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# The effect of fly ash on clay

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# THE EFFECT OF FLY ASH

# ON CLAY

by

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## ABSTRACT

Preliminary studies to determine the effect of mixing fly ash with regional swelling of clayey soils indicated these mixtures were superior in certain engineering properties. Mixtures of clay soil, and fly ash at 10, 20, 30, and 40 percent exhibited reduced plasticity and swelling characteristics while the unconfined compression strength of the mixture increased as the percentage of fly ash increased. Based upon the laboratory test results, the possibility of stabilizing swelling soils by using fly ash in structural fills should be practical; The use of fly ash to reduce high plasticity and swelling in soils may prove to be a useful and inexpensive technique.

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# Chapter 1

# INTRODUCTION

Native expansive clay soils have been utilized as structural fill to support both pavements and lightweight residential structures. Structures built on this compacted expansive soil performed well without variation in the moisture content of the soil. However, since the clay has an affinity to absorb water and expand, the infiltration of water through the soil increases the moisture content which can lead to expansion problems. Swelling soils can exert considerable uplift pressures in the magnitude of 2000 to 4000 psf, which is often enough to crack slabs or cause structural differential uplift. The amount of swelling depends on the degree of saturation and percent of compaction of the soil. To control the swell potential several methods are usually suggested. The most economical method is the addition of stabilization agent, such as fly ash. An evaluation of soil-fly ash stabilization for three different expansive soils are presented in this study. The fly ash was added to the soils and the specimens were cured 24 hours and 14 days. The properties of the raw or treated soil samples were analyzed for stabilization purposes after they were subjected to the laboratory tests, and the test results were similar to those in the literature. In general, the testing procedures were in accordance with American Society

for Testing and Materials (ASTM); in addition a swell test under 60 pounds per square foot, which is a local practice, was conducted to evaluate the swell potential.

The purpose of this study is to assess the suitability of fly ash as an agent to reduce the swell potential, reduce the plasticity index, and increase the shear strength of the clay soil.

# Chapter 2

# BACKGROUND

The output of waste fly ash from coal plants in the world exceeds five hundred million tons every year. It has been a tradition to use this solid waste as a stabilizing construction material. Stabilization techniques are usually mechanical or chemical or both, but generally chemical stabilization is favored. There is a need to improve poor on-site soils due to the increased cost of removing it or replacing it with more suitable materials. The possible favorable economic advantage of using boiler waste compared to cement or lime is the availability of fly ash with approximately 6 to 21 percent calcium oxide (Table 1 ). Also a greater awareness on the part of engineers/designers with regard to swelling and other undesirable soil properties has led to soil stabilization using fly ash.

Fly ash is the finer portion of the noncombustible residue produced during the operation of coal-fired boiler units. It is composed primarily of fine-grained particles, most of which are glassy spheres, with other compositions as tabulated in Table 1. The glassy spheres are composed of glass-like structures and relatively resistant to dissolution in a water environment. The self-hardening of characteristics of classic fly ash allow this solid waste to be used as a soil stabilizer.

TABLE 1

Properties of Fly Ash

| | % Compounds | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Fly Ash Source | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | LOI | Calcium Oxide |
| *California Power Plan | 13.36 | 3.34 | 1.23 | 40.66 | 1.41 | 0.13 | 1.72 | 35.65 | 21.1% |
| **Nevada Power Plan | 57.36 | 20.59 | 4.46 | 6.00 | 1.73 | 0.92 | 0.98 | 7.29 | 6.0% |

Notes: *Truesdail Laboratories, Inc.
** ETEC Testing Labs, Inc.

Chemical stabilization for expansive clay soil property improvement consists of changing the physical/chemical environment around the clay particles, changing the nature of water that moves into and out of the voids, and affecting behavioral changes in the soil mass as a whole. These methods include making the clay require less water to satisfy the charge imbalance (making it less difficult for water to move into and out of the system), flocculating the clay to cause aggromulation, and cementing particles together to reduce volume change.

The absorbed water molecules are more intense near the clay particle, with the intensity decreasing with an increase in distance from clay particles. The combination of the negatively charged mineral surface and positively

charged space around the mineral forms what is known as the electric double layer or double layer. The ions absorbed on the soil particle may exchange places with another ion within a double layer.

The criteria of expansive soils are as follows:

- Comprise a plastic clay mineral with a tight layered structure and a weak cation linkage between layers that can be easily broken by water molecules. The minerals such as kaolinite, which exhibit the greatest volume change, have strong hydrogen bonding between two plate structures, which retain a high degree of moisture stability.
- The natural water content must be close to the plastic limit.
- A source of moisture must be available. The percent of swell is proportional to the permeability of expansive soil and degree of saturation.

Heaving of clayey soils poses a difficult problem to geotechnical engineers; to eliminate this problem one of the most common methods is the addition of stabilization agents such as fly ash. Chemical stabilization using fly ash has been experienced and reduction of swell potential has been proven. A case study for stabilization of subgrade soils using class C fly ash was also conducted (Glen Ferguson, 1993) and the survey indicated the

pavement was performing as expected. The unconfined compressive shear strengths of clay-fly ash mixture can be effectively increased as the percentage of fly ash increases (Mohammad Sarker et. al., 1995).

## LOCAL PRACTICE AND CONSIDERATION

Soil exploration and case studies indicate moderate to highly expansive clay soils exist in the northern part of the Las Vegas Valley. The following criteria are common recommendations by local geotechnical engineers.

- Isolation of structure from expansive soils using deep foundation systems or construction of void space between slab and the ground surface for vertical movement of expansive soil. For concrete floor slabs placed directly on potentially expansive clays, provide expansion joints so the floor can move freely from the structural frame.
- Removal of the soil to a depth below the fluctuation of moisture. The excavated native soils will be replaced with structural fill of lower plasticity. The average depth of excavation is of the order of 3 feet,(Fu Hua Chen 1975); this method is more economic than using deep foundations and has been recommended frequently.

Foundation design follows a series of swell tests under 60 psf which are conducted on remolded samples. Specimen preparation and test procedures will be described in the test procedure section of this research. Table 2 shows the criteria for swell test under 60 psf for local practice. In accordance with the table, a clay soil (under 60 psf surcharge) with a maximum swell of 8 percent is assumed to be suitable material for structural fill. The maximum 8 percent swell is representative of one inch tolerable heave under structure when the water infiltrates through one foot of expansive soil; however, the amount of swelling depends on the thickness of the clay layer and the rate of water infiltration.

TABLE 2

Expansive Potential Criteria
for Structural Fill

| Description | Low | Moderate | High | Critical |
|---|---|---|---|---|
| Percent Expansion Under Surcharge Load (60 psf) | 0 - 4 | 4 - 8 | 8 - 12 | 12+ |

# Chapter 3

# METHODOLOGY

The method of study included the following sections:

## PROCEDURE

For this study, three types of soil from different locations were selected. The physical properties of the soils are presented in Table 3. The testing was conducted in two phases. Phase I entailed the determination of Atterberg limits, minus 200 sieve, percent of clay, compaction test, swell test and unconfined compression test. The objective of Phase I was to determine the physical properties and parameters of the raw soil. Phase II consisted of ascertaining the effect of fly ash on the aforementioned properties and parameters of the soils. The soil samples were air-dried and broken down by a mortar and rubber-covered pestle into a minus No. 4 sieve. Each soil was mixed properly and split into portions (ASTM C702) required for each test and stored in sealed plastic bags. For the tests in Phase II, different percentages of fly ash were added to the raw soil and placed in sealed plastic bags, and the mixtures were kept at room temperature for curing. At the ends of curing periods, which were 24 hours and 14 days, the specimens were subjected to laboratory tests. These test results were compared to those from Phase I. The test results were

analyzed. The suitability of treated soils with fly ash were determined in accordance with Table 2.

## EXPERIMENTAL APPROACH

A mixture of clay (sample No. 1) and fly ash was subjected to swell tests under 60 pounds per square feet (PSF) surcharge to evaluate and establish experimental data to study the effect of fly ash on clay.

As shown in Table 3, the liquid limit and plasticity index of North Las Vegas clay (Sample No. 1) are 280 and 192, respectively, with a swell potential of 56.5 percent. As presented in Table 3, 50% fly ash was added to the clay to reduce the swelling potential from 56.5% to 8.8%, which is moderately expansive (Table 2). Since this type of clay is seldom encountered in the valley, the sample was eliminated from the testing program.

## TESTING PROGRAM

The parameters of the raw soils and the mixtures of soil and fly ash were determined by routine testing. The parameters consisted of unconfined compressive strength, swell potential and plasticity index of the mixtures.

## DISCUSSION OF RESULTS AND CONCLUSION

The stress versus strain curves for unconfined compression tests were plotted, and the strengths of the specimens were evaluated based on the percentages of fly ash and curing time. Reduction in the swell potential associated with the percentages of fly ash in the mixtures were calculated, and the suitability of the mixtures were determined in accordance with Expansive Potential Criteria for Structural Fill (Table 2). The Atterberg limits of the mixtures were determined, and the materials were classified in accordance with the Unified Soil Classification System.

