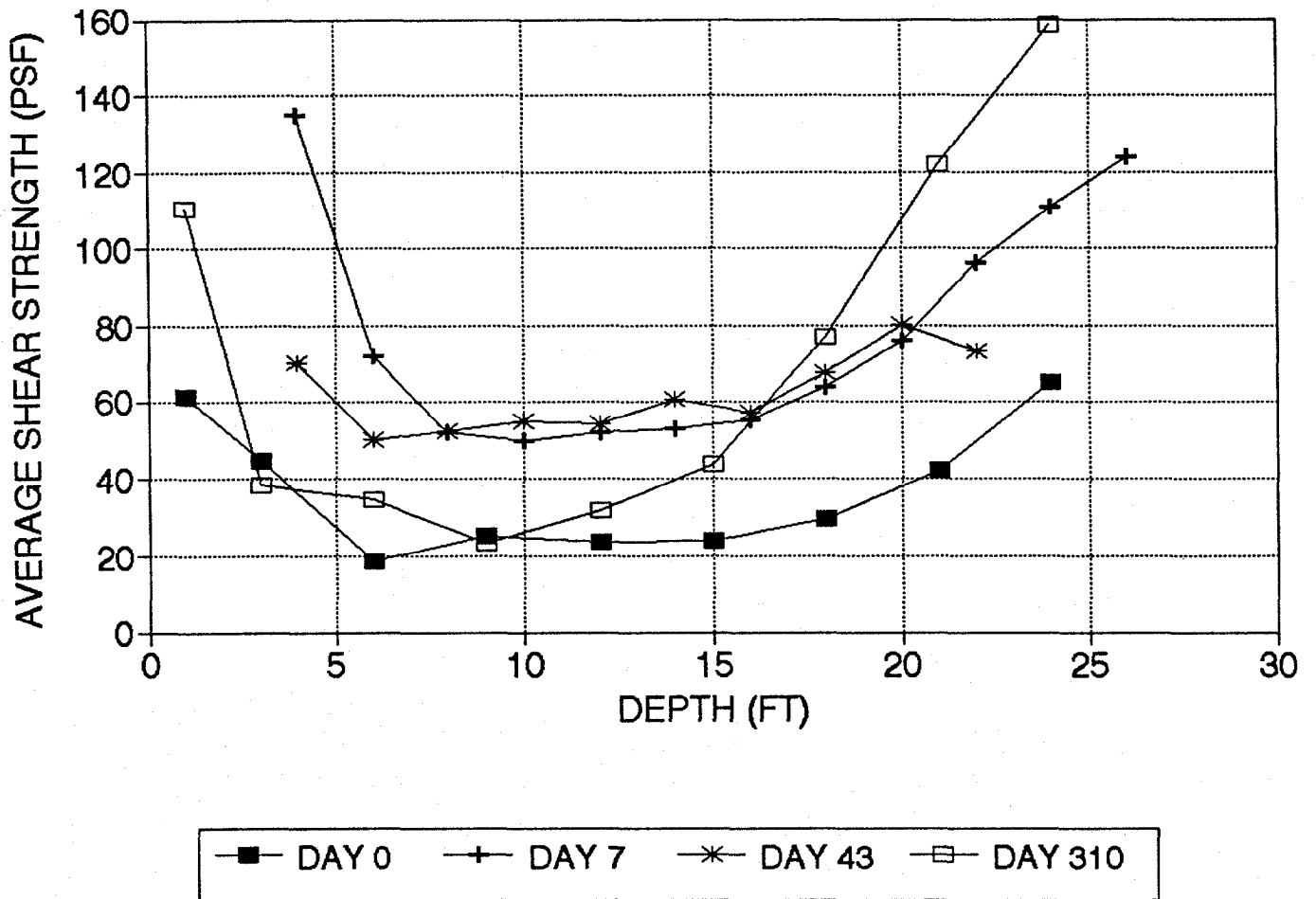
FIGURE 24

DEPTH VS. SOLID CONTENT (PLOT A)
BEFORE AND AFTER COLUMN INSTALLATION
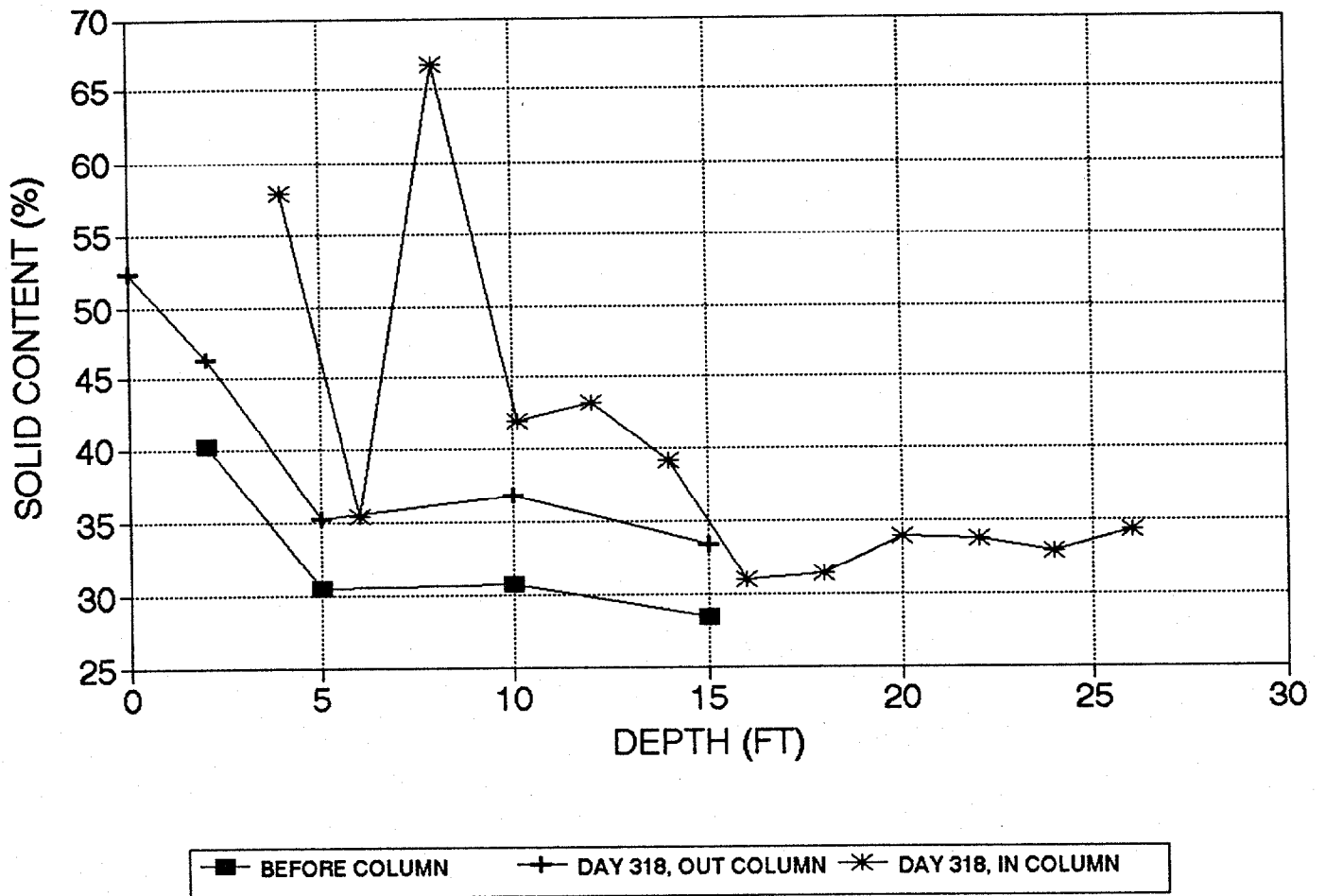
FIGURE 25

DEPTH VS. SOLID CONTENT (PLOT B)
BEFORE AND AFTER LIME COLUMN

BEFORE COLUMN   DAY 318
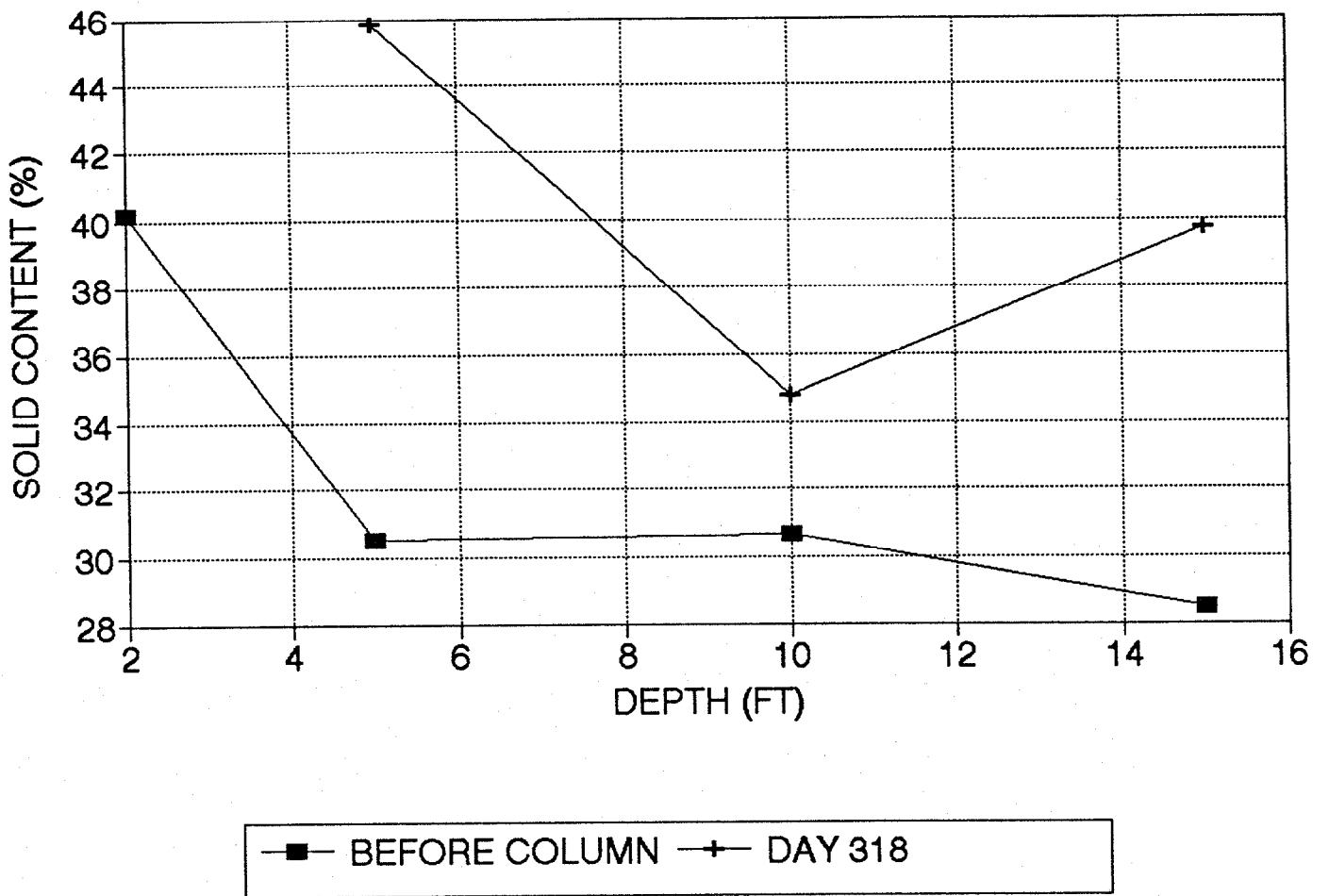
FIGURE 26

NOTE:
Clay deposit under proposed structure to be removed by excavation or treated by lime columns.

Ȼ

75'

CLAY

20'

75'

N.T.S.

EARTHWORK OPTION

	EXCAVATE	REPLACE	UNIT RATE	NO. UNITS	COST
LOW	4.50/CY	2.50/CY	7.00/CY	4167 CY	$ 29,169
HIGH	6.50/CY	4.50/CY	11.00/CY	4167 CY	$ 45,837

LIME COLUMN OPTION (15% COVERAGE)

	% LIME	WT. LIME	LIME UNIT COST	COST LIME	NO. COLUMNS	PRODUCTION RATE
LOW	15	15 T	$ 70/T	$ 1050	256	500 FT/10 HRS
HIGH	15	15 T	$ 90/T	$ 1350	256	300 FT/10 HRS

	TOTAL NO. HRS.	$COST/HR	INSTALLATION COST	TOTAL COST	COST PER METER	/COST PER FT
LOW	102 HR	$ 125	$ 12,750	$ 13,800	8.10 /	2.70
HIGH	170 HR	$ 145	$ 24,650	$ 26,000	15.23 /	5.08

BCI
FIGURE 27
EXAMPLE
COST ANALYSIS

APPENDIX A

SHEAR STRENGTH

DEPTH VS. SHEAR STRENGTH (PLOT A)
IN THE COLUMNS - DAY 310
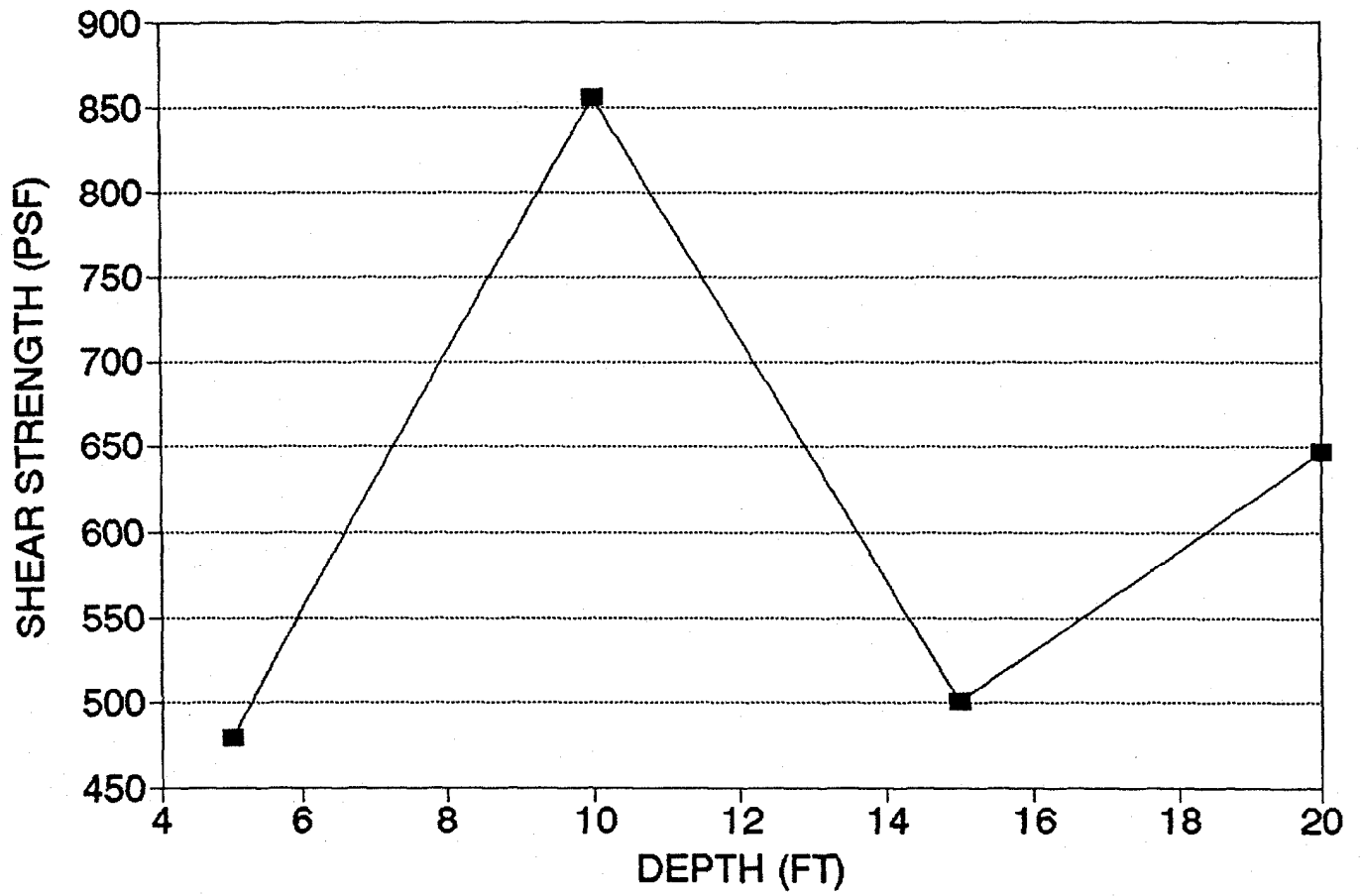
DEPTH VS. PEAK SHEAR STRENGTH
PLOT A - OUTSIDE COLUMNS - DAY 310
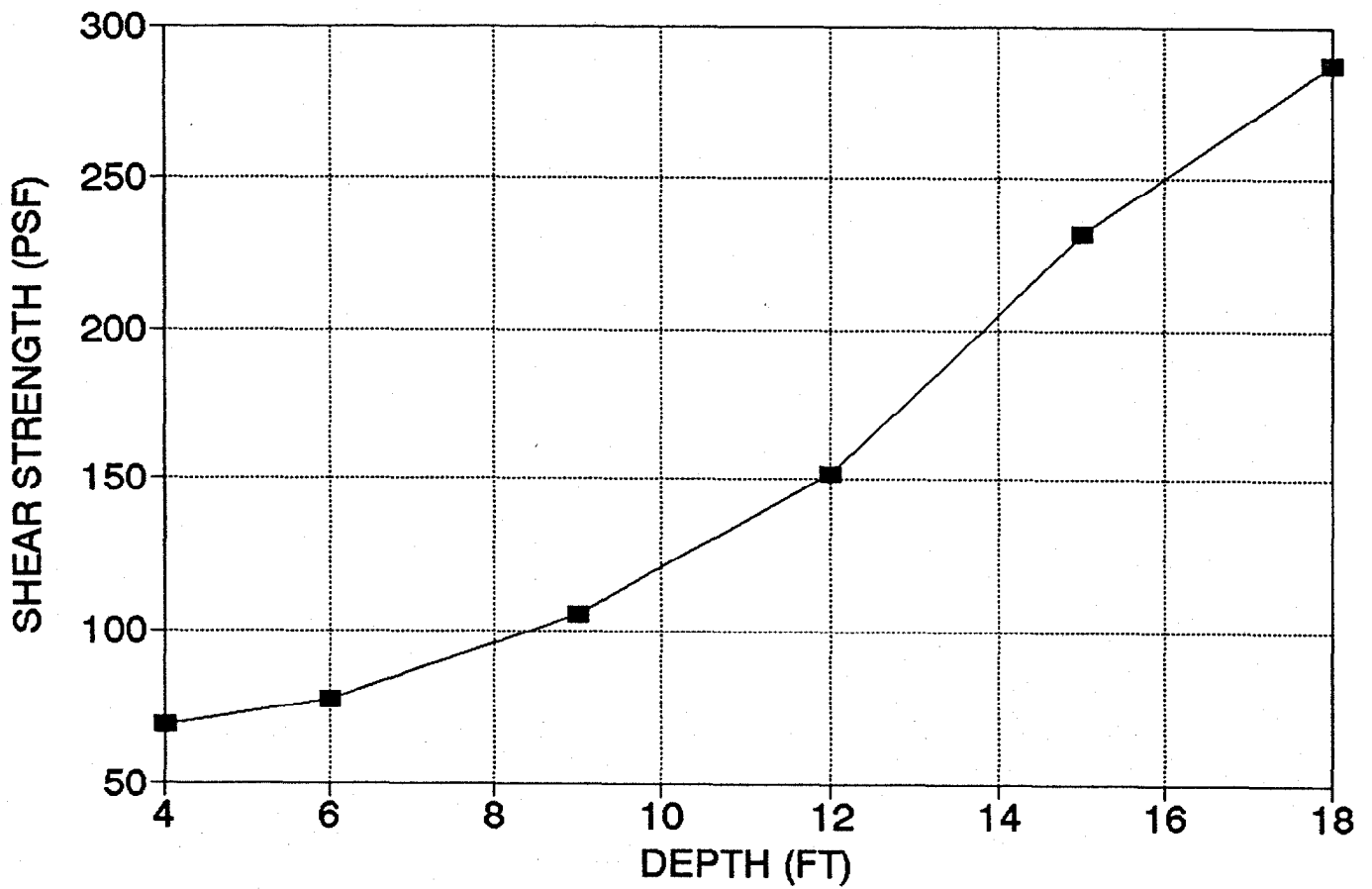
DEPTH VS. REMOLDED SHEAR STRENGTH
PLOT A - OUTSIDE COLUMNS - DAY 310
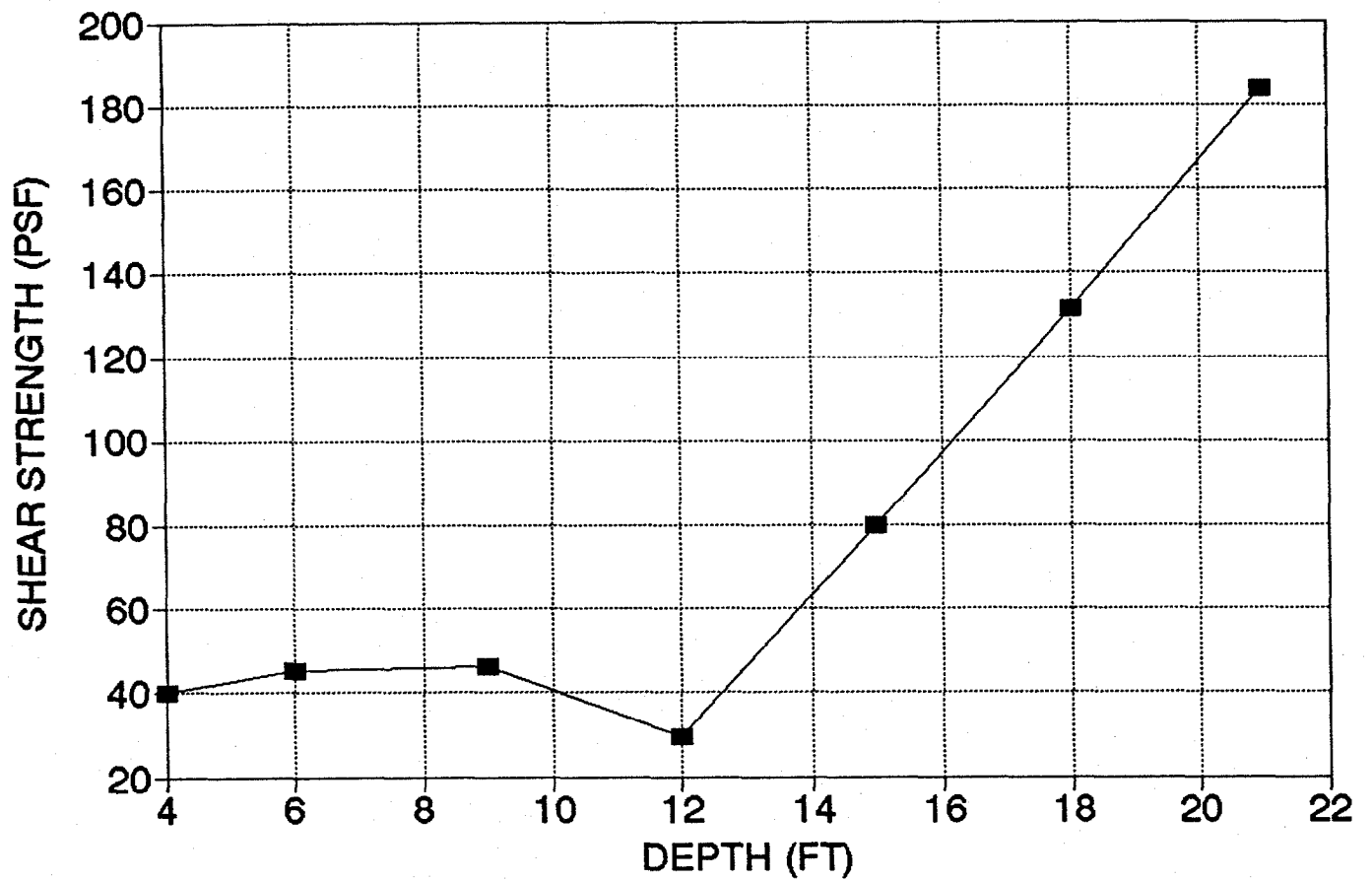
DEPTH VS. PEAK SHEAR STRENGTH
PLOT-B (CONTROL PLOT) - DAY 310
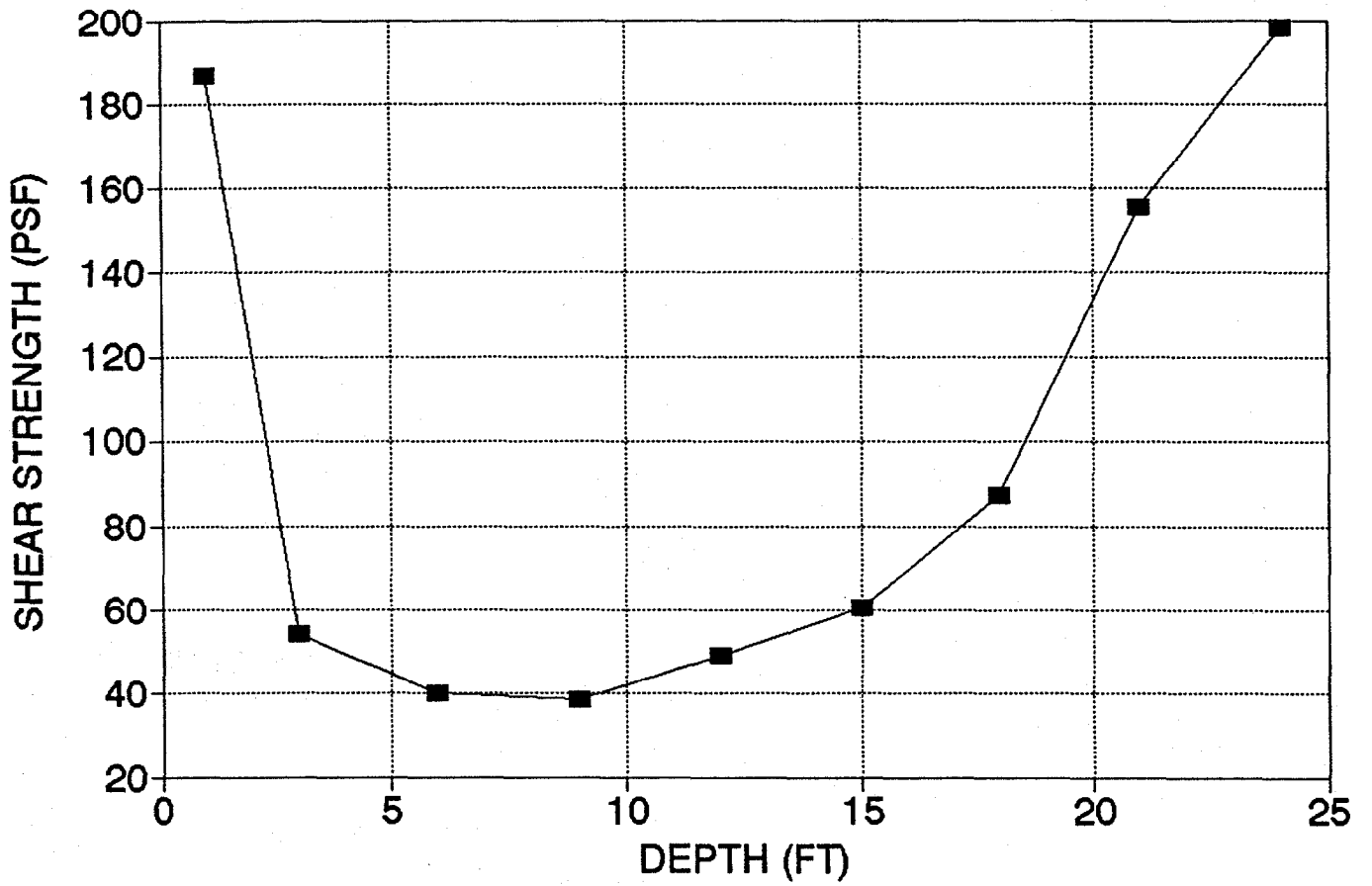
DEPTH VS. REMOLDED SHEAR STRENGTH
PLOT-B (CONTROL PLOT) - DAY 310
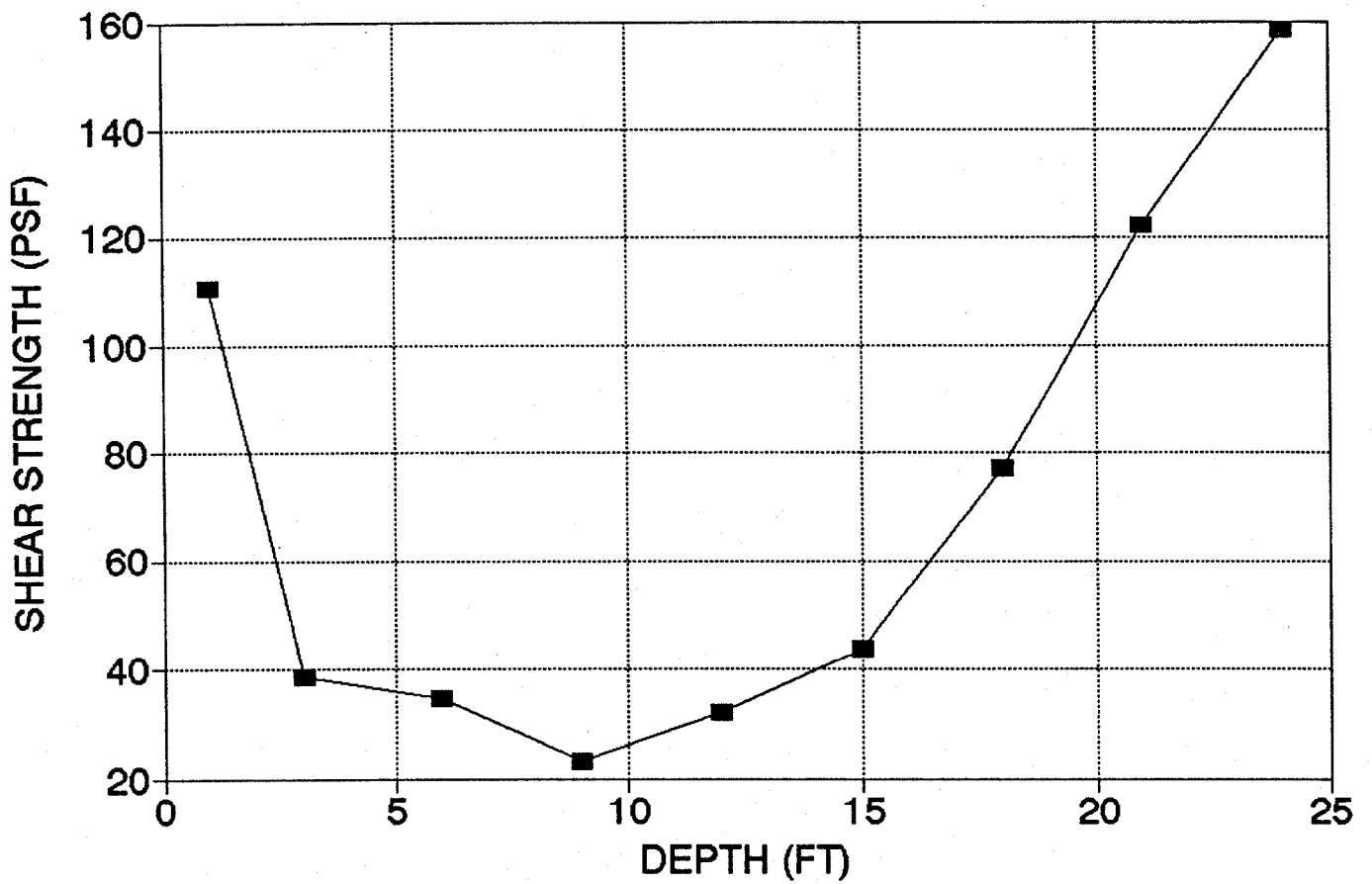
WILLIAMS
EARTH SCIENCES INC.