## ENGINEERING PROPERTY OF MATERIALS

### Fly ash

The fly ashes employed in this research are the waste products of California power plant and Nevada power plant. The California fly ash at different percentages was mixed with North Las Vegas clay (sample No. 1) to establish experimental data in the laboratory to determine the percentage of fly ash required to achieve the desired degree of stabilization for the clay. Hence, the stabilization was assessed on the basis of swell potential. Further laboratory testing continued with local fly ash and two different clay soils (samples No. 2 & 3) to study maximum dry density, plasticity index, and unconfined compressive strength of the mixture. Properties of the fly

ash are presented in Table 1.

Clay

The fine grain clay soils utilized in this study were taken from the following areas.

North Las Vegas - Clay Sample No. 1 was classified as (CH) and contained smectites mineral, a high concentration of sodium sulfate, high liquid and plasticity index. The general location of construction site was at Cheyenne Avenue and Simmons. Clay Sample No. 3 was obtained from a site of excavation at Cheyenne and Lamb Avenues and classified as halloysite clay (CL) with gypsum.

Colorado - Sample No. 2 was obtained from the site of an ongoing construction in Douglas County, Colorado. The soil classified as kaolinite clay (CL). The mineral exhibited a very high shear strength at natural moisture content. Table 3 presents the index properties of clay soil and fly ash.

ROUTINE TEST PROCEDURES

The following is a summary of the methods used in the testing program; also the number of tests conducted in the study is summarized in Table 5.

1. Atterberg Limits (ASTM 4318)
2. Amount of material in soils finer than the No. 200 sieve (ASTM D1140)
3. Particle size (ASTM D422)
4. Unified Soil Classification (ASTM D2487)
5. Modified Compaction test (ASTM D1557)
6. Specific gravity (ASTM D854)
7. Unconfined compression test (ASTM D2166)

TABLE 3

ENGINEERING PROPERTIES OF EXPANSIVE SOILS

North Las Vegas Clay (Sample No. 1) Mixed With Fly Ash

| Type of Mix | Raw Soil | 10% FA | 20% FA | 30% FA | 40% FA | 50% FA |
|---|---|---|---|---|---|---|
| % Swell (@ 60 psf surcharge) | 56.5 | 23.0 | 20.8 | 14.1 | 9.7 | 8.8 |

TABLE 4

Index Properties of Clay Soil & Fly Ash

| | % Clay | % finer than No. 200 sieve | Specific Gravity | LL | PL | PI | Clay Activity | ASTM D2487 (USCS) | Mineral | Total Available Water Soluble Sodium Sulfate (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| North Las Vegas Clay Sample #1 | 100 | 100 | - | 280 | 82 | 192 | 192 | CH | Smectites | 2.35 |
| Colorado Clay Sample #2 | 78 | 55.0 | 2.87 | 41 | 17 | 24 | 0.24 | CL | Kaolinite | 0.03 |
| North Las Vegas Clay Sample #3 | 52 | 55.1 | 2.67 | 48 | 23 | 25 | 0.25 | CL | Halloysite | 0.77 |
| Fly Ash | - | 85.6 | 2.41 | NP | NP | NP | - | Class F Fly Ash | - | |

Clay Acitivity = [Plasticity Index (PI)] + (% < 2 μm)

Note: Nonplastic (NP)

TABLE 5
Number of Tests Conducted in the Study

| Test | -200 | PI | Specific Gravity | Hydrometer | Compaction | Swell | UNC* | Soluble Sodium Sulfate |
|---|---|---|---|---|---|---|---|---|
| California Fly Ash (FA.1) | - | - | - | - | - | - | - | |
| Nevada Fly Ash (FA.2) | 1 | - | 1 | - | - | - | - | |
| FA.1 and/or North Las Vegas Clay (Sample 1) | 1 | 1 | 1 | 1 | 3 | 5 | - | 1 |
| FA.2 and/or Colorado Clay (Sample2) | 1 | 4 | 1 | 1 | 4 | 4 | 8 | 1 |
| FA.2 and/or North Las Vegas Clay (Sample3) | 1 | 4 | 1 | 1 | 4 | 4 | 8 | 1 |

* Unconfined Compression Test

# Chapter 4

# TEST PROCEDURE

To evaluate the engineering properties of untreated and mixtures of clay and fly ash, ASTM and AASHTO standard test methods were employed. The following sections describe the sample preparation and test procedure.

## MINUS 200 SIEVE

The percent passing a No. 200 sieve was determined in accordance with ASTM D 1140. The samples were dried, weighed, soaked in water until individual soil particles were separated, and then washed on the No. 200 sieve. That portion of the material retained on the No. 200 sieve was oven-dried and weighed. The ratio of retained to total dry weight is calculated as the percent retained.

## ATTERBERG LIMITS

The Atterberg limits of the specimen was determined according to ASTM D4318. The raw or treated soil with fly ash samples were air dried for 24 hours in room temperature. The materials were passed through a No. 40 sieve. The minus 40 materials were mixed with distilled water and placed in containers with snug-fitting lids and soaked. Liquid and plastic

limit tests were conducted on the materials after a 24-hour soaking period.

## SOIL CLASSIFICATION

Atterberg limits and the amount of material finer than No. 200 sieve were used to classify the soils according to ASTM D2487.

## SPECIFIC GRAVITY

ASTM D854 was used to determine the specific gravity of the fly ash and raw soils. Approximately 110 grams of air dry specimens were mixed with distilled water in an evaporating dish to form a creamy paste, after 30 minutes of soaking period the paste transferred into a 500 millimeter volumetric flask. Additional distilled water was added to fill the volumetric flask about three-fourths full, by boiling procedure the entrapped air was removed. When the de-airing process was completed, distilled water was added into the bottom of the meniscus was exactly at the volume mark, the flask and contents were weighed and the specific gravity of the samples were determined according to ASTM D854. The test results are shown on table 4.

HYDROMETER

Hydrometer analysis tests (ASTM D422) were run on the raw soils to evaluate percent of clay; The ratio of plasticity index to the percentage by weight of particles finer than minus 200 sieve is calculated as the activity of clay. Approximate values for the activities of different clay minerals are shown in Table 6, which was used to identify the clay minerals in the study. Table 3 shows the test results.

TABLE 6

Activities of Various Minerals

| Activity | Mineral |
|---|---|
| 1-7 | Smectites |
| 0.5-1 | Illite |
| 0.5 | Kaolinite |
| 0.5 | Halloysite ($2H_2O$) |
| 0.1 | Halloysite ($4H_2O$) |
| 0.5-1.2 | Attapulgite |
| 0.5-1.2 | Allophane |

(After Mitchell)

MOISTURE DENSITY RELATIONSHIP

Four point modified Proctor curves were developed using a 4-inch mold and a 10-pound manual rammer. The soil and fly ash was mixed by

hand until the blend was homogeneous. Tap water was added and mixed to prepare the specimen before compaction. Four specimens were prepared by adding increasing amounts of water to each sample so that the moisture contents were different by approximately 2%. The soil and fly ash mixture at a selected water content (2%, 4%, 6%, and 8%) was placed into the mold in five layers and compacted by 25 blows per layer. Virgin fly ash and soil were used for each separate Proctor point to ensure particle deformation due to compaction did not effect densities.

## UNCONFINED COMPRESSION TESTS

Specimens for the unconfined compressive strength were compacted in a Harvard miniature mold using modified compaction effort (5 layers; 25 blows per layer). The specimens were extracted from the mold, placed in sealed plastic bags, and were cured at room temperature for 24 hours, and 14 days. At the end of the curing periods, the specimens were unwrapped and tested for unconfined compressive strength. The tested specimens were 1.31 inches in diameter and 2.83 inches in length, and were loaded axially in compression with a strain rate of 0.5 percent/minute.

## EXPANSION MEASUREMENTS PROCEDURE

AASHTO T-258-78 is the standard procedure for expansion

measurements of disturbed specimens. In this study, AASHTO T-258-78 is followed utilizing a consolidometer. The maximum dry density and optimum moisture content of each clay soil was determined according to ASTM D1557 before and after different percentages of fly ash were added to the materials. The soil samples for expansion tests were prepared at optimum moisture content and cured for 24 hours in sealed plastic bags. By using maximum dry density and optimum moisture content of each soil sample, the amount of raw soil or mixture of soil and fly ash for each specimen was calculated. The required cured samples were weighed and compacted in five equal layers in a standard brass ring with a dimension of one inch high and 2.495 inches inside diameter. A one inch diameter tamper was used to compact the materials inside each ring using the same compaction energy level. These samples were representative of the natural state of clay in the field with a 90 percent Modified Proctor. The compacted ring specimens were allowed to air dry at room temperature for 48 ($\pm$4) hours before conducting the expansion test.

The expansion measurement procedure was as follows:

1. The weight of the specimen was recorded before the test. From the weight of the ring and sample, the moisture content of the soils and the volume of specimen and the initial moisture was calculated.