September 3, 1993

Bromwell & Carrier, Inc.
P.O. Box 5467
Lakeland, Florida 33807-5467

Attention: Mr. Fran Hardianto

Subject: Laboratory Testing of Sample
            Bromwell & Carrier, Inc. Project № 8233 (RICI)
            WES Project № C393214

Gentlemen:

Williams Earth Sciences, Inc. has completed laboratory testing for the subject project as requested by Mr. Hardianto in a letter of transmittal dated August 25, 1993. The requested testing consisted of one Triaxial Permeability Test (performed according to Triaxial Shear Test Manual, Brainard-Kilman Drill Company, 1981).

Williams Earth Sciences, Inc. appreciates the opportunity to be of service on this project. If we may be of further help or if you have any questions, please contact our office.

Very truly yours,

WILLIAMS EARTH SCIENCES, INC.

Monica L. Fowler, P.G.
Staff Geologist
Florida License № PG0001388

Keith D. Bennett, P.E.
Senior Geotechnical Engineer
Florida Registration № 33075

MLF/KDB/lf/SEP93/C393214.rpt
Submittals (3) Addressee

GEOTECHNICAL & MATERIALS ENGINEERING & TESTING

TRIAXIAL SHEAR TEST

☐ Consolidated Drained ☐ Unconsolidated Undrained

☒ Consolidated Undrained ☒ Pore Water Pressure

Project RICI Triaxial Test

Job Number C393214

Boring/Sample # Unknown   Depth 15.0'-17.0'

Soil Description Green slightly calcareous slightly sandy clayey silt Natural moisture cont.=156.3%

Remolded ☐   Undisturbed ☒   Stage Test ☒
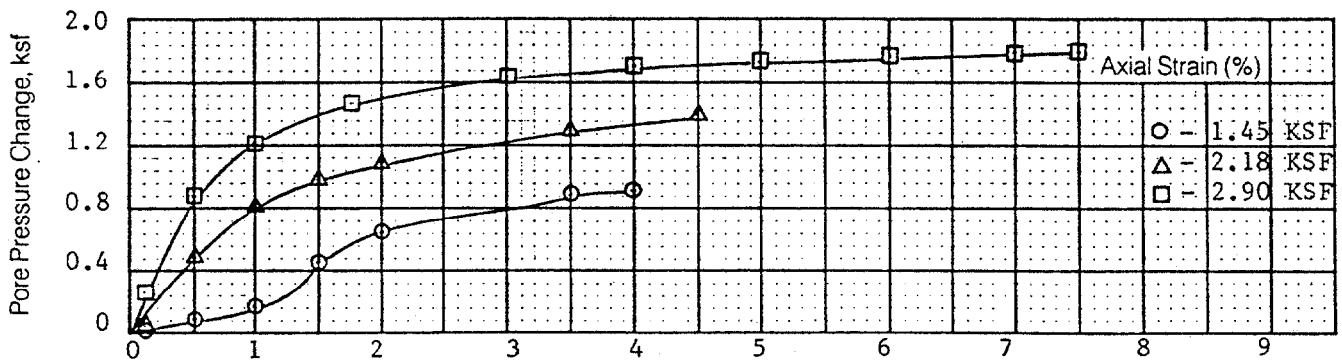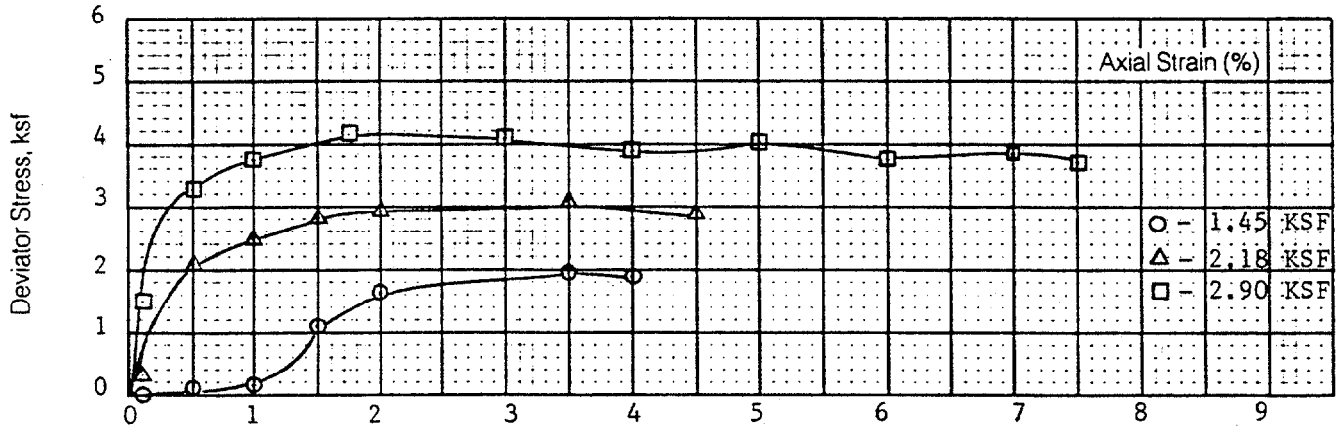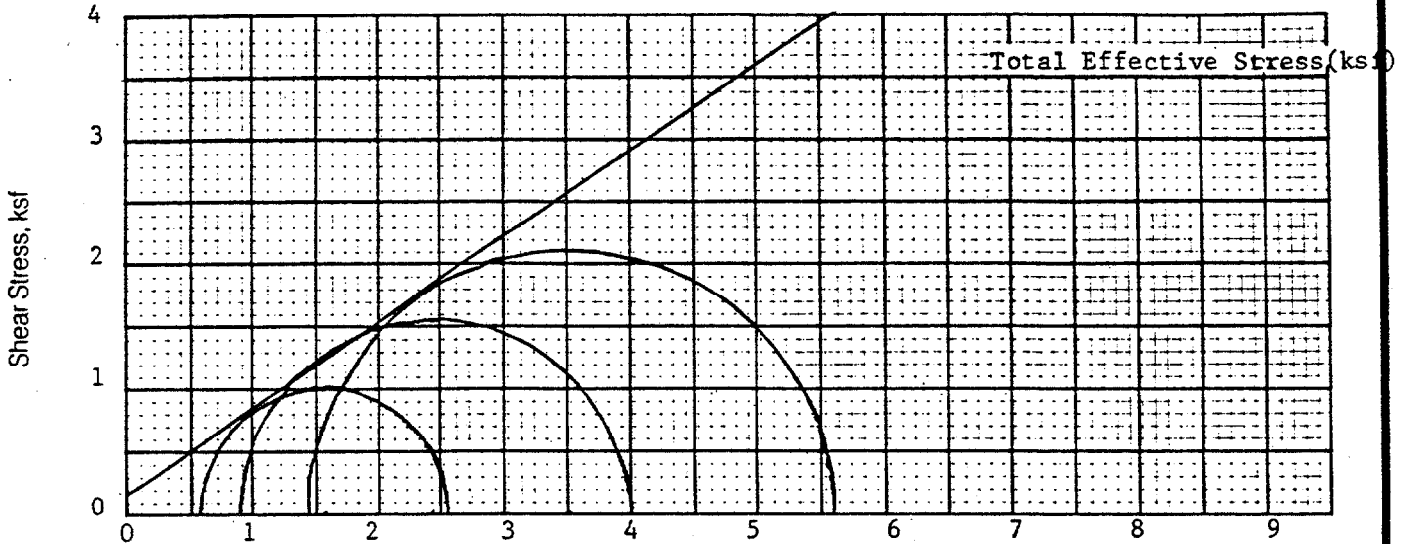
Shear Stress, ksf — Total Effective Stress (ksf)

Deviator Stress, ksf — Axial Strain (%)

O – 1.45 KSF
△ – 2.18 KSF
☐ – 2.90 KSF

Pore Pressure Change, ksf — Axial Strain (%)

O – 1.45 KSF
△ – 2.18 KSF
☐ – 2.90 KSF

	Specimen 1	Specimen 2	Specimen 3
Water Content, %	190.4	174.6	165.2
Unit Weight, pcf	24.6	26.2	27.3
Unit Weight – Consolidated, pcf	26.2	27.3	28.3
Cohesion, ksf	0.2	0.2	0.2
Friction Angle, °	34.0	34.0	34.0

W I L L I A M S
EARTH SCIENCES INC. GEOTECHNICAL ENGINEERS

SL-013.83

A-7

TRIAXIAL SHEAR TEST

☐ Consolidated Drained
☐ Unconsolidated Undrained
☒ Consolidated Undrained
☒ Pore Water Pressure

	Specimen 1	Specimen 2	Specimen 3
Water Content, %	190.4	174.6	165.2
Unit Weight, pcf	24.6	26.2	27.3
Unit Weight – Consolidated, pcf	26.2	27.3	28.3
Cohesion, ksf	0.0	0.0	0.0
Friction Angle, °	24.5	24.5	24.5

SL-013.83

WILLIAMS EARTH SCIENCES GEOTECHNICAL ENGINEERS

A-8

BROMWELL & CARRIER,INC.
UNCONFINED COMPRESSION TEST DATA SHEET

CLIENT: FIPR   PROJECT #:   8233
PROJECT: LIME COLUMN STUDY   DATE COMPACTED: N.A.
LOCATION: R2C10:10'   DATE TESTED: 7/21/93
MATERIAL: LIME/WASTE CLAY MIXTUR   SAMPLE DIAMETER: 2.8"

DIAL READING (x.0001)	LOAD [LB]	STRESS [PSI]
0.2	1.50E+00	2.419E-01
0.3	2.25E+00	3.629E-01
0.5	3.75E+00	6.048E-01
0.6	4.50E+00	7.258E-01
0.9	6.75E+00	1.089E+00
1.0	7.50E+00	1.210E+00
1.0	7.50E+00	1.210E+00
1.0	7.50E+00	1.210E+00
1.0	7.50E+00	1.210E+00
1.1	8.25E+00	1.331E+00
1.1	8.25E+00	1.331E+00
1.2	9.00E+00	1.452E+00
1.3	9.75E+00	1.573E+00
1.4	1.05E+01	1.694E+00
1.5	1.13E+01	1.815E+00
1.5	1.13E+01	1.815E+00
1.5	1.13E+01	1.815E+00
1.0	7.50E+00	1.210E+00
1.0	7.50E+00	1.210E+00
0.9	6.75E+00	1.089E+00
0.5	3.75E+00	6.048E-01
0.3	2.25E+00	3.629E-01
0.2	1.50E+00	2.419E-01

Qu = 1.815 psi = 261.36 psf

APPENDIX B

CONSOLIDATION

CONSOLIDATION CURVE
WASTE CLAY - REMOLDED SAMPLE
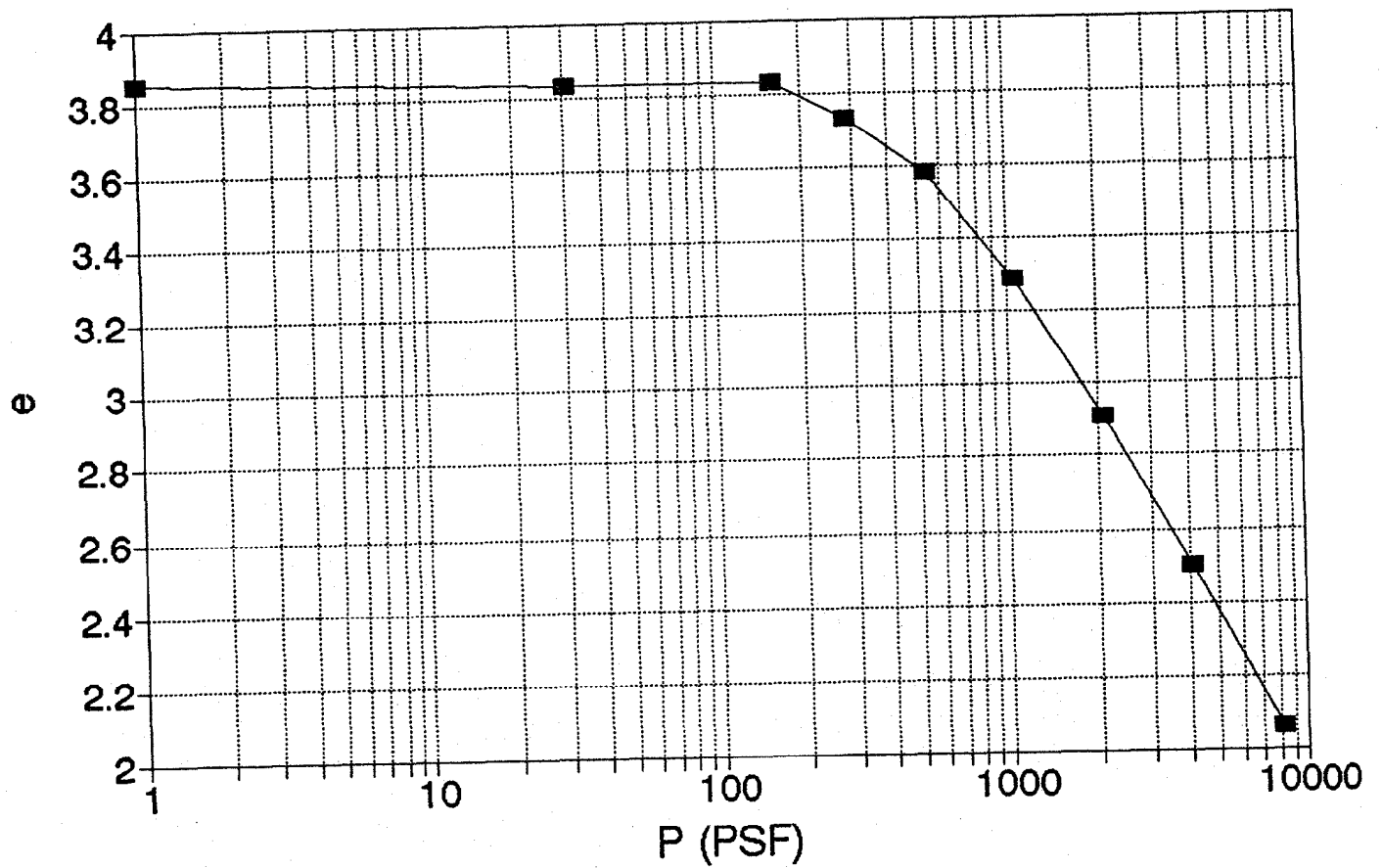
INITIAL SOLIDS CONTENT 42 %

CONSOLIDATION TEST

BROMWELL & CARRIER, INC.