2. The soil specimen was placed between two porous stones with the size slightly smaller than the inner diameter of the brass ring. The specimen with the porous stones were placed in a fiberglass water dish, an apparatus was set in the consolidometer, a 60 PSF surcharge was applied, the vertical displacement dial was set, the initial reading was recorded, and the specimen was submerged.
3. After the tap water was added to the fiberglass dish, dial readings were taken at 1, 2, 4, and 24 hours. The expansion test was terminated when the dial moved less than 0.0001 inch. The ratio (in percent) of difference between the final and initial dial readings to the initial specimen height is the percentage of expansion.
4. The specimen with ring was removed from consolidometer and the excess water was allowed to drain. The specimen was weighed and oven-dried to determine its final moisture content. The oven was set to a temperature between 50 to 60 degrees Centigrade (122 to 140 degrees Fahrenheit).

# Chapter 5

## DISCUSSION OF RESULTS

### ATTERBERG LIMITS

The Atterberg limit of tests were conducted on the raw soil and the soil treated with fly ash. The plasticity index for raw soils ranged from 24 to 25 for Colorado clay (sample No. 2) and North Las Vegas clay (sample No.3). It was observed that the liquid limit and plasticity index were substantially lowered by incremental additions of fly ash. The plasticity index (PI) of North Las Vegas clay lowered from 25 for raw soil to 4 for 20% fly ash in the mixture. Similarly, the PI value for Colorado clay was lowered from 24 for the raw soil to 7 for 20% fly ash in the treated soil. Plasticity tests data are shown in Figure 1 and 2. In this study, the calcium ion contained in the fly ash has replaced the sodium ion in the clay sample. This transformation has a significant effect on the properties of clay. The thickness of the absorbed water layer may be reduced as a result of an ion exchange. Thus, the relative movement of adjacent particles was reduced. This permits the soil to deform plasticity without cracking. Table 1 presents the percent concentration of calcium in the fly ash and sodium in the clay sample.

## MOISTURE DENSITY RELATIONSHIP

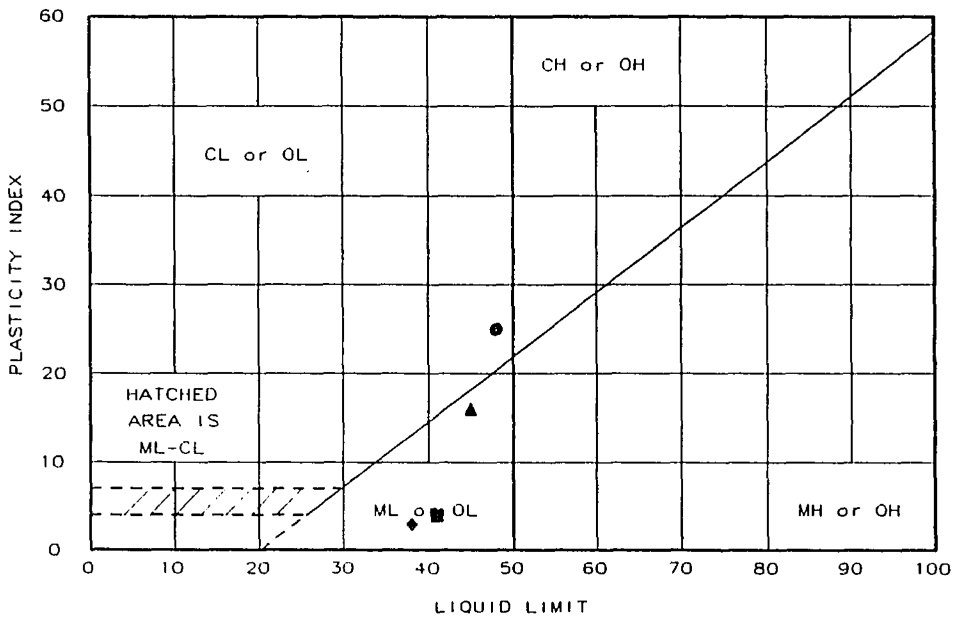
The family compaction curves for each of the mixtures is shown in Figures 7 through 8. When the fly ash is mixed with the clay, the maximum dry density decreases and the optimum moisture content increases. The variation in maximum dry density is related to the low specific gravity of fly ash.

## SWELL POTENTIAL

Table 5 and 6 shows the percentage of swell versus 60 psf surcharge load. A substantial reduction in the swell potential was observed. The test results indicated that when raw soil was subjected to the swell test, the time period required to achieve maximum swell was over 48 hours, while the time period for the mixture of clay and fly ash was approximately two hours, during this time and saturated condition, the ion exchange and flocculation of the clay minerals were taking place, the cementitious product formed, and no further swell occurred.

For 10% and 40% fly ash mixed with sample No. 2 and 3, the maximum swell was found to be 4% and 4.4% respectively. In accordance with table 2 the materials were classified as moderately expansive soil which meets the criteria for structural fill.

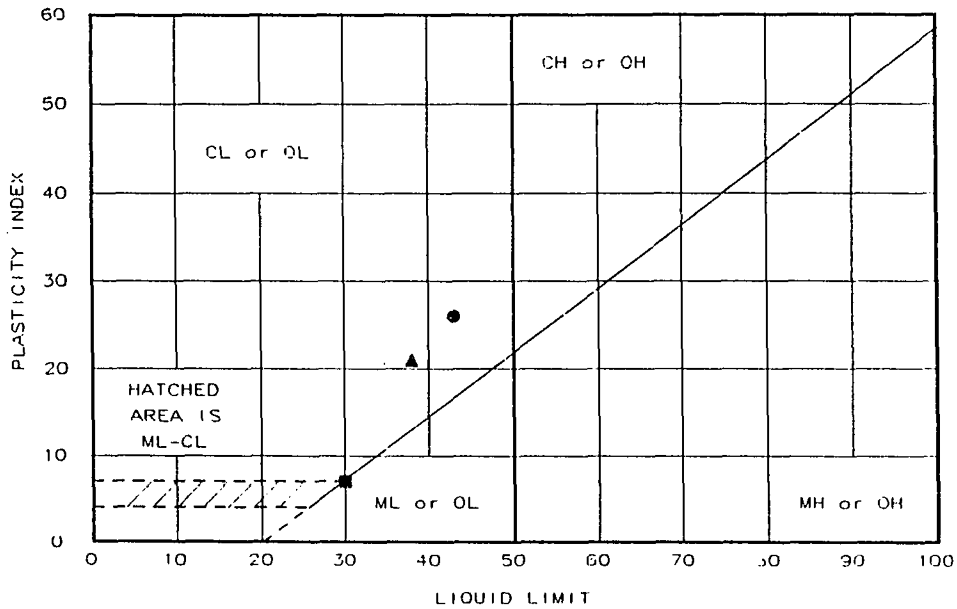
# LIQUID AND PLASTIC LIMITS TEST REPORT




| | Location + Description | LL | PL | PI | -200 | ASTM D 2487-90 |
|---|---|---|---|---|---|---|
| ● | NORTH LAS VEGAS<br>Clay, light brown | 48 | 23 | 25 | 55.1 | CL, Sandy lean clay |
| ▲ | NORTH LAS VEGAS<br>Clay, light brown<br>10% of fly ash added | 45 | 29 | 16 | | |
| ■ | NORTH LAS VEGAS<br>Clay, light brown<br>20% of fly ash added | 41 | 37 | 4 | | |
| ◆ | NORTH LAS VEGAS<br>Clay, light brown<br>30% of fly ash added | 38 | 35 | 3 | | |
| | | | | | | |

| | |
|---|---|
| Project No.: BP95<br>Project: THESIS - EFFECTS OF FLY ASH ON CLAY<br><br>Location: UNIVERSITY OF NEVADA, LAS VEGAS<br><br>Date: MARCH 4, 1995 | Remarks:<br>North Las Vegas Clay<br>Sample No. 3 |
| LIQUID AND PLASTIC LIMITS TEST REPORT | Fig. No. 1 |

# LIQUID AND PLASTIC LIMITS TEST REPORT




| | Location + Description | LL | PL | PI | -200 | ASTM D 2487-90 |
|---|---|---|---|---|---|---|
| ● | Colorado Clay, dark brown | 43 | 17 | 26 | 55.0 | CL, Sandy lean clay |
| ▲ | Colorado Clay, dark brown<br>10% of fly ash added | 38 | 17 | 21 | | |
| ■ | Colorado Clay, dark brown<br>20% of fly ash added | 30 | 23 | 7 | | |
| ◆ | Colorado Clay, dark brown<br>30% of fly ash added | NV | NP | | | |
| | | | | | | |