PROJECT:	LIME COLUMN DEMONSTRATION
LOCATION:	HAYNSWORTH
TESTED BY:	SLH/RLO
PROJECT ENGINEER:	FSH
CONSOLIDOMETER TYPE: WYKHAM-FARRANCE	
DIAL FACTOR:	.002 mm

JOB NO.	8233
SAMPLE NO.	1 , OVERBURDEN
SAMPLE DEPTH:	
DATE OF TESTING:	AUGUST 93

RING DIMENSIONS: DIAM.(CM):   7.000   AREA: 38.484   H(CM):   1.905

************ ************ **************** ************ ************ ********* ************ ************ ************ ************

DESCRIPTION OF SAMPLE: OVERBURDEN - GRAY CLAYEY SAND W/ BROWN SL. SILTY SAND LENSES

INITIAL HEIGHT OF SAMPLE (Hi,cm):	1.90
SPECIFIC GRAVITY OF SOIL (Gs):	2.80
INITIAL WT. RING+SPECIMEN,g:	179.87
WT. OF RING, g:	79.57
WT. OF WET SOIL, g.:	100.30

```
|================= ======= |
|    INIT.WATER CONTENT     |
|     WET:              13.96 |
|     DRY:               6.70 |
|     TARE:              1.38 |
|     Wo=             136.47 |
|===== ======= ======= |
```

COMPUTED WT. DRY SOIL,g (Ws'):	42.42
OVEN DRY WT. OF SOIL,g (Ws):	42.20
COMPUTED HT. OF SOLIDS,cm (Hs):	0.39
INITIAL HT. OF VOIDS,cm (Hv=Hi-Hs):	1.51
INITIAL DEGREE OF SATURATION, Si=(Wt-Ws)/(HvA):	100.09%
INITIAL VOID RATIO (e=Hv/Hs):	3.852

******** FINAL TEST DATA *********

INITIAL DIAL READING:	0
FINAL DIAL READING:	3505
CHANGE IN SAMPLE HEIGHT (CM):	0.701
FINAL HT OF VOIDS:	0.807
FINAL VOID RATIO:	2.062

```
|===== ======= ======= |
|    FINAL WATER CONTENT    |
|     WET:             236.77 |
|     DRY:             213.40 |
|     TARE:             79.56 |
|     W final=         17.46 |
|===== ======= ======= |
```

ADDITIONAL INFORMATION:

ATTERBERG LIMITS: LL   24   PL   15   PI   9

ORGANIC CONTENT: _____

WATER LEVEL IN BORE HOLE: _____

PERCENT PASSING #200 SIEVE: 25

NOTES CONCERNING TEST AND SPECIAL INSTRUCTIONS:

PROJECT NO.   8233
SAMPLE NO.   1 , OVERBURDEN
SOIL DESCRIPTION: WASTE CLAY
SAMPLING LOCATION   HAYNSWORTH
SPECIMEN DIAMETER   70.0   MM=   2.76 INCHES
INITIAL SPECIMEN HEIGHT   19.0   MM=   0.75 INCHES
INITIAL WATER CONTENT (%)   136.5
FINAL WATER CONTENT (%)   17.5
WEIGHT OF DRY SOIL SPECIMEN
SPECIFIC GRAVITY   2.8   ACTUAL

\\
\   CALCULATION OF VOID RATIO AND Cv FOR ALL LOADS
\\

HEIGHT OF SOLIDS (cm)   0.392
INITIAL VOID RATIO   3.852

INCREMENT	PRESS {g/cm2}	PRESS {PSF}	DIAL RDG. {D100}	T90 {min}	HEIGHT CHANGE {cm}	CUMUL SAMPLE STRAIN {%}	SAMPLE HEIGHT {cm}	FINAL VOID RATIO {e}	1/2 AVERAGE HEIGHT {cm}	COEFF. OF CONSOL (Cv) {sq.cm/s}	COEFF. OF PERM (K) {cm/s}
0	0	0.00	0		0.000	0	1.900	3.852			
1	15	30.7	37	8000	0.007	0.39	1.893	3.833	0.948	1.59E-06	4.1E-10
2	77.5	159	40	10000	0.001	0.42	1.892	3.831	0.946	1.27E-06	6.4E-12
3	140	286	240	20000	0.040	2.53	1.852	3.729	0.936	6.19E-07	2.1E-10
4	265	542	520	700	0.056	5.47	1.796	3.586	0.912	1.68E-05	4.2E-09
5	515	1054	1100	100	0.116	11.58	1.680	3.290	0.869	1.07E-04	2.9E-08
6	1015	2077	1850	120	0.150	19.47	1.530	2.907	0.802	7.58E-05	1.5E-08
7	2015	4123	2640	80	0.158	27.79	1.372	2.503	0.726	9.30E-05	1.1E-08
8	4015	8215	3500	100	0.172	36.84	1.200	2.064			
9		0			-0.700	-0.00	1.900	3.852			
10		0			0.000	-0.00	1.900	3.852			

Cr=
Cc=   0.55

APPENDIX C

PORE PRESSURE

LIME COLUMN PLOT

TIME VS. POREWATER PRESSURE
LC-1-1A, DEPTH = 8 FT

LIME COLUMN PLOT

TIME VS. POREWATER PRESSURE
LC-1-1B, DEPTH = 12 FT
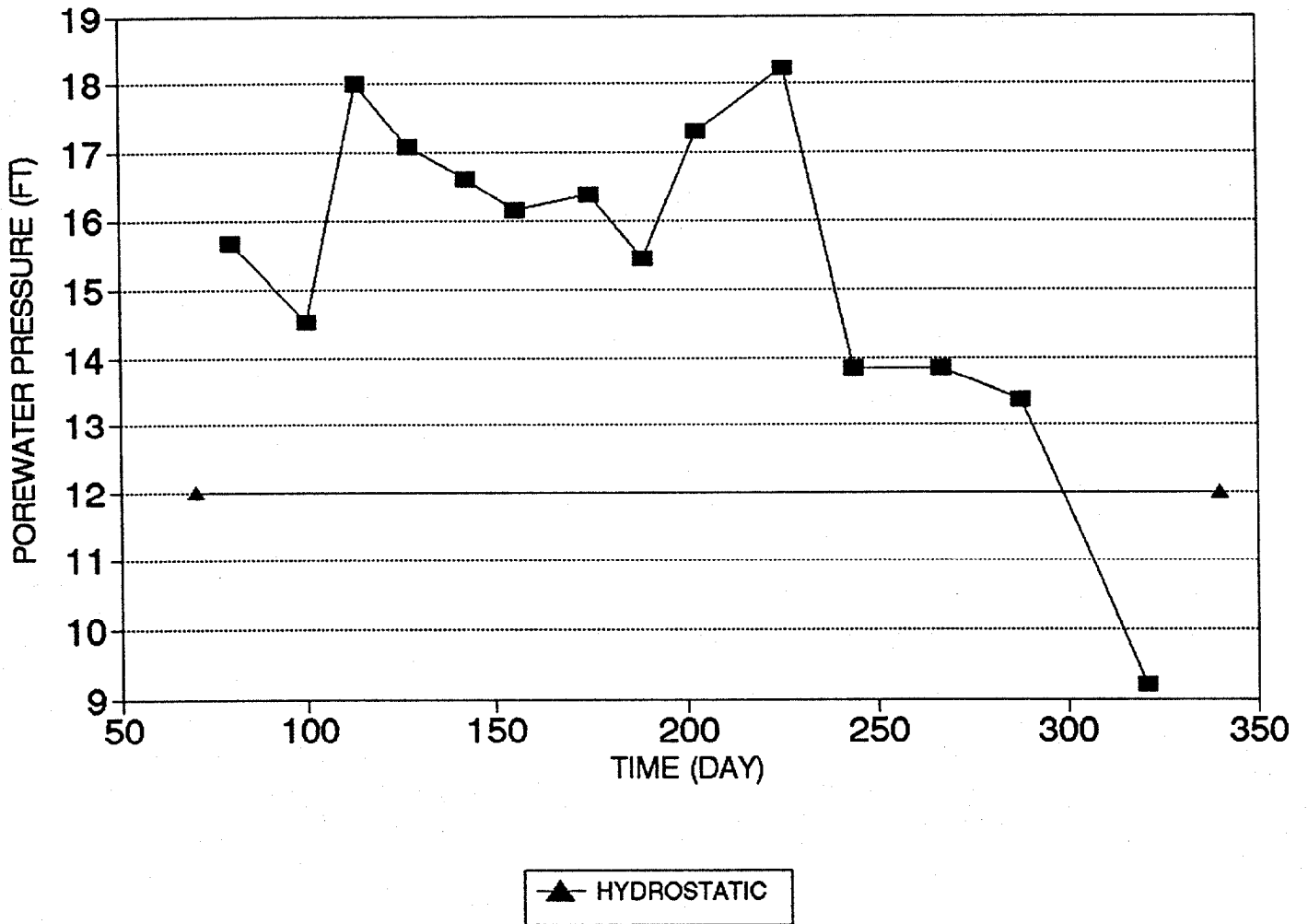
LIME COLUMN PLOT

TIME VS. POREWATER PRESSURE
LC-1-2A, DEPTH = 20 FT

C-3
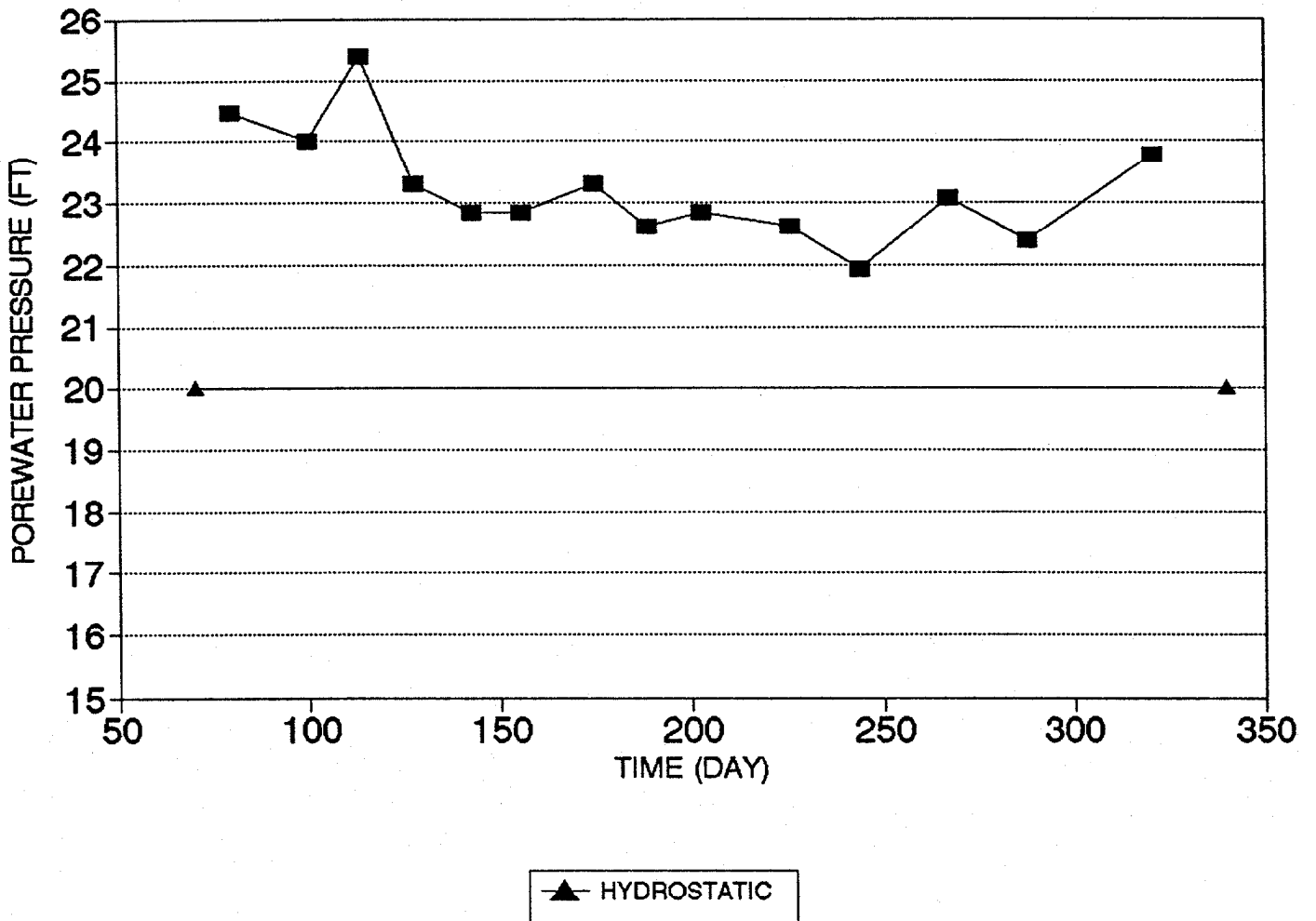
LIME COLUMN PLOT
TIME VS. POREWATER PRESSURE
LC-2-2B, DEPTH = 8 FT
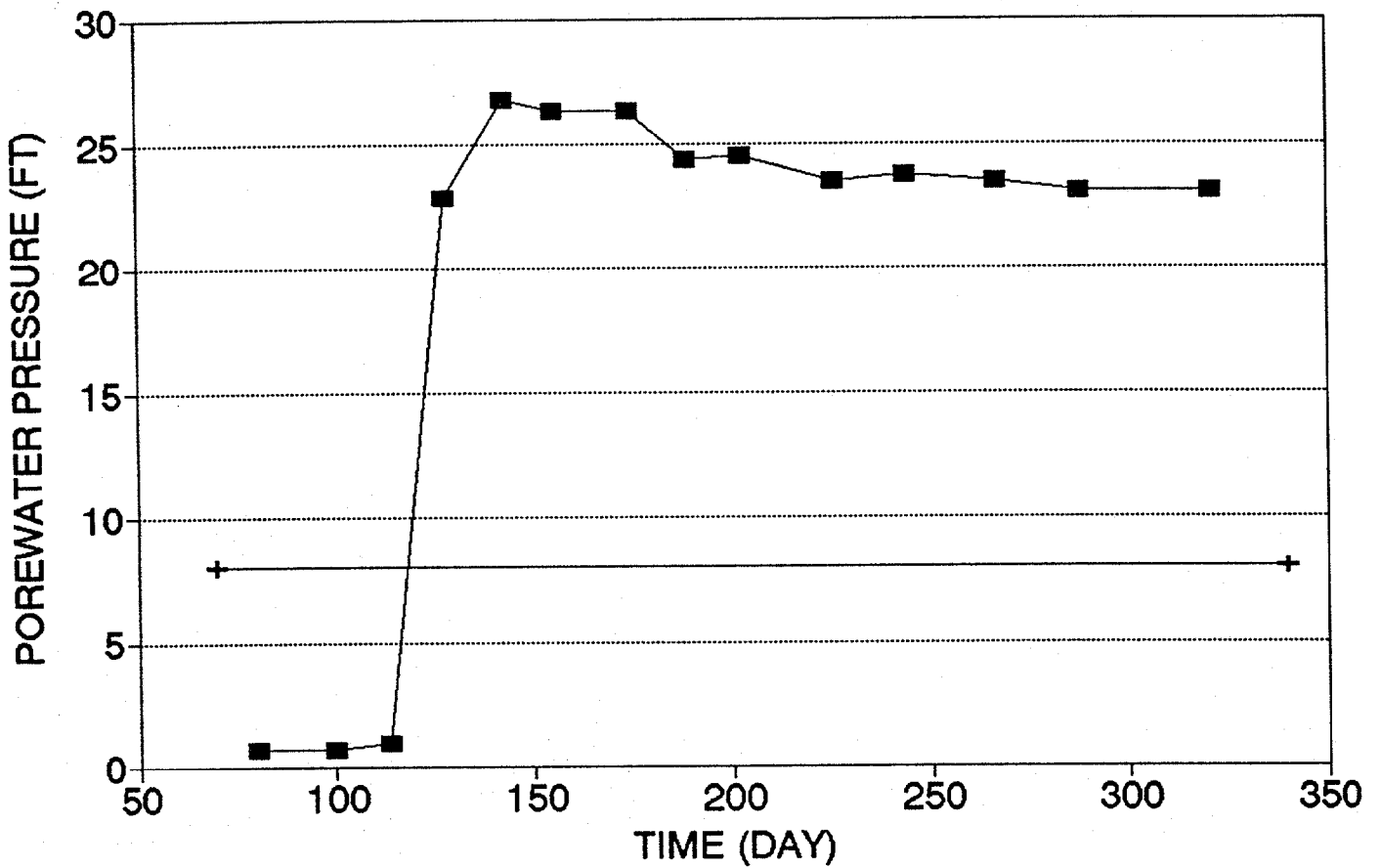
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

LIME COLUMN PLOT

TIME VS. POREWATER PRESSURE
LC-2-3A, DEPTH = 12 FT
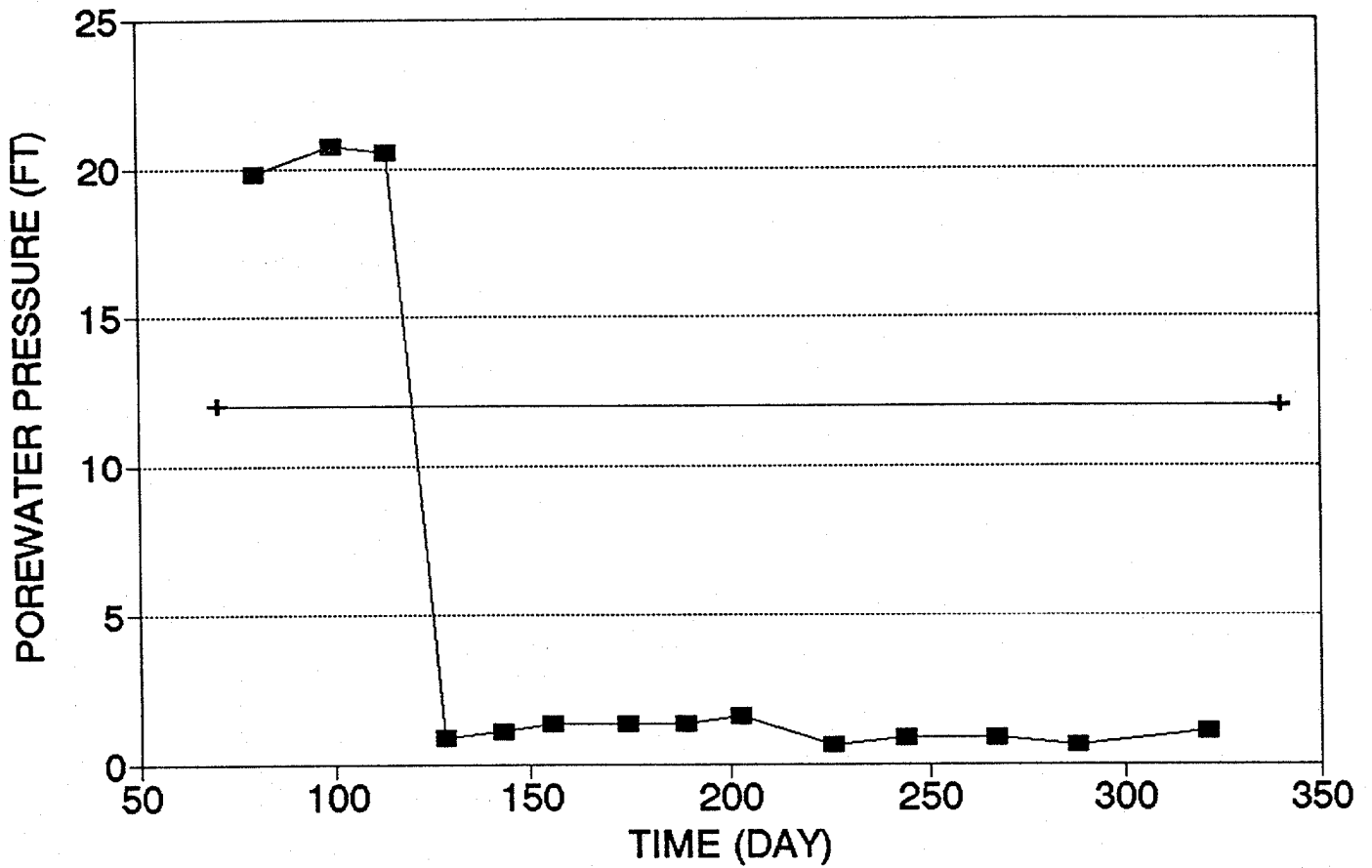
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

LIME COLUMN PLOT
TIME VS. POREWATER PRESSURE
LC-2-3B, DEPTH = 20 FT
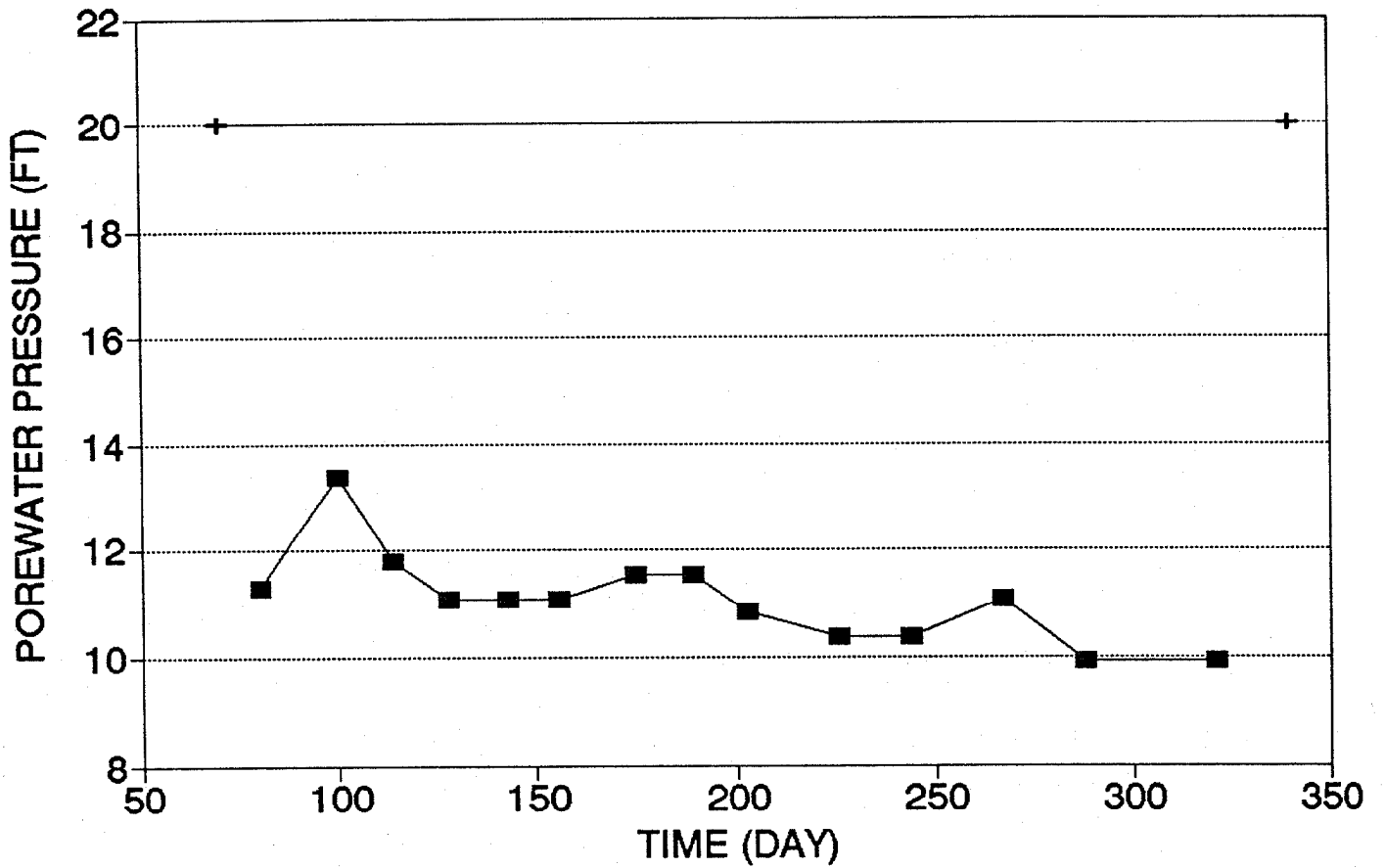
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

LIME COLUMN PLOT
TIME VS. POREWATER PRESSURE
LC-3-4A, DEPTH = 12 FT
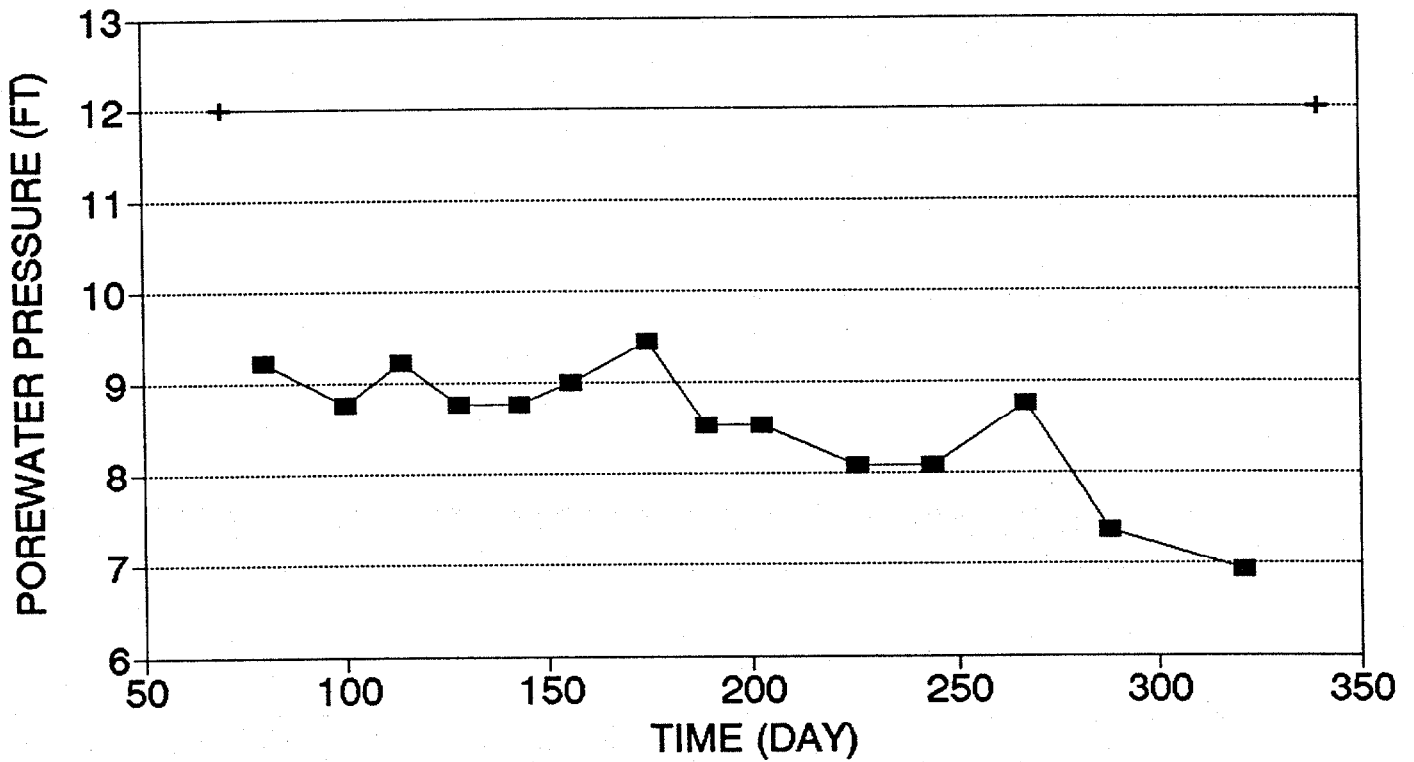
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

LIME COLUMN PLOT
TIME VS. POREWATER PRESSURE
LC-3-4B, DEPTH = 16 FT

LIME COLUMN PLOT
TIME VS. POREWATER PRESSURE
LC-3-5A, DEPTH = 24 FT
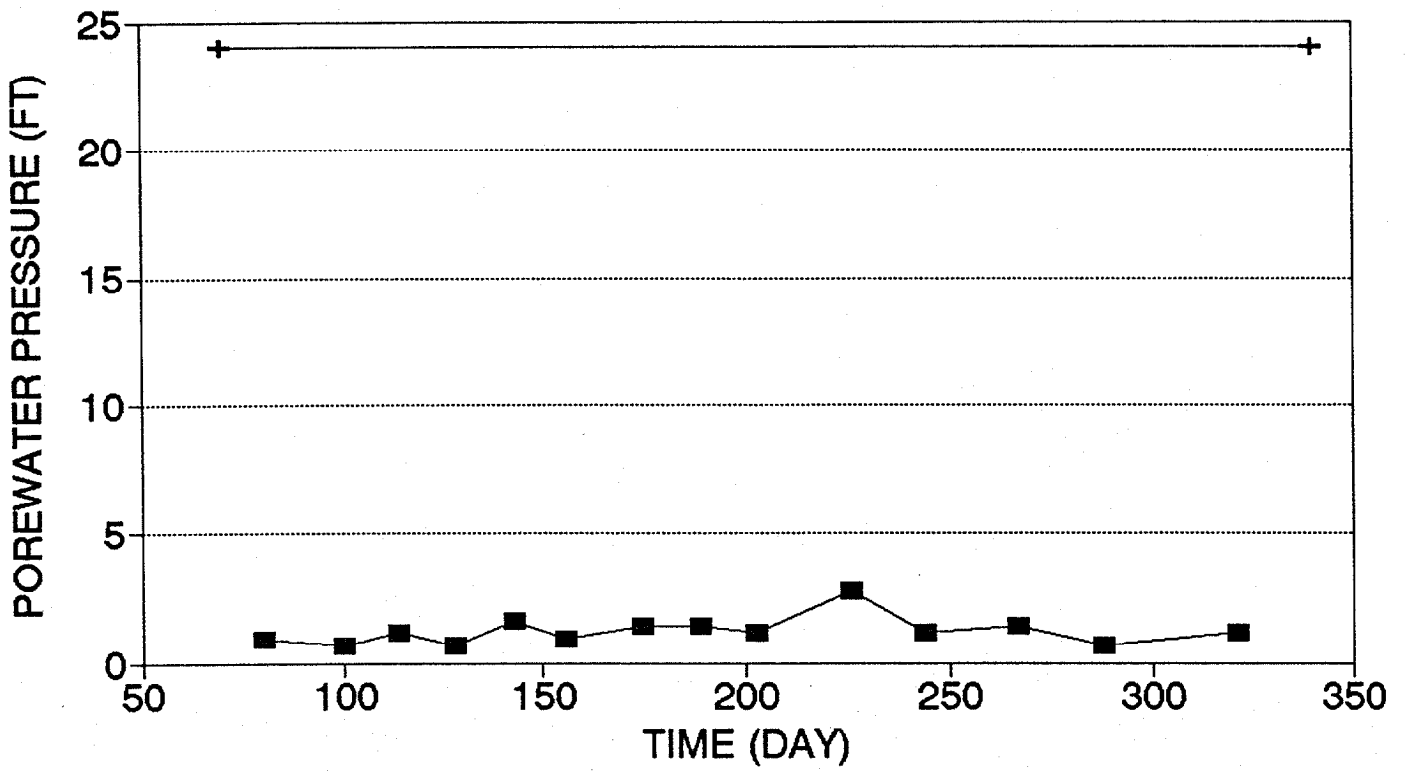
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