NV - Non-Viscous NP - Non-Plastic

Project No.: BP95
Project: THESIS - EFFECTS OF FLY ASH ON COLORADO CLAY

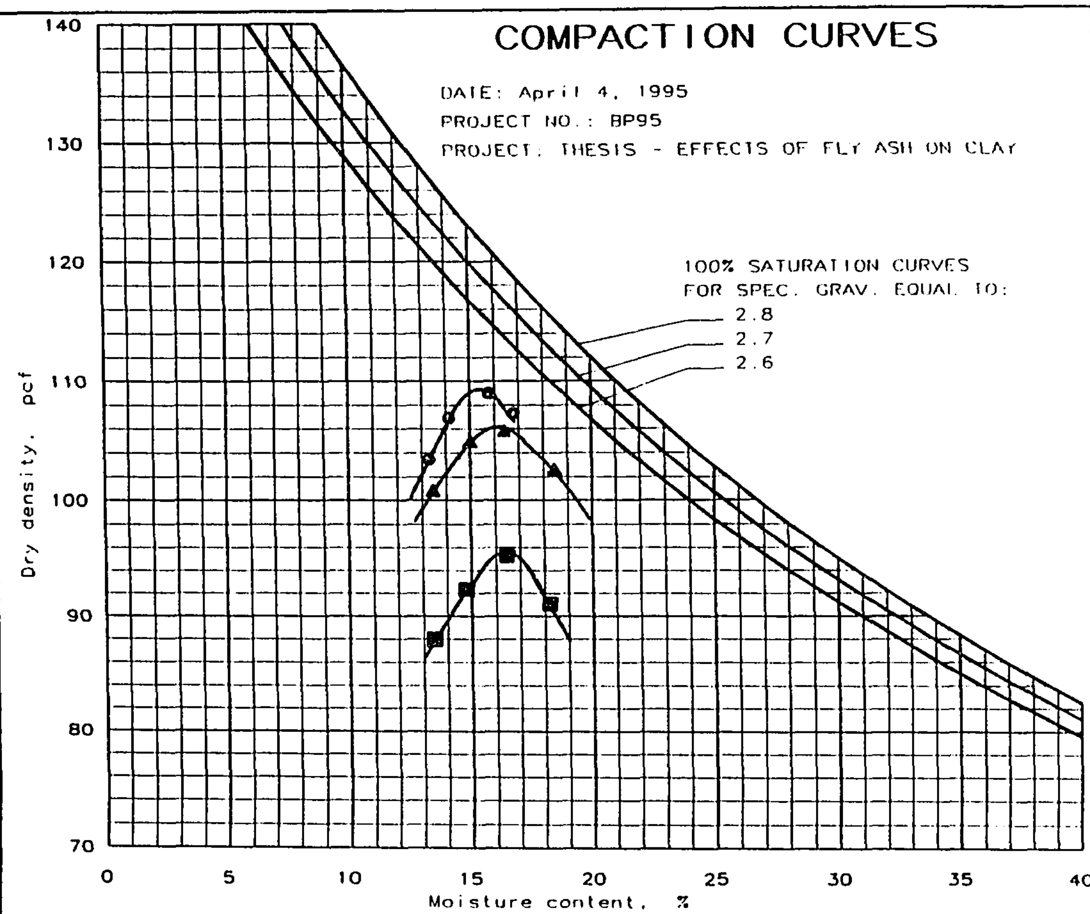
Location: UNIVERSITY OF NEVADA, LAS VEGAS

Date: APRIL 4, 1995

LIQUID AND PLASTIC LIMITS TEST REPORT

Remarks:
Non-plastic (NP)

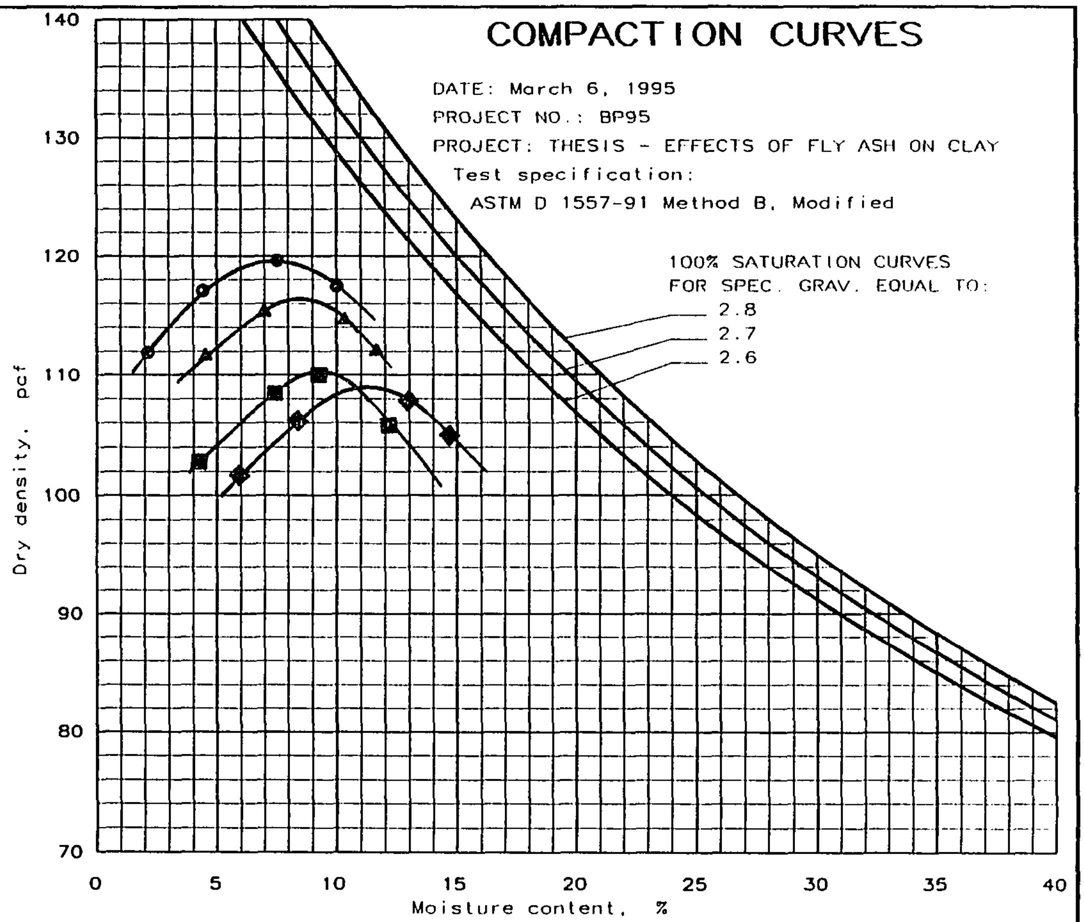
Fig. No. 2




| | NO. | LOCATION AND DESCRIPTION | REMARKS |
|---|---|---|---|
| ● | 1 | UNIVERSITY OF NEVADA, LAS VEGAS<br>Clay, light brown | North Las Vegas clay<br>no fly ash added |
| ▲ | 2 | UNIVERSITY OF NEVADA, LAS VEGAS<br>Clay, light brown | 10% of fly ash added |
| ■ | 3 | UNIVERSITY OF NEVADA, LAS VEGAS<br>Clay, light brown | 20% of fly ash added |
| | | | |
| | | | |

| | NO. | PL | LL | | %< No.200 | MAX. DRY DEN. | OPT. MOIST. |
|---|---|---|---|---|---|---|---|
| ● | | 88 | 280 | | 100% | 109.3 pcf | 15.4% |
| ▲ | | | | | | 106.1 pcf | 16.1% |
| ■ | | | | | | 95.6 pcf | 16.4% |
| | | | | | | | |
| | | | | | | | |

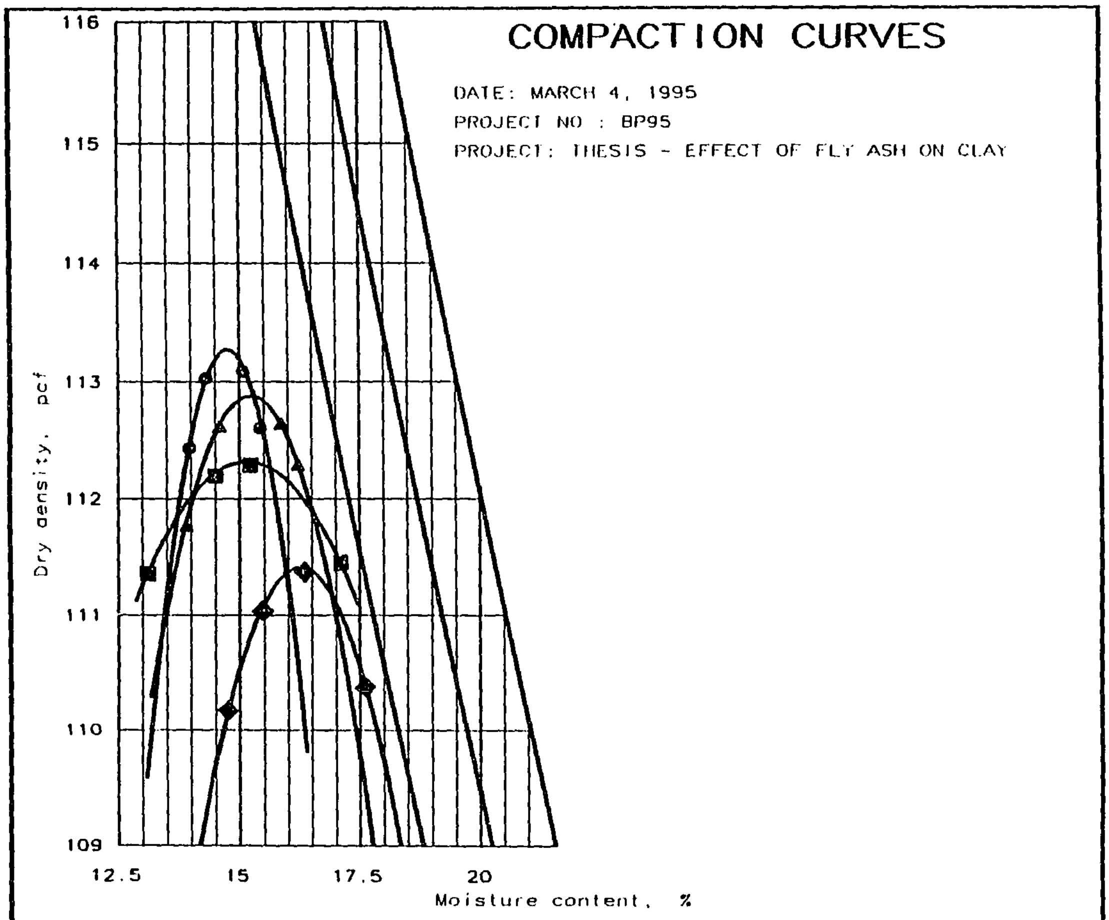
Figure No. 3




| | NO. | LOCATION AND DESCRIPTION | REMARKS |
|---|---|---|---|
| ● | 1 | UNIVERSITY OF NEVADA, LAS VEGAS<br>Clay, dark brown | Colorado clay<br>no fly ash added |
| ▲ | 2 | Clay, dark brown | 10% of fly ash added |
| ■ | 3 | Clay, dark brown | 20% of fly ash added |
| ◆ | 4 | Clay, dark brown | 30% of fly ash added |

| | NO. | PL | LL | | %< No.200 | MAX. DRY DEN. | OPT. MOIST. |
|---|---|---|---|---|---|---|---|
| ● | | 17 | 43 | | 55.0% | 119.5 pcf | 7.4% |
| ▲ | | 17 | 38 | | | 116.4 pcf | 8.5% |
| ■ | | | NP | | | 110.2 pcf | 9.3% |
| ◆ | | | NP | | | 108.9 pcf | 11.3% |

Figure No. 4




| | NO. | LOCATION AND DESCRIPTION | REMARKS |
|---|---|---|---|
| ● | 1 | NORTH LAS VEGAS<br>Sandy lean clay light brown | No fly ash added |
| ▲ | 2 | NORTH LAS VEGAS<br>Sandy lean clay, light brown | 10% of fly ash added |
| ■ | 3 | NORTH LAS VEGAS<br>Sandy lean clay, light brown | 20% of fly ash added |
| ◆ | 4 | NORTH LAS VEGAS<br>Sandy lean clay, light brown | 30% of fly ash added |
| | | | |

| | NO. | PL | LL | | %< No.200 | MAX. DRY DEN. | OPT. MOIST. |
|---|---|---|---|---|---|---|---|
| ● | | 23 | 48 | | 55.1% | 113.3 pcf | 14.8% |
| ▲ | | 29 | 45 | | | 112.9 pcf | 15.2% |
| ■ | | 37 | 41 | | | 112.3 pcf | 15.1% |
| ◆ | | 34 | 38 | | | 111.4 pcf | 16.3% |
| | | | | | | | |

Figure No. 5

TABLE 7

ENGINEERING PROPERTIES OF EXPANSIVE SOILS
Colorado Clay mixed with Fly Ash

Sample No. 2

| Type of Mix | Raw Soil | 10% FA | 20% FA | 30% FA | 40% FA | Remark |
|---|---|---|---|---|---|---|
| % Swell (@ 60 psf surcharge) | 14.4 | 12.7 | 10.7 | 8.8 | 4.4 | |
| Unconfined Compressive Strength (psi) | 66.1 | 39.0 | 22.4 | 3.0 | - | 24 hours curing time |
| | 103.2 | 109.6 | 115.0 | 214.9 | - | 14 days curing time |
| Plasticity Index | 24 | 21 | 7 | NP | NP | |

Notes: FA - Fly Ash
NP - Non-plastic

TABLE 8

ENGINEERING PROPERTIES OF EXPANSIVE SOILS
North Las Vegas Clay mixed with Fly Ash

Sample No. 3

| Type of Mix | Raw Soil | 10% FA | 20% FA | 30% FA | Remark |
|---|---|---|---|---|---|
| % Swell (@ 60 psf surcharge) | 7.6 | 4.0 | 2.1 | 0.8 | |
| Unconfined Compressive Strength (psi) | 25.0 | 16.0 | 4.0 | 3.0 | 24 hrs. curing time |
| | 38.3 | 47.6 | 122.0 | 214.9 | 14 days curing time |
| Plasticity Index | 25 | 16 | 4 | 3 | |

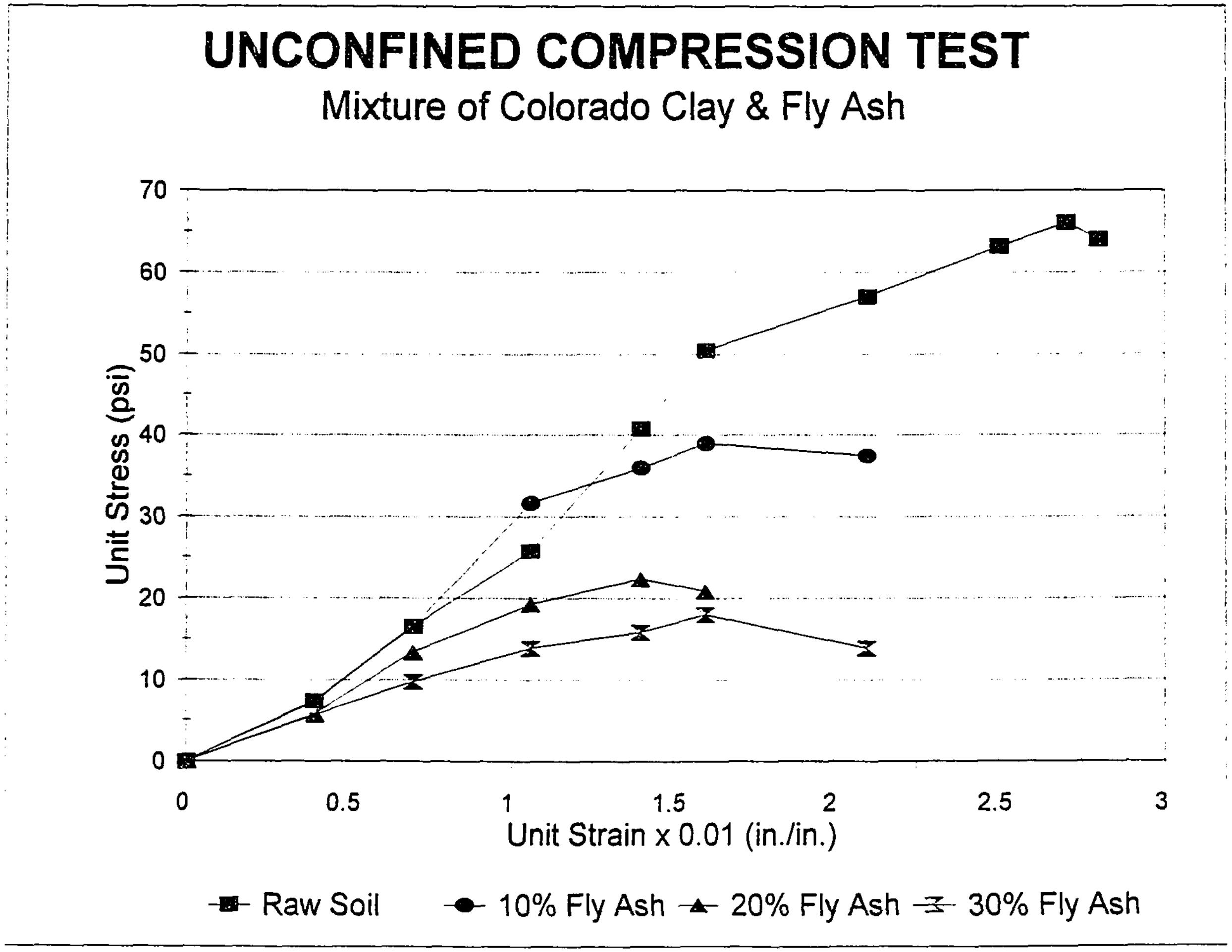
Notes: FA - Fly Ash
NP - Non-plastic

UNCONFINED COMPRESSION TEST

For the samples tested after 24 hours curing time (Figures 6 and 8) the increase of Young's initial modulus of elasticity of clay-fly ash (slope of the curves) generally follows the pattern of the increase of the strength. While the strengths of specimens with 14 days of curing time show significant increases in Young's modulus, this increase is most noticeable where strain is approximately greater than 1.5 in/in, as presented in Figure 7 and 9. The change in the slope is proportional to the percent of fly ash in the mixture. As a result, the percent of fly ash in the mixture effects the cementitious property and rigidity of the specimens and increases with curing time.