LIME COLUMN PLOT

TIME VS. POREWATER PRESSURE
LC-4-5B, DEPTH = 12 FT
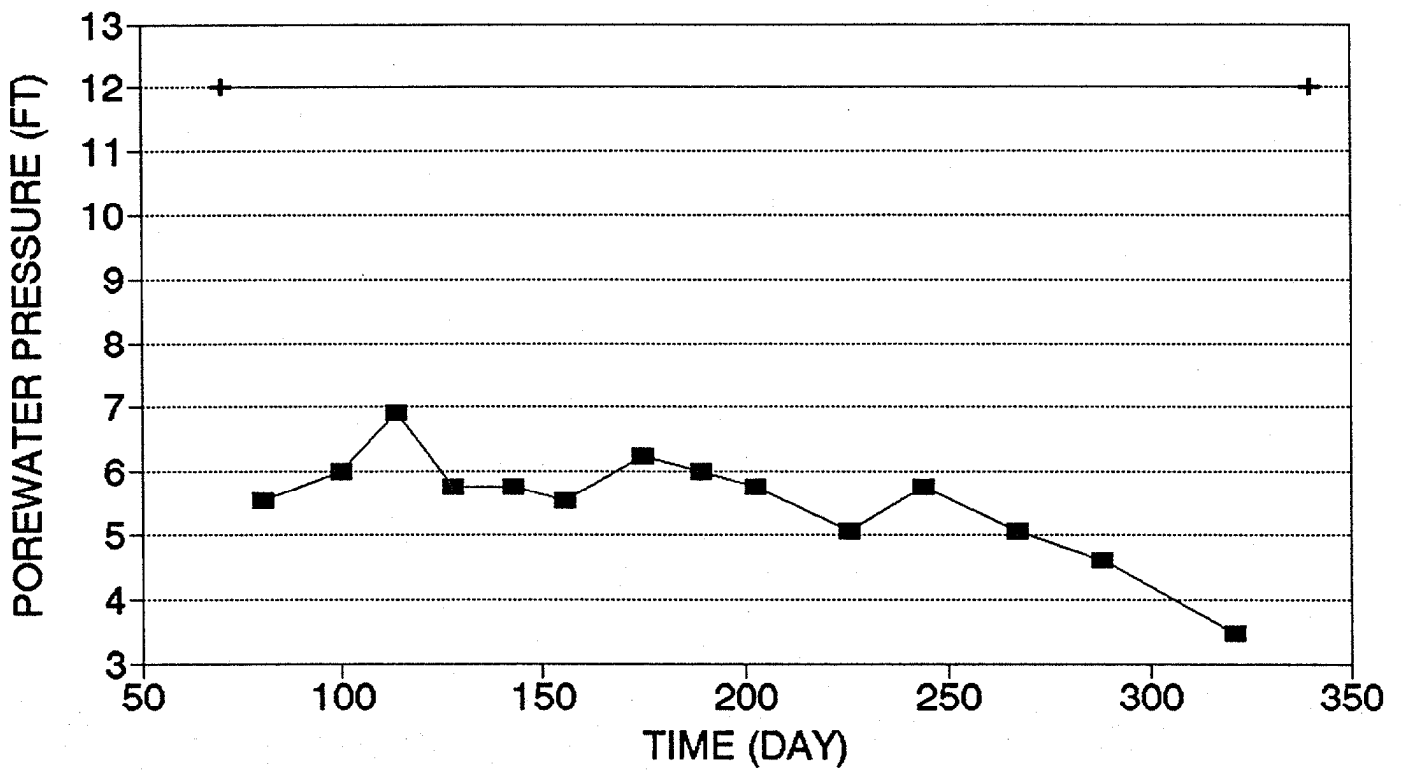
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

LIME COLUMN PLOT
TIME VS. POREWATER PRESSURE
LC-4-6A, DEPTH = 16 FT
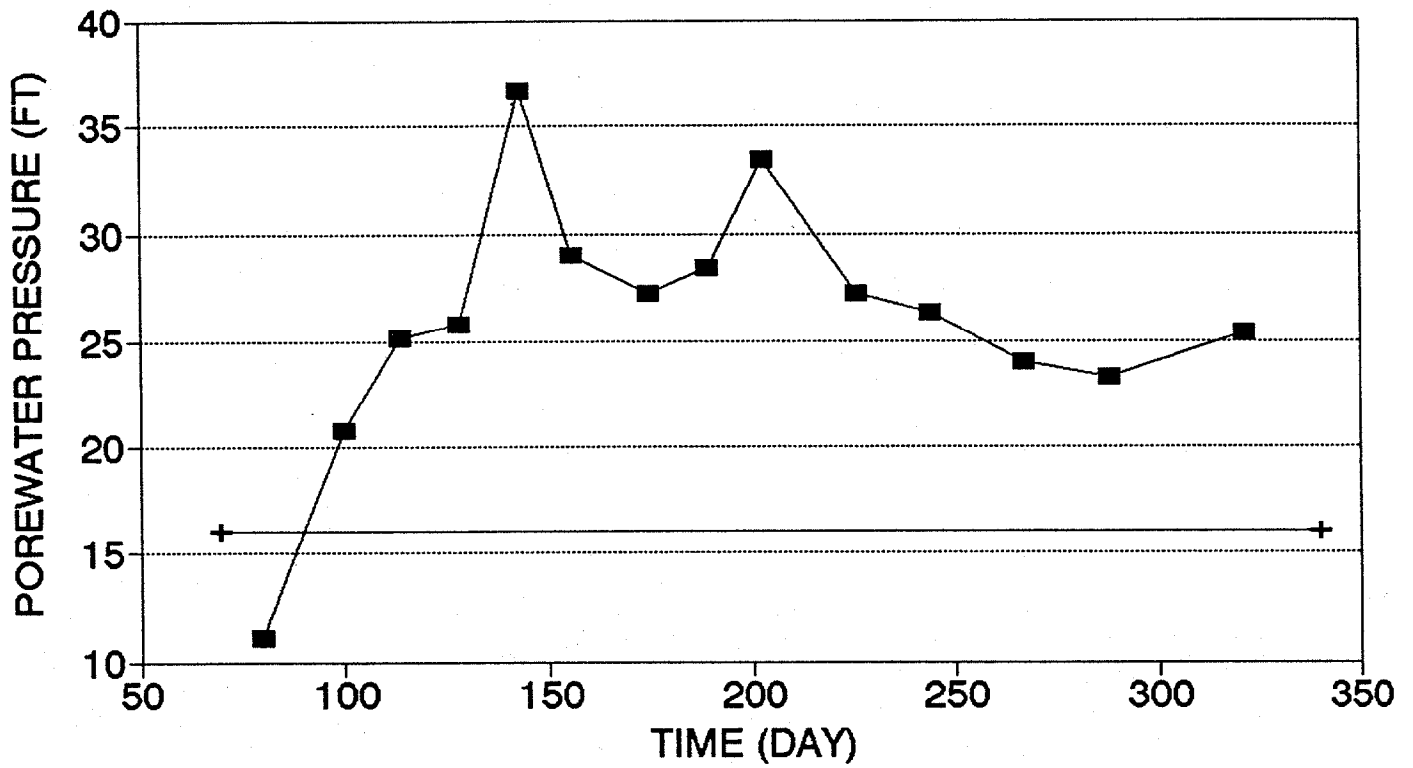
Legend: ──+── HYDROSTATIC

LIME COLUMN PLOT
TIME VS. POREWATER PRESSURE
LC-4-6B, DEPTH = 24 FT

CONTROL PLOT

TIME VS. POREWATER PRESSURE
CP-1-1, DEPTH = 6 FT
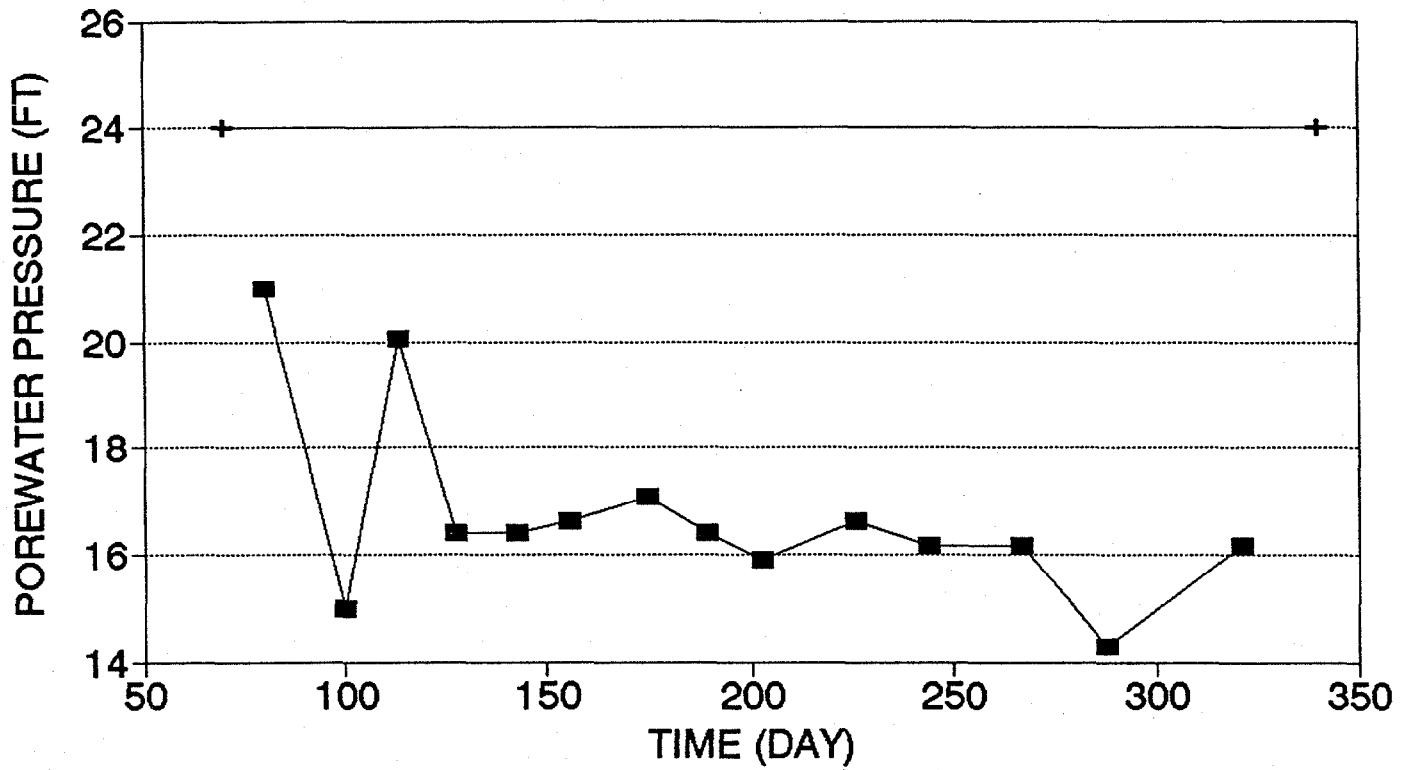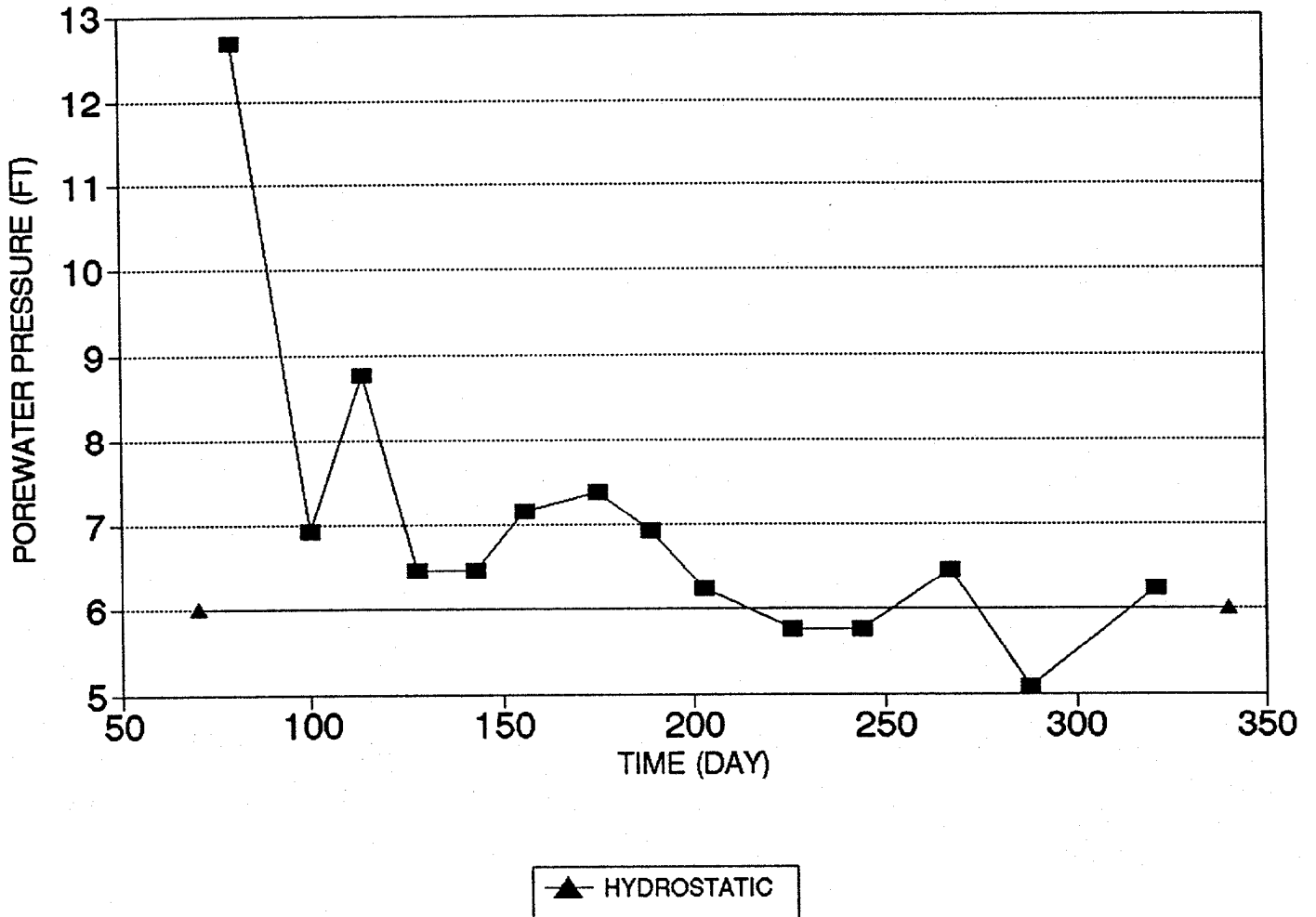
HYDROSTATIC