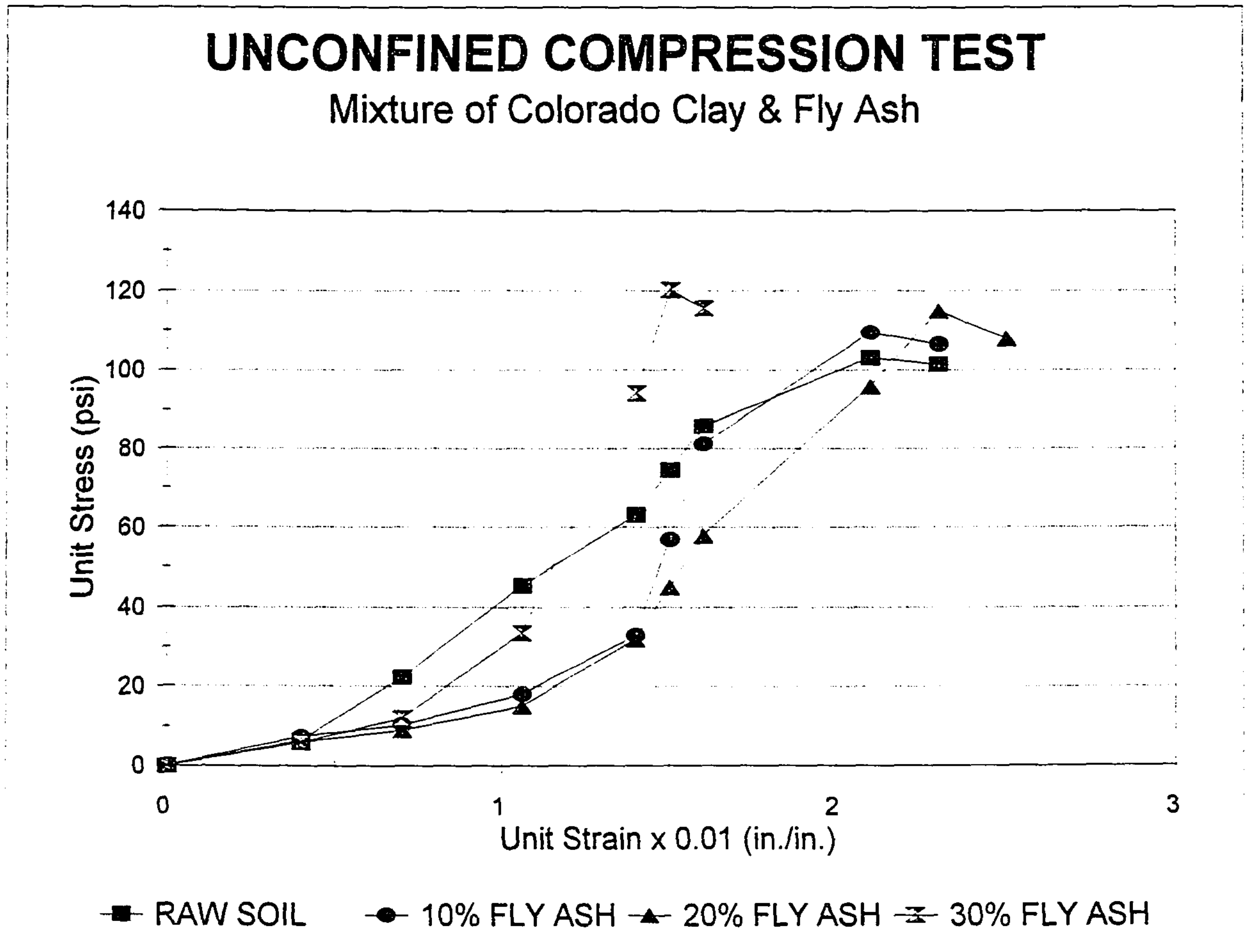
Figure 10 and 11 shows an initial loss in compressive strength with the addition of fly ash associated with 24 hours curing time. The strength was regained with the addition of fly ash with aging of the specimens (Figures 12 and 13). The increase in strength is at a steady rate for at least 90 days (Peter G. Nicholson and Vinai Kashyap 1993).

Figure 6



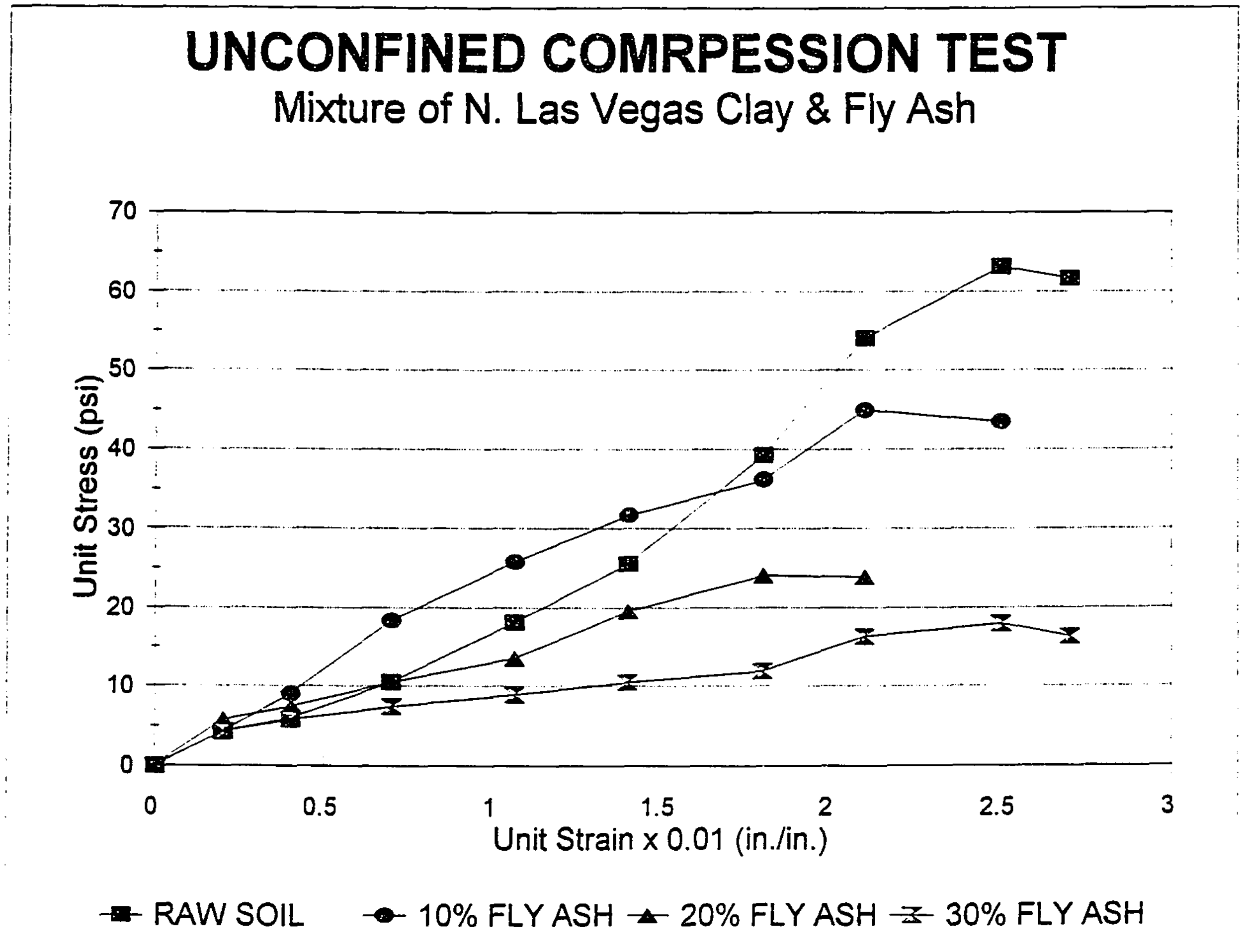

Note: Sample was tested after 24 hours of curing time.