CONTROL PLOT

TIME VS. POREWATER PRESSURE
CP-1-2, DEPTH = 12 FT
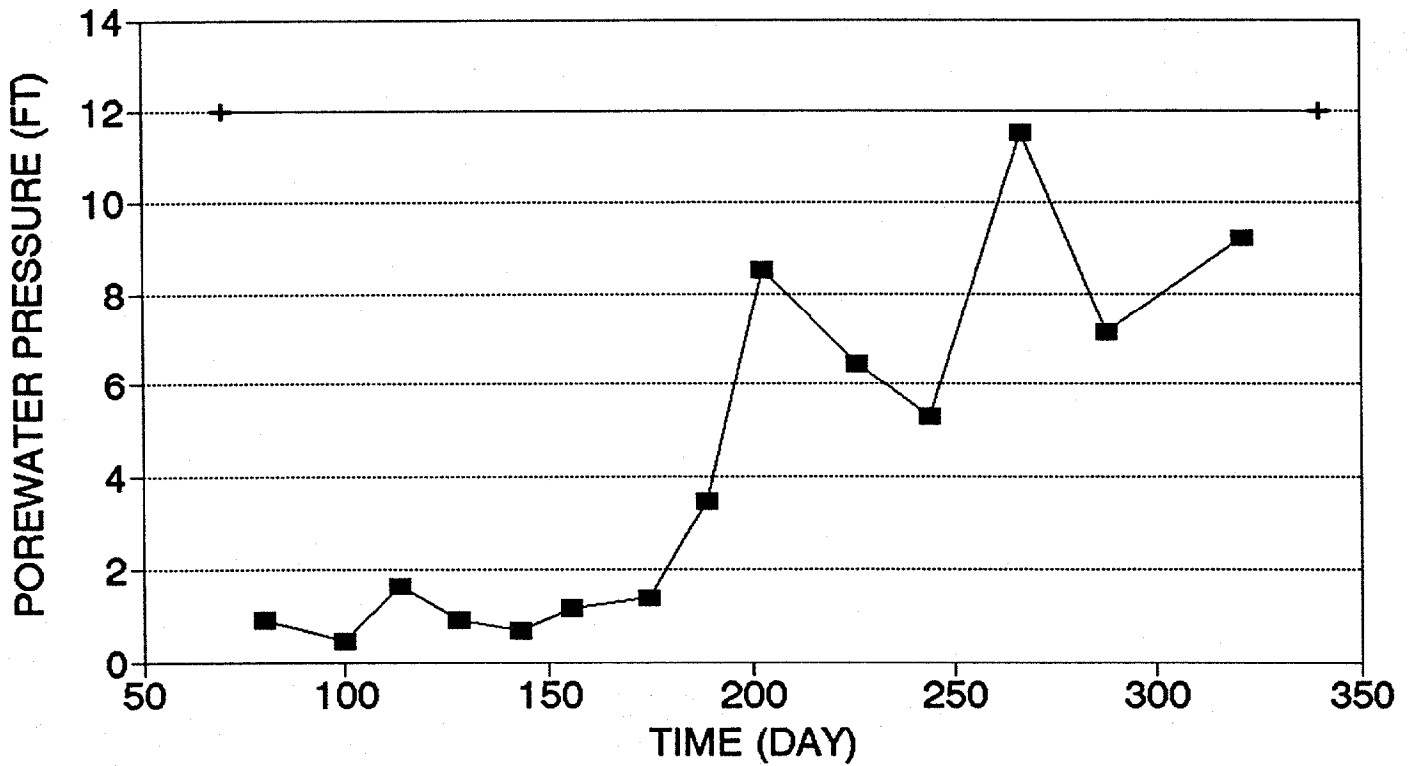
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

CONTROL PLOT

TIME VS. POREWATER PRESSURE
CP-1-3, DEPTH = 18 FT
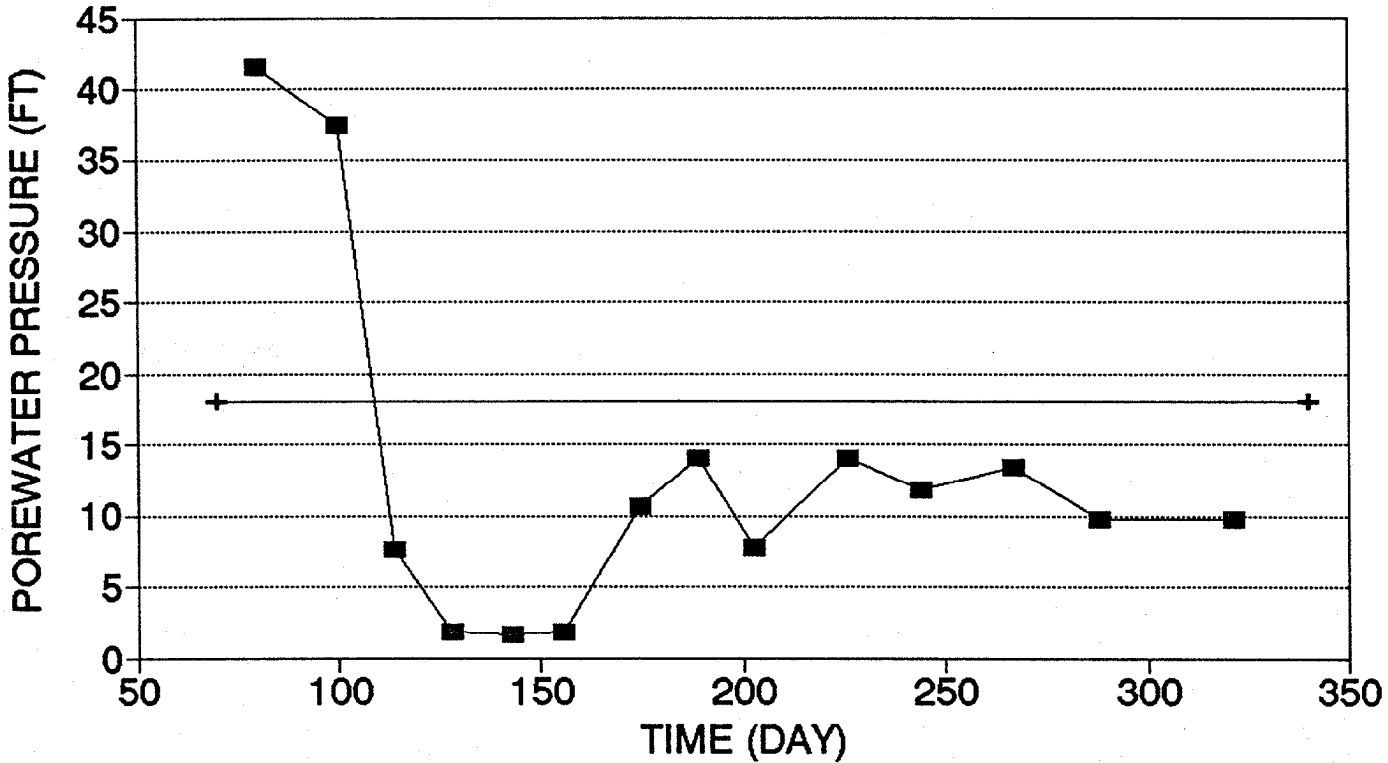
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

CONTROL PLOT
TIME VS. POREWATER PRESSURE
CP-2-4, DEPTH = 12 FT
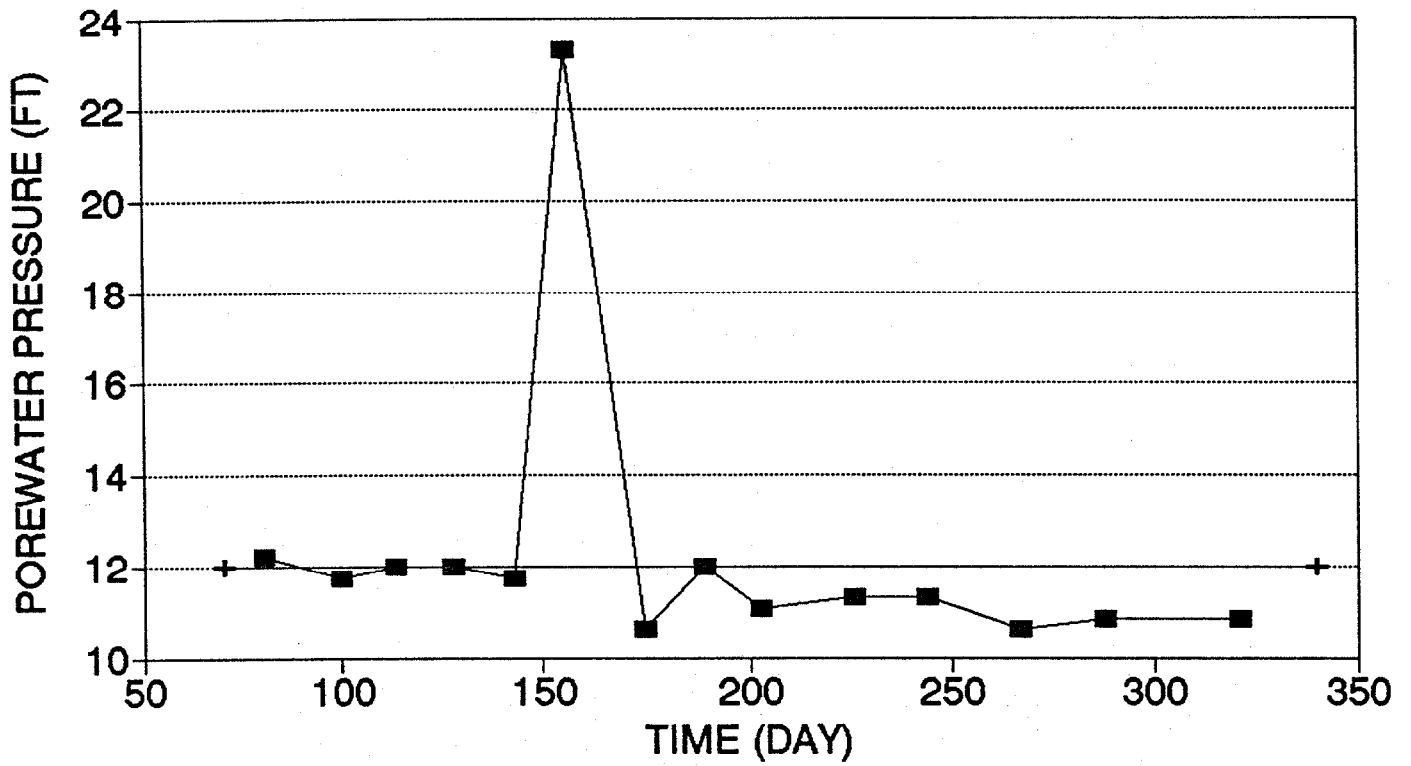
Result is not included in analysis.
Invalid data may be due to clogging of the piezometer tip.

CONTROL PLOT
TIME VS. POREWATER PRESSURE
CP-2-5, DEPTH = 18 FT

CONTROL PLOT
TIME VS. POREWATER PRESSURE
CP-2-6, DEPTH = 24 FT
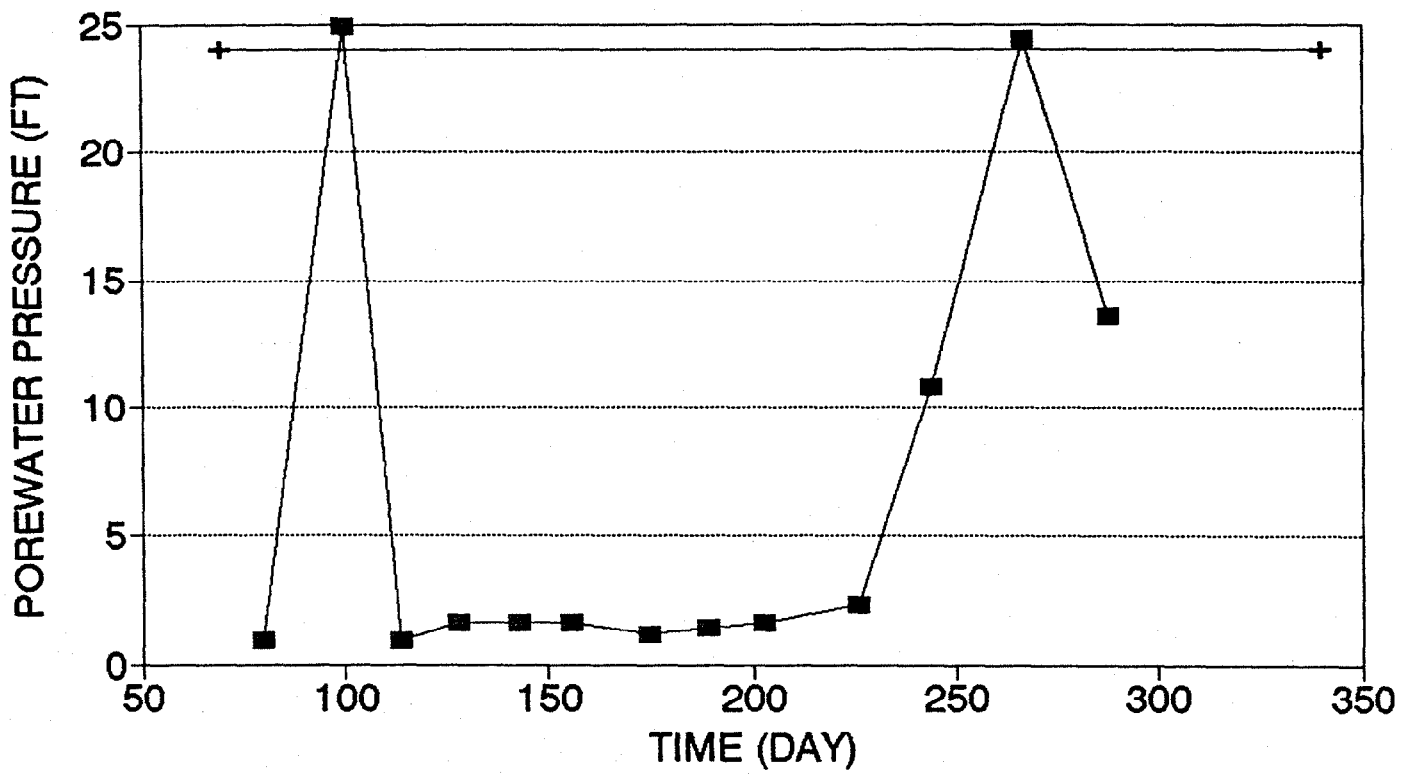
APPENDIX D

SOLIDS CONTENT

DEPTH VS. SOLID CONTENT (PLOT A)
IN THE COLUMNS - DAY 318
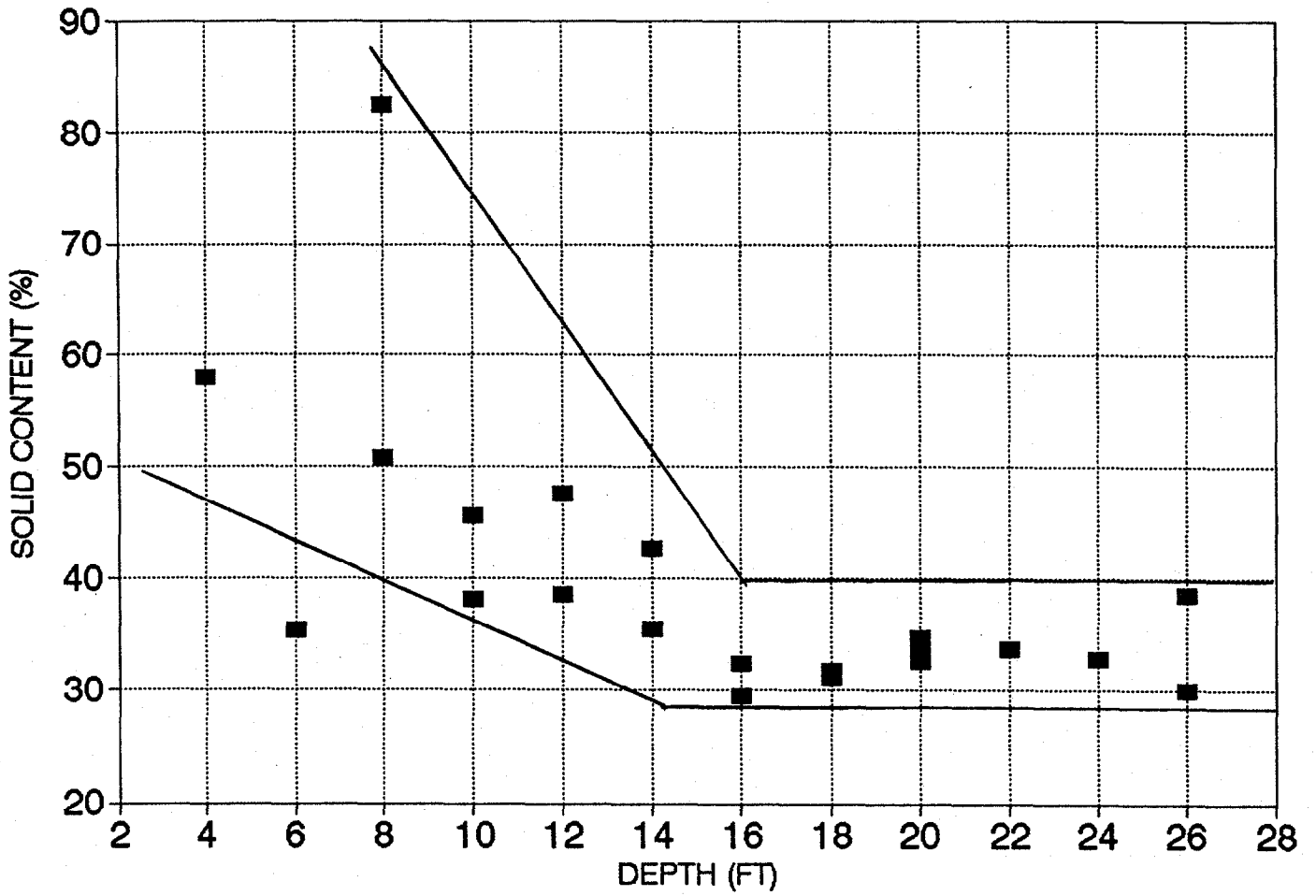
DEPTH VS. SOLID CONTENT (PLOT A)
OUTSIDE COLUMNS - DAY 318
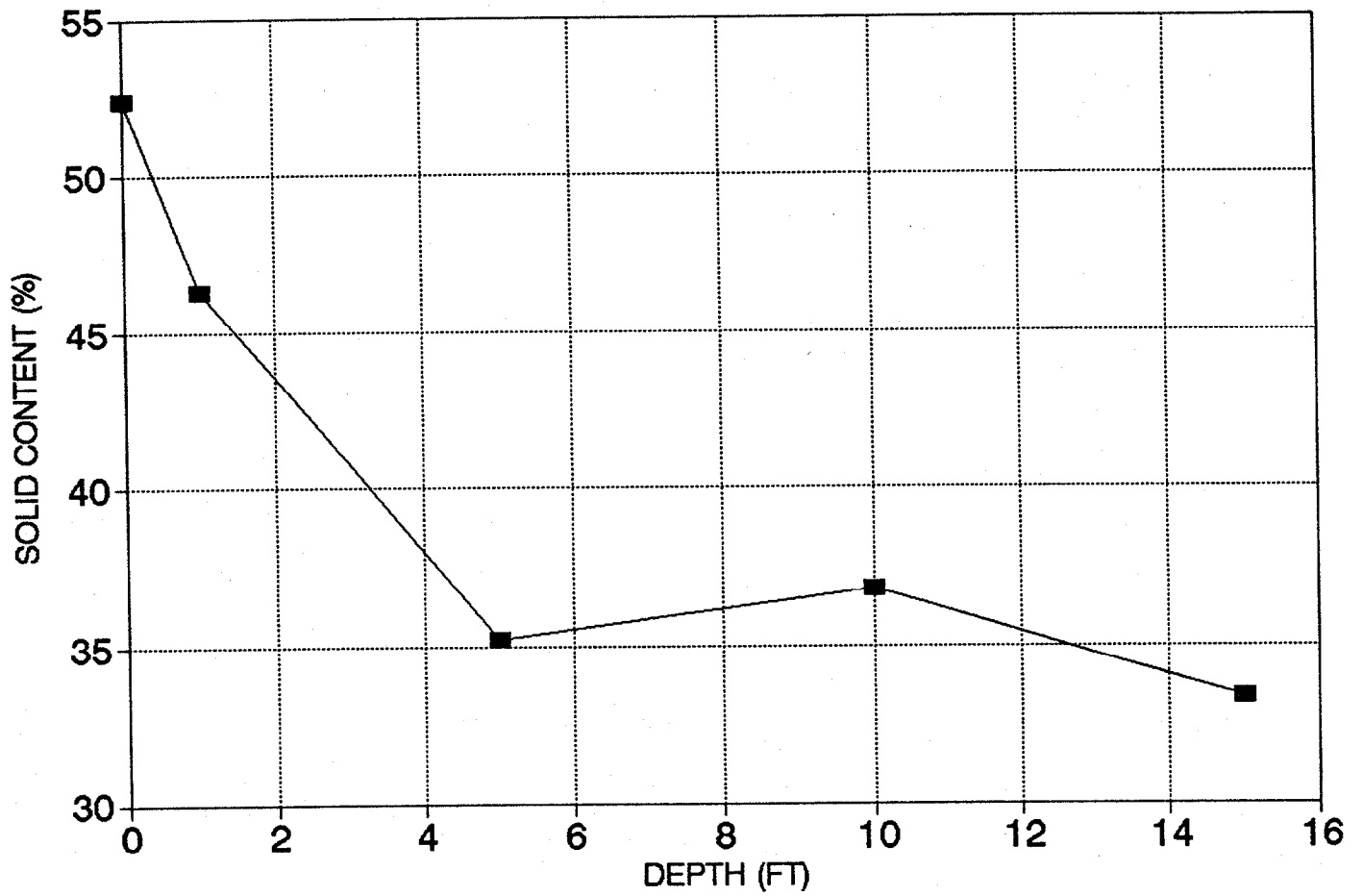
DEPTH VS. SOLID CONTENT (PLOT B)
CONTROL PLOT - DAY 318
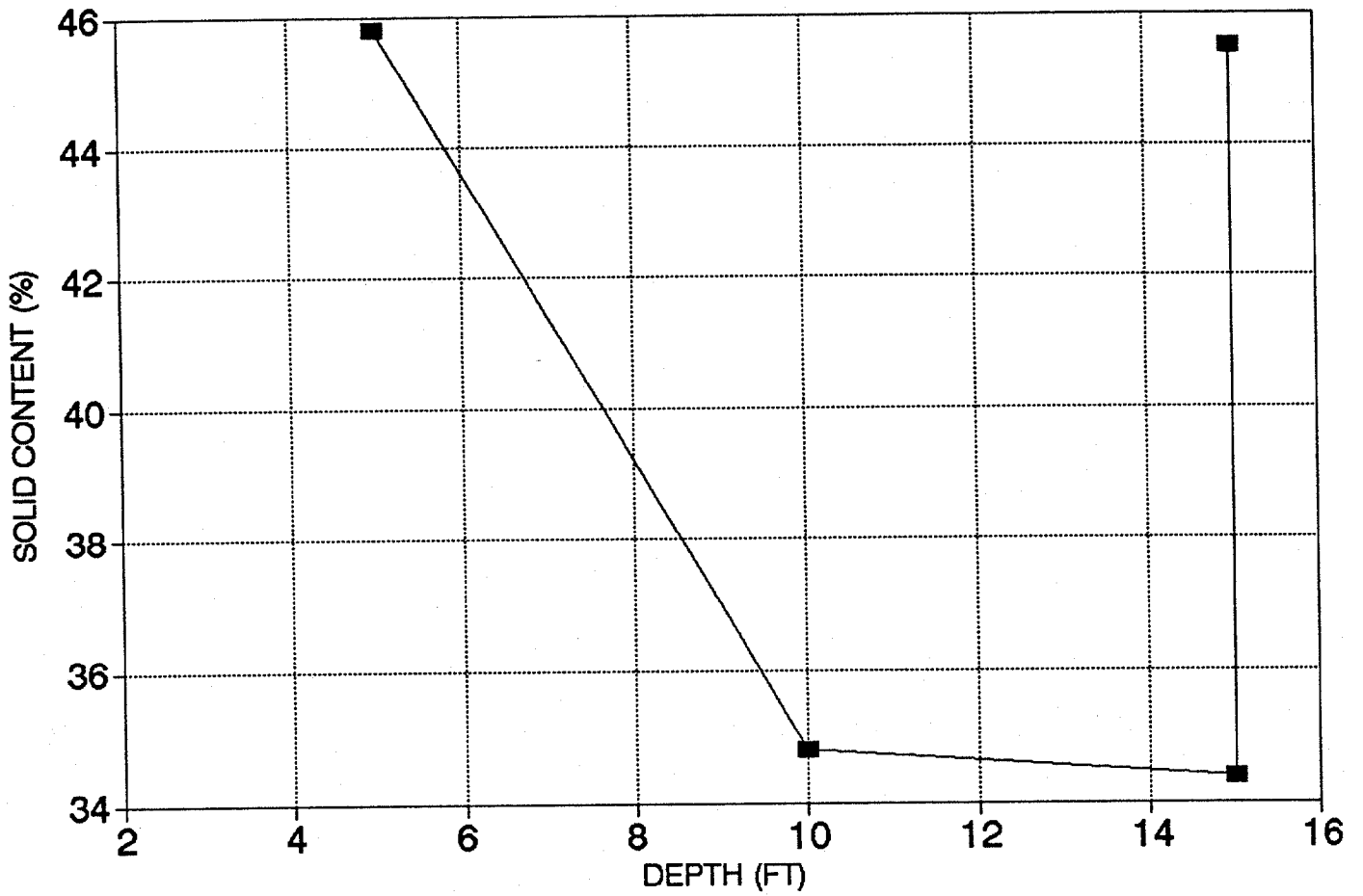
	% SOLIDS, WATER CONTENT					WET SIEVE TEST				
SAMPLE ★	WEIGHT CNTNR. + WET SOIL, g	WEIGHT CNTNR. + DRY SOIL, g	WEIGHT CNTNR., g	SOLIDS CONTENT, %	WATER CONTENT, %	WEIGHT CNTNR. + WET SOIL, g	WEIGHT CNTNR. + DRY SOIL, g	WEIGHT CNTNR., g	% FINER / SEIVE	CLAY SOLIDS
A-A1 (2')	90.07	38.18	2.21	40.9						
-A1 (5')	87.48	28.58		30.9						
-A1 (10')	92.14	30.73		31.7 →		Ave HA-A1	=	33.0%		
-A1 (15')	91.44	27.86		28.7						
-A2 (2')	85.93	35.41		39.9						
-A2 (5')	105.45	35.24		32.0 →						
-A2 (10')	112.52	35.56		30.2		Ave HA -A2	=	32.25 %		
-A2 (15')	81.79	23.63		26.9						
-A3 (2')	104.67	40.28		37.2						
-A3 (5')	101.92	31.99		29.9						
-A3 (10')	93.83	29.62		29.9 →		Ave HA -A3	=	31.0%		
-A3 (15')	95.37	27.30		26.9						
-A4 (2')	70.66	29.85		40.4						
-A4 (5')	109.55	38.53		33.8 →						
-A4 (10')	54.98	18.58		31.0		Ave HA-A4	=	33.2%		
-A4 (15')	94.83	27.85		27.7						
-A5 (2')	106.55	40.39		36.6 →						
-A5 (5')	106.51	34.59		31.0						
-A5 (10')	111.41	34.76		29.8		Ave HA -A5 =		31.0%		
-A5 (15')	97.92	27.78		26.7						
-A6 (2')	85.08	34.58		39.1						
-A6 (5')	99.78	30.28		28.8 →						
-A6 (10')	104.54	34.08		31.1		Ave HA - A6 =		32.4%		
-A6 (15')	94.98	30.66		30.7						

NOTE: SAVE SAMPLES AFTER TESTING FOR BOBBY TO LOOK AT THEM!

PROJECT: NAME _LIME COLUMNS / HAYNESWORTH_ NUMBER _8233_ DATE _8/11/92_

	% SOLIDS, WATER CONTENT					WET SIEVE TEST				
SAMPLE ✱	WEIGHT CNTNR. + WET SOIL, g	WEIGHT CNTNR. + DRY SOIL, g	WEIGHT CNTNR., g	SOLIDS CONTENT, %	WATER CONTENT, %	WEIGHT CNTNR. + WET SOIL, g	WEIGHT CNTNR. + DRY SOIL, g	WEIGHT CNTNR., g	% FINER / SEIVE	CLAY SOLIDS
HA - B1 (2')	109.96	46.75	2.21	41.3						
" - B1 (5')	77.90	24.28		29.2						
" - B1 (10')	103.60	32.03		29.4 →		Ave	HA-B1	= 32.4%		
" - B1 (15')	102.16	31.83		29.6						
" - B2 (2')	77.84	34.96		43.3						
" - B2 (5')	103.59	31.31		28.7 →						
" - B2 (10')	106.60	35.39		31.8		Ave HA	-B2 =	33.2%		
" - B2 (15')	100.07	30.65		29.1						
" - B3 (2')	107.98	44.60		40.1						
" - B3 (5')	107.87	36.51		32.5						
" - B3 (10')	116.35	40.10		33.2 →		Ave HA	-B3 =	34.3%		
" - B3 (15')	121.30	39.50		31.3						
" - B4 (2')	73.94	38.62		39.7						
" - B4 (5')	80.05	27.07		31.9 →						
" - B4 (10')	103.38	32.58		30.0		Ave HA	-B4 =	32.7%		
" - B4 (15')	82.88	25.61		29.0						
" - B5 (2')	92.62	39.05		40.7						
" - B5 (5')	92.80	28.67		29.2 →						
" - B5 (10')	99.98	30.91		29.4		Ave HA	-B5 =	32.3%		
" - B5 (15')	96.50	30.19		29.7						
" - B6 (2')	94.18	41.53		42.8						
" - B6 (5')	86.08	25.62		27.9		Ave HA	-B6 =	31.6%		
" - B6 (10')	91.74	29.52		30.5 →						
" - B6 (15')	105.44	28.18		25.2						

NOTE: SAVE SAMPLES AFTER TESTING FOR BOBBY TO LOOK AT THEM!

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