Figure 7



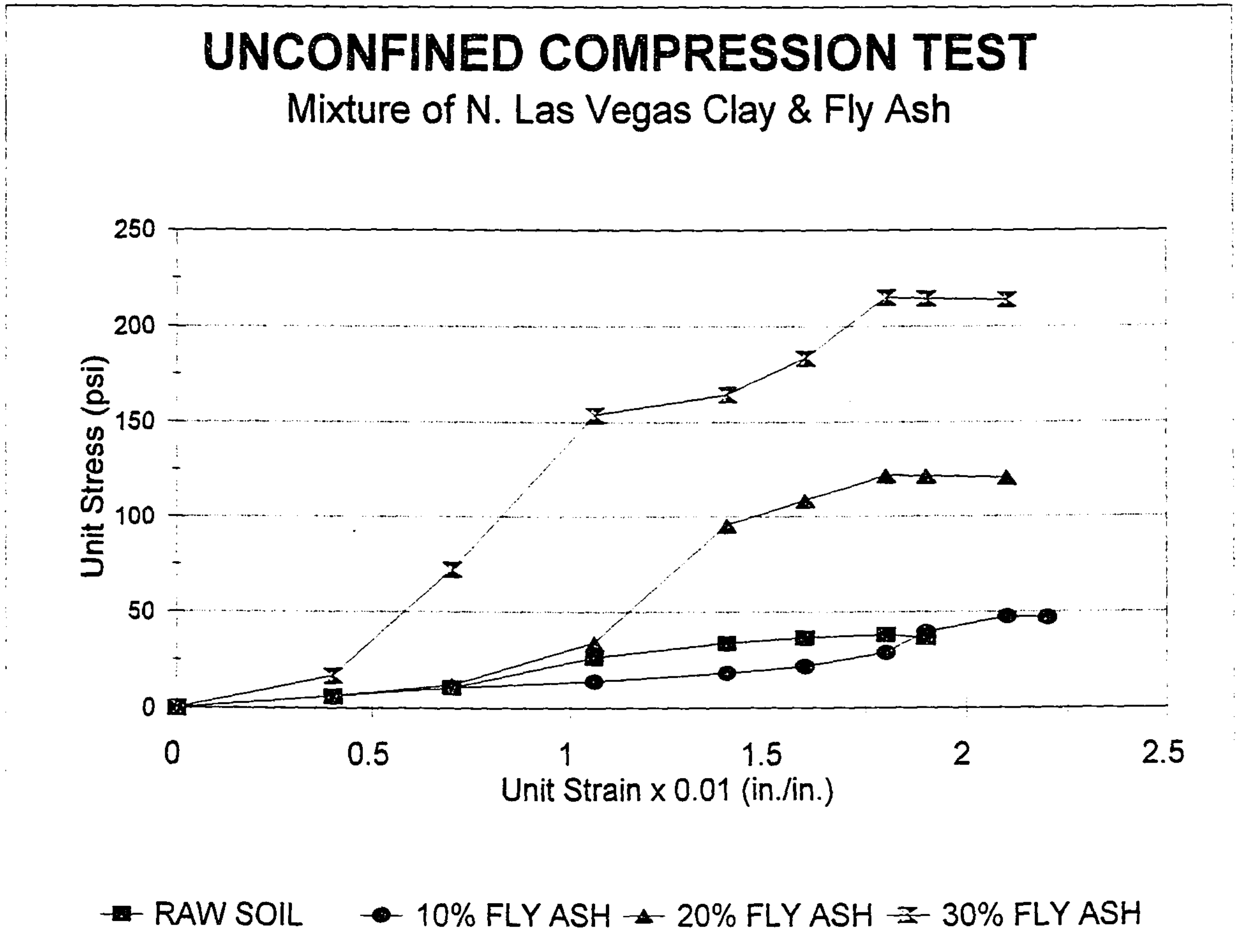

Note: Sample was tested after 14 days of curing time.

Figure 8



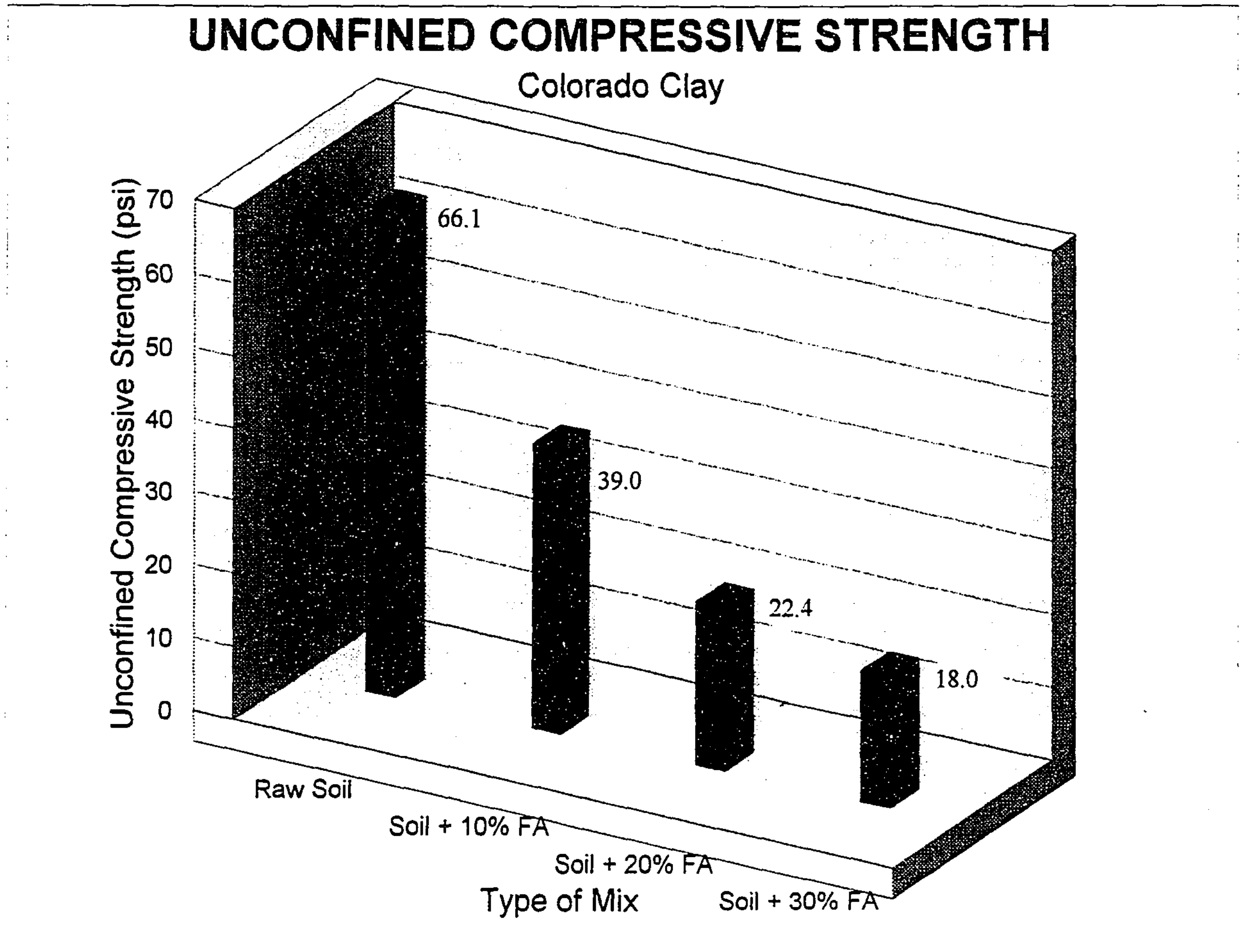

Note: Sample was tested after 24 hours of curing time.

Figure 9



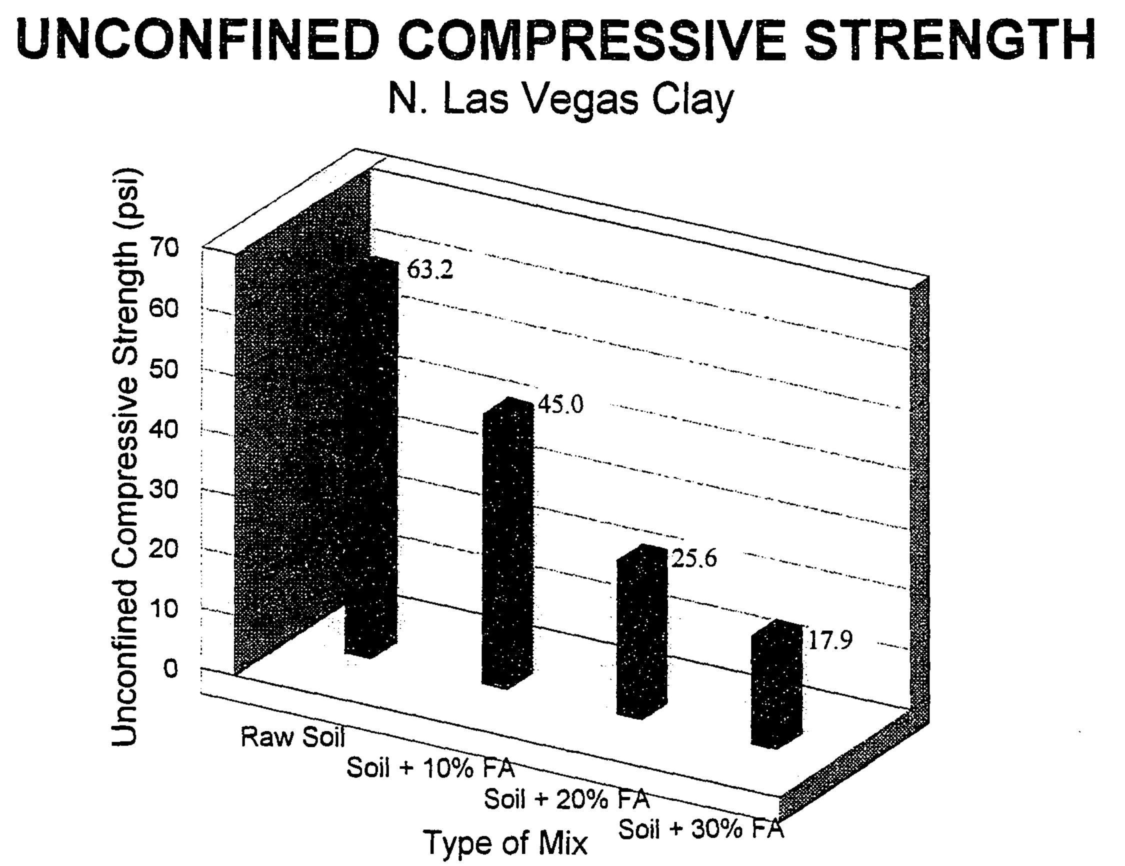

Note: Sample was tested after 14 days of curing time.

Figure 10




Note: 24 hours curing time

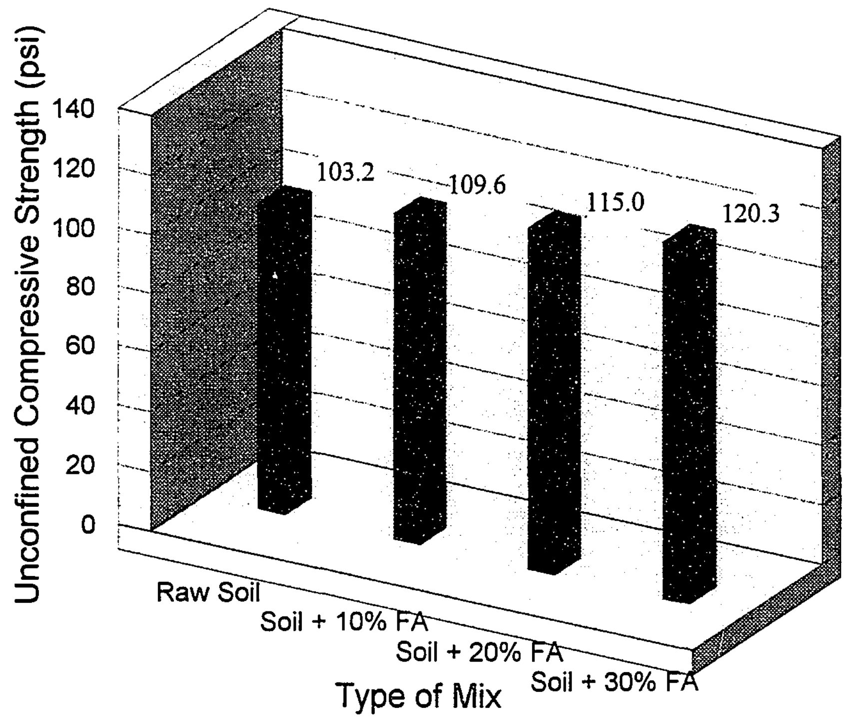
Figure 11




Note: 24 hours curing time

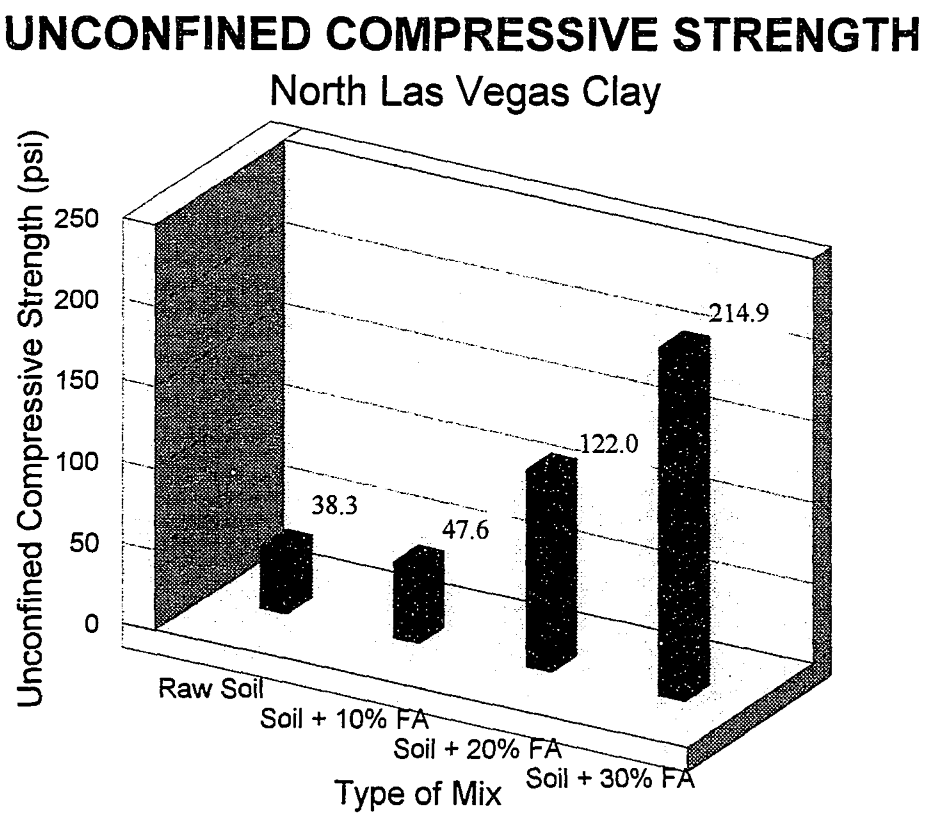
Figure 12

## UNCONFINED COMPRESSIVE STRENGTH
Colorado Clay




Note: 14 days curing time

Figure 13




Note: 14 days curing time

# Chapter 6

# CONCLUSION

Based on the preliminary observations, incorporating fly ash into unsuitable natural soil increases their shear strength, reduced the swell potential and plasticity index and may result in an acceptable material for structural fill. Fly ash stabilization was more effective with North Las Vegas clay than Colorado clay. On the basis of this experience, not all expansive soils are amenable to the same degree to stabilization with fly ash. The fly ash content required is dependent upon the specific fly ash, the type of clay mineralogy, and must be evaluated for each situation. For the results obtained and for the percentage of fly ash used, the following conclusions are warranted.

- The liquid limit and the plasticity index decreased, and the classification of soils changed from clay (CL) to silt (ML, OL).
- Increasing percent fly ash decreased dry unit weight and optimum moisture content of the soils.
- The change in the physical properties caused by the addition of fly ash decreased the potential expansiveness of the soils from very high to low which decreased with increasing percent fly ash.

- The unconfined compressive strength of treated soil substantially increased both with percent of fly ash and curing period.

## REFERENCES


Al-Suhaibani, A. S., and Tons, E. T., 1991. *Properties of Fly Ash - Extended Asphalt Concrete Mixes*, in Transportation Research Record, No. 1323, Asphalt Mix Materials, N. C. Kassabian, and A. G. Tobias, (editors), National Research Council, Washington D. C., pp. 123 - 133.

ASTM (American Society for Testing and Materials), 1994, Soil and Rock; Dimension Stone; Geosynthetics, ASTM D422, ASTM 854, ASTM D1140, ASTM D2166, ASTM D2487, ASTM D4318.

Bowles, Joseph E., 1979. Physical and Geotechnical Properties of Soils, Mcgraw - Hill Inc., U.S.A., 465 p.

Cernica, John N., 1982. Geotechnical Engineering, Holt, Rinehart, and Winsto, U.S.A., 488 p.

Chen, Fu Hua, 1975. Foundations on Expansive Soils, Elsevier Scientific Publishing Company, Amsterdam - Oxford - New York, Vol. 12, 280 p.

Dennis, K. C., 1994. *Expansive Soils*, in The Construction Specifier, pp. 108 - 117.

Ferguson, G., 1993. *Use of Self-Cementing Fly Ashes As A Soil Stabilization Agent*, in Fly Ash For Soil Improvement, K. D. Sharp (editor), Geosystems Engineering Inc., Kansas, pp. 1 - 25.

Holtz, R. D., and Kovacs, W. D., 1981. An Introduction To Geotechnical Engineering, Prentice - Hall Inc., New Jersey, 733 p.

Maher, M. H., Butziger, J. M., DiSalvo, D. L., and Oweis, I. S., 1994. *Lime Sludge Amended Fly Ash for Utilization as an Engineering Material*. Rutgers University, New Jersey, pp. 72 - 87.

Mitchell, Tomesk., 1976. Fundamentals of Soil Behavior, John Wiley & Sons, Inc. U.S.A., 422 p.

Nicholson, P. and Kashyap, V., 1993. *Fly Ash Stabilization of Tropical Hawaiian Soils*, in Fly Ash For Soil Improvement, K. D. Sharp (editor), Geosystems Inc., Kansas, pp. 15 - 29.

Vruno, D. M. Downs, M. B. and Smith, S. S., 1991. *Lignite Fly Ash Concrete Highway Pavement - A 15-Year Performance History* in Transportatoin Research Record, No. 1301, Factors Affecting Properties and Performance of Pavements and Bridges, N. C. Kassabian, and A. G. Tobias, (editors), National Research Council, Washington D. C., pp. 155 - 159.